Data Repository item 2003152

Brittle Structures and Their Role in Controlling Porosity and Permeability in a Complex Precambrian Crystalline Rock Aquifer System in the Colorado Rocky Mountain Front Range

Data Repository Item: Detailed Description of Methods

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Introduction

The following data repository appendix is intended to be a supplement to the paper Brittle Structures of the Turkey Creek Watershed, Colorado Rocky Mountain Front Range: Aquifer System Characterization and Controls on Groundwater Hydrology. This appendix is a detailed description of that which is synopsized in the paper and it covers how fracture network data were collected in the field, how that data was compiled and analyzed in order to generate the needed parameters to construct Discrete Fracture Network (DFN) models, how the models were constructed, and how fracture network potential porosity and fracture network potential permeability were calculated. Figure numbers refer to those in the paper. Table numbers also refer to those in the paper with the exception of those prefixed by the letter DR which are data repository items.

Field Data Collection

Overview

Several approaches have been used to characterize fracture network hydraulic parameters. These have included aquifer hydraulic tests and numerical modeling with discrete fracture network modeling schemes (Anna and Wallman, 1997; Jones et al., 1999); fracture network data collection from pavements and tunnels (Sweetkind et al, 1997); analysis of mineralized and altered fracture networks as indicators of the systematics of paleoflow in an aquifer (Taylor et al., 1999); borehole televiewer logging and flow metering (Paillet and Pedler, 1996); lineament analyses (Bryant et al., 1975); and environmental tracer analyses (Abelin et al., 1991). Many studies, however, only address one of two major components of the needed information for comprehensive groundwater resource evaluation in fractured rock at the watershed-scale (notable exceptions come from work at Mirror Lake, New Hampshire, e.g., Barton, 1996; Hsieh and Shapiro, 1996; Tiedeman, et al., 1998). These components include either field-based characterization of the geometric properties of fracture networks (typically from the borehole to outcrop to aerial photographic scales) or aquifer hydraulic testing to directly measure hydraulic parameters (typically at the scale of individual to multiple boreholes). The following describes the field data collection techniques used in this study (for raw on-line data see Caine, 2001). The analyses of the fracture network data, how it is modeled and combined with geologic characterization; and limited borehole-scale aquifer test data are described in subsequent sections.

Outcrop Selection and Fracture Data Collection Along Scanlines

Field work and inspection of color aerial photographs (at a scale of about 1:12,000) were used to select representative exposures of the dominant lithologic groups segregated by assuming: 1) groundwater flow and storage in crystalline rocks dominantly occurs in fracture networks 2) the groups are composed of similar lithologies with a similar geological history and response to brittle deformation, they should exhibit similar hydrogeological properties (e.g., permeability and storage capacity). Three hydraulically significant lithologic groups were identified at the watershed scale: 1) metamorphosed and foliated gneisses and schists, 2) large intrusive quartz monzonites and other granitic rocks found in plutons, and 3) major fault zones that cut both the metamorphic and igneous rock groups (Figure 1 and Table 1).

Nine natural outcrops were selected (Figure 1) and they have length scales of at least thirty meters and exposures of at least two near orthogonal faces were sought. By taking measurements on two near-orthogonal faces, fractures that were subparallel to one face were captured on the second face in an attempt to eliminate scanline orientation bias (e.g., Terzaghi, 1965). Typically at least three and up to nine scanlines were analyzed at each of nine localities shown in Figure 1. Scanline sampling was used to collect the raw fracture network data (e.g., Priest, 1993). A graduated tape, or "scanline" was stretched across the outcrop face and where practical, scanlines were set up at near right angles to major fracture sets to further avoid scanline-fracture set orientation bias. For each fracture that intersected the tape position (from which spacing and density are derived – see below), orientation, trace length, termination, an estimate of aperture, degree and type of mineralization, shape, roughness, and any indicators of timing relationships (e.g. crosscutting and offset of other fracture sets) were recorded (Table DR1). These parameters form the basic fracture data from which the DFN models are constructed.

Since the foliated rocks were folded and faulted, at least prior to the emplacement of the Silver Plume, any indication of structural position of each locality was also determined. Rock type, 'unit' contacts, compositional layering, foliations and a variety of lineations were also recorded at each locality.

Fracture Network Data Analysis, DFN Model Construction, and Matching DFN Models to Field Data

Overview

The statistical analysis of natural fracture data for construction of DFN models and estimation of potential porosity and potential permeability were completed in several steps combining a number of methods and computer programs (Figure 2). A spreadsheet program, Stereonet (Allmendinger, 1995), and FracMan^{TM} (see Dershowitz et al., 1996) by Golder Associates, Inc., were the primary computer codes used to calculate statistical representations of the field parameters needed to construct the DFN models.

Analyses completed in this study are based on the assumption that fracture sets can be distinguished by statistical methods (e.g., mean orientations and dispersions) and that the interaction of these sets and their individual properties determine the hydraulic behavior of the fracture networks at a variety of scales. All other fracture set parameters, such as trace length, are then calculated on a set by set basis. Although natural fracture sets can be distinguished by a number of parameters such as orientation, mineralization species, relative ages, length, and morphology, the sets assigned in this study are based exclusively on orientation. This is primarily due to the lack of unique mineralization signatures, age markers, and general uniformity of length and morphology in any given set.

FracMan^{TM} creates three-dimensional rectangular regions that are filled with synthetic fractures whose properties statistically honor field data. All fractures in this study are modeled as smooth, parallel walled, hexagonal plates. The fracture network parameters that are most closely matched to the field data in the DFN models include fracture position, orientation, trace length, and terminations. Mineralization, spacing, shape, roughness, and particularly aperture are the most poorly honored parameters in the DFN models.

When constructing a DFN model, FracMan^{TM} initially selects a fracture center point from a random seed for the first fracture in the first simulated fracture set. It then randomly selects an orientation and length from the statistical distribution for that set. These parameters are assigned to the first fracture and the synthetic fracture is "grown" in the specified model domain. The center point of the next fracture is positioned as defined by a fracture spacing model. The above process is repeated, until the first set has been completely "grown" in accordance with the specified fracture intensity for that set. Each successive set is generated until the DFN model is complete. As each fracture is generated the fracture termination data are honored by allowing for random truncations and free tips in accordance with the field data for each set. The following is a description of how each fracture network parameter is obtained or simulated to form input into FracMan^{TM}.

Modeling Fracture Orientations and Set Designation

Field orientation data are plotted on lower hemisphere equal area projections and contoured using the Kamb method (Figures 1 and 2). Clusters of the raw and contoured data are segregated, and the mean orientation and Fisher dispersion for each cluster (set) are calculated (Table DR1). The choice of any individual set is based on the tightness of the cluster and observations made in the field. For each fracture set all data for individual fractures (e.g., position, trace length, and terminations) in that set are segregated to form a complete data set.

Fracture Length Modeling

Trace length statistics, including means, standard deviations, and functional probability distributions for each set are the next parameters that are simulated from field data. A probability density function is plotted for the raw trace length data using FracMan^{TM}. Fracture termination style (e.g., free tips and truncations by neighboring fractures) and type of censorship, if any, are also incorporated into the simulated fracture length distributions (Table DR1). In order to assign an appropriate distribution and derive a mean fracture radius that best matches the field data, trace planes and scanlines are simulated with the same orientations and sizes of those in the field from which the data was collected (Dershowitz et al., 1996). Multiple simulations of fracture traces are generated with the FracSize^{TM} module of FracMan^{TM}. The initial simulation uses the field-derived mean radius, standard deviation, and distribution model. Simulations are repeated until a satisfactory match is obtained between the observed and measured data. The criteria for a 'good' fit is arbitrarily based on the results of standard Kolomogorov-Smirnov (K-S) and Chi-Squared (χ^2) tests. Ninety percent or better significance was sought for both K-S and χ^2 for most simulations. Much of the data were difficult to fit at such high degrees of significance for both tests, although the K-S tests were generally successful in obtaining high percent significances. The average K-S test percent significance for all sets is 93.5% and 69.0% for all of the χ^2 tests (Table DR1).

Outcrop measurements give trace lengths that are usually not the actual diameter of any individual fracture which presents an interesting problem with converting trace length data to fracture radii. For example, fracture traces on an outcrop face represent a partial arc of a circular fracture, and therefore tracelengths always represent a length less than or equal to the true fracture diameter. Conversion from trace length to diameter or radius, the input parameter for FracMan TM, depends on the shape of the fracture and the location of the fracture center relative to its intersection with the outcrop face. In making the conversion we have assumed the field data yield a random sample and that the actual fractures can be adequately represented by circular (penny-shaped) fractures intersected by the outcrop face. The FracSizeTM module handles this problem by generating a set of random fractures with specified a mean, standard deviation, and distribution for fracture lengths (in this case the measured field data) and then samples the simulated fracture set in the specified trace plane (in this case using the outcrop face orientation and dimensions). The fracture set lengths simulated in FracSizeTM use radii picked from the mean, standard deviation, and a simulated probability density function to produce a statistically best-fit set of trace lengths that form the closest match to the field data.

Fracture Spacing Model

Following fracture length, spacing and intensity are the next parameters to be modeled. Fracture spacing is best represented by a uniform distribution, and an Enhanced Baecher model (Dershowitz et al., 1996) yields DFN models that best match the field observations. The Enhanced Baecher model locates fracture centers in a model domain using a Poisson distribution and allows for fracture terminations at intersections with preexisting fractures (Dershowitz et al., 1996). The Enhanced Baecher model produces fracture sets with relatively uniform spatial distributions and minimal clustering, as generally observed in the field.

Simulation of Fracture Intensity and Calibration to Field Data

Fracture intensity can be expressed as fracture area per unit volume (i.e., m^2/m^3, or P32 in the language of FracManTM). Fracture intensity is defined here as the number of fractures per unit line length (i.e., 1/m, or P10 in the language of FracManTM). Previous attempts to quantify fracture intensity in the TCW were based on lineament analysis of high elevation aerial photographs and limited outcrop work (Hicks, 1987; Table DR3). Although fracture intensities estimated from lineament analysis are two dimensional, highly biased to linear features that are often quite large (100's to 1000's of meters), are at high angles to the surface of the Earth, and may not actually be fractures, Hicks' (1987) results yield intensities in the range of 0.06 to 6 fractures per meter.

Since fracture-dominated fluid flow is a three dimensional problem, three dimensional modeling is appropriate. Although fracture intensity in a volume cannot be measured directly it can be simulated from scanline or P10 data. Because the dimensions of fracture area per unit volume (P32) and number of fractures per unit line length (P10) are the same (i.e., 1/length), P32 can be estimated from P10. Simulation of fracture intensity is also part of 'calibrating' simulation input parameters to field data. The essence of the calibration is to first set up a three dimensional, cubic model region or model domain in FracManTM that is just larger than the largest scanline measured in the field. Three adequately orthogonal scanlines are simulated within the model region. These have the same orientations and lengths as those measured in the field for each locality. The relative positions of the simulated scanlines in the model region can be chosen at random, as are the actual scanlines in the field locations. Values for P10 are calculated for each fracture set on each scanline (see Table DR1 and DR2). An initial value is specified for P32 (usually the observed P10 value) and used in Monte Carlo simulations to generate model P10 values for each fracture set on each scanline. The simulated P10 values are compared to the observed P10 values and the simulations are repeated until the input P32 value results in a close match to the observed and simulated P10 values. The relative quality of a match is determined by calculating the relative percent error for each simulation. Thus, given 100 realizations constructed with the same statistical parameters but different initial seeds, the resulting number of simulated fracture intersections (*Mi*) in each simulated scanline is compared with the observed number of intersections (*Oi*) from the field scanlines. The relative percent error (*Mi-Oi/Oi**100) is then calculated for each simulation and the input P32 is adjusted until the error is arbitrarily and usually less than 20 percent (Table DR2).

The next step in the process is to further adjust and match P32 using all of the fracture sets in the full model domains and three orthogonal scanlines for the location being simulated, using 15 meter cubes for all non-fault zone model domains, and 2 meter cubes for all fault zone model domains. Once reasonable estimates of P32 are derived from the P10 matching process described above, a similar process of populating the full model domains with all fracture sets is initiated. An estimate of P32 for each fracture set is run 100 times using a Monte Carlo style simulation. The number of intersections for each simulated fracture set on each simulated scanline is compared with the observed data and the average relative error is again calculated for all of the 100 realizations (Table DR2). The P32 values are systematically adjusted within reasonable values compared to the field data until the average relative error for each simulated scanline is arbitrarily within about 20 percent of the observed values.

For most of the DFN models, single scanline calibrations are well within 20 percent average relative error (Table DR2). Several fracture sets were outliers that would not successfully calibrate to within 20 percent, however, because this study is a first attempt to generically represent the field data the results are considered acceptable. The final step in the fracture generation process is to choose the best single realization generated by one random seed, which has the lowest relative percent error using all scanlines. For each of the DFN models, each simulated fracture set along each simulated scanline is within 20 percent and generally below 10 percent with an average total percent relative error of 3.7 for all DFN models (Table DR2). This best single DFN model for each location is saved and used for calculating potential fracture porosity scenarios and running fluid flow simulations as described below.

Estimates of Fracture Network Potential Porosity

Approach

Calibrated DFN models were constructed for each of the representative outcrop localities in the TCW as described above (Figure 1). Three DFN models represent the Silver Plume quartz monzonite, four DFN models represent the foliated gneissic rocks, and three DFN models represent the distributed deformation zone faults (as in Caine and Forster, 1999). Two of the fault zone models are representative of the faulted gneissic rocks and one is representative of faulted Silver Plume quartz monzonite.

In each DFN model the fracture apertures were initially set to a constant value in each model domain. In order to calculate fracture volume (V_f) and total potential porosity (n_P), estimates of aperture (b), fracture intensity (I_f), and model domain volume (V_m) are the only parameters needed. V_f and n_P were calculated using:

$$V_f = b \times I_f \times V_m \tag{1}$$

and

$$n_P = \frac{V_f}{V_m} \tag{2}$$

V_f and V_m have the dimensions of [L^3], b has the dimension of [L], and P_{32} has the dimension of [L^2/L^3] where L is length. In making these calculations we assume two end members and one intermediate case for constant apertures that range from 1000μm (or 1mm) to 100μm to 10μm.

Estimates of Potential Fracture Network Permeability

Overview

Potential fracture network permeability, or potential permeability, was estimated using the same calibrated DFN models that were constructed for potential porosity estimates using the same assumptions for the definition of this parameter. Flow simulation results can be used to estimate DFN model domain sizes for bulk equivalent potential permeabilities, potential permeability anisotropy and the relative magnitudes of potential permeability at single locations and from one location to another. The results can also be used as input into other simulators, such as a watershed model, for estimating infiltration and recharge into the bedrock aquifer.

Approach

Potential permeabilities are calculated by simulating water flow at standard temperature and pressure in the fracture models using the three-dimensional finite element code Mafic™ (Miller et al., 1995). Use of Mafic™ assumes that all fractures act as parallel, smooth-walled conduits with rectangular cross sections. This assumption is commonly made when simulating fluid flow through discrete fracture networks (Snow, 1968; Witherspoon et al., 1980; Long et al., 1982). Each element in the mesh is assigned a fracture transmissivity, T_f, that can be directly related to fracture aperture a:

$$T_f = \frac{a^3}{12}\frac{\rho g}{\mu} \qquad (3)$$

where T_f is fracture transmissivity [L^2/T], a is aperture [L], ρ is the fluid density [M/L^3], g is the acceleration due to gravity [L/T^2], and μ is the dynamic fluid viscosity [M/LT] (M=mass, L=length, T=time). Single values for transmissivity and aperture are assigned to each individual fracture in each DFN model. Transmissivities used in this study range from 1×10^{-9} m^2/s to 1×10^{-3} m^2/s (corresponding to apertures from 10μm to 1000μm). Although the simulated absolute values of potential permeability are completely dependent on the chosen aperture and transmissivity distributions that are not constrained by site-specific hydraulic data, they do represent a reasonable estimate of the architecture of each fracture network loosely conditioned to the aperture and transmissivity data described above in the potential porosity section. The architectural elements include the primary rock fabric elements measured in the field (e.g., position and derived intensity, orientation, length, and terminations). Moreover, because each of the DFN models were constructed with the same constant aperture and transmissivity distributions, the simulation results are also excellent measures of the relative potential permeability and potential permeability anisotropy from one DFN model or locality to another.

The steady-state distribution of hydraulic head is computed using Mafic™ at each node within each DFN model and the volumetric fluid flux is computed along each external boundary. A form of Darcy’s law for steady-state water flow is solved subject to the specified boundary conditions using the Galerkin finite element method. Two-dimensional triangular elements are constructed within each fracture plane that comprise the fully three-dimensional DFN models using MeshMaker™. Interested readers are referred to Miller et al. (1995) and Dershowitz et al. (1996) for more complete descriptions of MeshMaker™ and Mafic™.

Bulk and directional permeabilities are calculated using the results of numerical, one-dimensional flow experiments. Boundary conditions are applied to each model cube as illustrated in Figure 8. DFN model domain sizes were chosen to represent outcrop scale potential permeabilities and to allow for computational efficiency. The results are valid only for the length and volume scales modeled, where the larger scale DFN models represent better estimates of bulk potential permeability. This is because the longest fractures are smaller than larger domain sizes and thus single, through-going fractures that are common at the smaller domain sizes do not dominate the flow. Also note that simulating potential permeability in only three directions does not give a complete view of anisotropy. This approach is used as a first estimate to evaluate whether anisotropy is large enough to warrant further simulations in additional directions.

One-dimensional flow was simulated in three mutually-perpendicular, real-space directions in each DFN model cube (i.e., north to south, east to west, and top to bottom or up and down). In each simulation, a uniform hydraulic head gradient (dh = 0.1m for example representing 100m head drop across 1km horizontal distance) was applied across a pair of opposing DFN model faces for each flow direction. Uniform values of hydraulic head are specified on each pair of opposing DFN model faces and a zero flux condition was specified on the remaining four faces (Figure 8). The total volumetric flux computed between the two opposing faces is used to compute the equivalent bulk potential permeability, k_P, for each full model domain, in each direction (Figure 8). Equivalent bulk potential permeabilities were calculated in each direction using Darcy's law:

$$k_p = \frac{\mu}{\rho g} \frac{Q}{IA} \tag{4}$$

where Q is the simulated volumetric flow rate output [L^3/T], I [dimensionless] is the specified hydraulic gradient, A [L^2] is the specified cross sectional area across which the discharge, Q, flows, k_P is the calculated permeability [L^2], ρ is the fluid density [M/L^3], g is the acceleration due to gravity [L/T^2], and μ is the fluid dynamic viscosity [M/LT].

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TABLE DR1. TCW FRACTURE SET INPUT DATA, TRACE LENGTH AND INTENSITY SIMULATION RESULTS

Abbreviations: no = number, disp = dispersion, st dev = standard deviation, min = minimum, max = maximum, term = fracture termination percent, K/S = Kolgogorov-Smirnov statistic, chi-sqr = Chi-Squared statistic, SL = sacn line, P10 = fracture intensity or number of fractures per unit line length, Qtz=Quartz, F-spar=Feldspar, Bio=Biotite

285S (Foliated Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	SL3	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	18	169/56	100	1.27	0.58	0.5	2.1	44.4	0.61	0.54	normal	96	29	1.5	0.28	0	
2	16	028/72	23	2.24	2.18	0.6	6.8	50	0.85	0.73	log norm	41	14	1.75	0.97	0	
3	15	007/05	66	2.41	0.99	0.5	3.8	26.7	1.25	2.41	normal	96	79	1.13	0	0	
4	12	259/69	17	2.11	1.08	0.6	4.2	66.6	1.06	0.82	normal	95	92	0.08	1.52	0	
5	15	320/47	18	1.85	1.16	0.4	5	40	0.86	0.95	log norm	50	75	0.53	0.55	1.06	
	76	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**75.6**	**57.8**	**5.0**	**3.3**	**1.1**	**P10 SUM**
																9.4	**TOTAL P10**

285N (Foliated Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL4	SL5	SL7	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	31	360/05	81	4.41	2.59	1	8	33.3	7.51	6.35	log norm	94	48	0.97	0	0	
2	30	245/25	22	1.51	1.09	0.3	5.2	43.3	0.44	0.71	normal	80	50	0	0.55	0.99	
3	9	111/30	24	3.26	2.21	0.5	7.1	35.5	2.58	1.93	normal	96	84	0	2.22	0	
	70	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**90.0**	**60.7**	**1.0**	**2.8**	**1.0**	**P10 SUM**
																4.7	**TOTAL P10**

LAMBERT (Foliated Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	SL3	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	47	317/08	73	2.52	1.68	0.4	6.5	46.8	2.08	2.79	log norm	95	97	3.31	0	0	
2	21	252/56	50	1.31	1.12	0.2	4.3	38.1	0.85	1.03	log norm	84	32	0.21	0.74	7.05	
3	12	230/19	13	1.14	0.42	0.3	1.7	66.7	0.7	0.39	uniform	100	97	0	1.27	0	
4	10	240/12	16	3.9	1.39	2	6.7	30	2.57	3.58	log norm	99	91	0.14	0.85	0	
	90	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**94.5**	**79.3**	**3.7**	**2.9**	**7.1**	**P10 SUM**
																13.6	**TOTAL P10**

LEGAULT PEAK EAST (Foliated Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL6	SL9	SL10	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	6	332/51	100	1.58	0.78	0.6	2.9	83.4	1.05	0.711	uniform	100	77	0.56	0	0	
2	25	249/74	33	2.84	1.85	0.7	6.8	56	2.43	1.38	log norm	99	55	0.94	0.38	2.97	
3	36	165/22	42	2.54	1.85	0.7	8.1	33.4	1.92	2.93	log norm	98	35	1.69	0.75	0	
	67	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**99.0**	**55.7**	**3.2**	**1.1**	**3.0**	**P10 SUM**
																7.3	**TOTAL P10**

HARRINGTON (Silver Plume Quartz Monzonite)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL6	SL10	SL11	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1a	85	300/04	48	2.3	1.16	0.6	6.2	44	1.48	0.9	log norm	98	79	0	0	0.93	
1b	13	302/04	68	11.5	5.27	7.1	29	31	5.75	5.27	log norm	100	85	0	0	0.4	
2	38	154/85	36	4.35	2.5	1	11	45	2.38	3.65	log norm	90	77	0.8	1.16	0.7	
3	57	210/09	16	2.22	1.11	0.6	5.8	33	1.3	1.11	log norm	100	95	1.85	0	0	
	193	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**97.0**	**84.0**	**2.7**	**1.2**	**2.0**	**P10 SUM**
																5.8	**TOTAL P10**

NOBEL (Silver Plume Quartz Monzonite)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL7	SL8	SL9	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	39	047/08	24	2.43	1.52	0.6	6	44	1.7	2.8	log norm	99	47	0	0	0.87	
2	30	224/64	27	2.57	1.51	0.8	7	37	1.45	2.1	log norm	95	93	1.8	0.14	0.13	
3	39	317/00	40	2.85	2.15	0.4	9.7	46	2.1	3.4	log norm	91	60	0	1.18	0.7	
4	42	093/07	19	2.5	1.74	0.3	8.9	38	1.9	2.1	log norm	93	79	0	0.56	0.33	
	150	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**94.5**	**69.8**	**1.8**	**1.9**	**2.0**	**P10 SUM**
																5.7	**TOTAL P10**

GREEN (Silver Plume Quartz Monzonite)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL5	SL6	SL7	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1a	46	179/04	9	2.59	1.9	0.4	8	26	1.8	2.6	log norm	83	61	0.17	0.2	0.13	
1b	4	006/05	74	17.63	8.76	10	30	0	10	9	log norm	100	100	0	0	0	
2	23	236/65	21	3.55	3.3	0.7	16	30	2.2	3.5	log norm	88	89	1.67	0.27	0.07	
3	107	256/03	9	2.92	2.3	0.5	12	51	2	3.8	log norm	93	52	0.5	0.87	1.13	
	180	**= TOTAL n**							**AVERAGE SIMULATION FIT**			**91.0**	**75.5**	**2.3**	**1.3**	**1.3**	**P10 SUM**
																5.0	**TOTAL P10**

TABLE DR1. TCW FRACTURE SET INPUT DATA, TRACE LENGTH AND INTENSITY SIMULATION RESULTS CONTINUED

JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 1 (Brittlely Deformaed and Highly Altered Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	
1	28	274/16	11	0.56	0.57	0.1	2.3	89	0.24	0.36	log norm	94	53	28.2	0	
2	14	160/62	46	0.83	0.52	0.2	1.8	93	0.37	0.18	normal	91	50	2	10.8	
ew	see grid 3 below															
	42	**= TOTAL n**									**AVERAGE SIMULATION FIT**	**92.5**	**51.5**	**30.2**	**10.8**	**P10 SUM**

JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 2 (Brittlely Deformed and Highly Altered Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	
1	9	226/05	15	0.46	0.51	0.2	1.8	100	0.2	0.29	log norm	91	61	8	1	
2	15	171/68	18	0.63	0.6	0.1	2.2	73.3	0.59	0.54	uniform	93	65	14	0	
3	13	049/46	18	0.58	0.35	0.2	1.5	92.3	0.61	0.35	normal	100	78	10.1	3	
ew	see grid 3 below															
	37	**= TOTAL n**									**AVERAGE SIMULATION FIT**	**94.7**	**68.0**	**32.1**	**4.0**	**P10 SUM**
															36.1	**TOTAL P10**

JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 3 (Brittlely Deformed and Highly Altered Quartz, Feldspar, Biotite Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	
ew	16	357/08	20	0.66	0.64	0.1	2.1	87.6	0.66	0.64	normal	94	39	14.9	1	
2	10	182/65	9.2	0.3	0.14	0.1	0.5	100	0.3	0.14	normal	99	100	2	8	
3	16	285/44	18	0.93	0.8	0.1	2.7	81.3	0.28	0.23	normal	94	70	3	13	
	42	**= TOTAL n**									**AVERAGE SIMULATION FIT**	**95.7**	**69.7**	**19.9**	**22.0**	**P10 SUM**
															41.9	**TOTAL P10**

CONIFER-ASPEN PARK FAULT ZONE GRID 1 (Brittlely Deformed and Altered Qtz Monzonite and Qtz, F-spar, Bio Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	SL3	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	8	346/26	53	0.6	0.5	0.2	1.6	100	0.6	0.5	normal	96	77	4.1	0	0.8	
2	10	177/23	17	0.59	1.17	0.1	3.9	90	0.28	0.725	log norm	99	36	4.6	0.8	0.5	
3	18	218/34	19	0.55	0.54	0.1	1.8	100	0.22	0.3	log norm	91	70	7.7	2.4	0.5	
4	11	264/43	51	1.39	0.79	0.3	2.5	100	1.31	0.764	normal	83	54	0.5	8.1	0.5	
5	3	033/41	48	0.27	0.15	0.1	0.4	100	0.25	0.06	log norm	100	92	0.5	0	0.2	
	50	**= TOTAL n**									**AVERAGE SIMULATION FIT**	**93.8**	**65.8**	**16.4**	**3.2**	**1.8**	**P10 SUM**
																21.4	**TOTAL P10**

CONIFER-ASPEN PARK FAULT ZONE GRID 1 w GRID 2 NS SET (Brittlely Deformed and Altered Qtz Monzonite and Qtz, F-spar, Bio Gneiss)

set		orient		**raw trace length data**					**simulated radii statistics**			**simulation fit (%)**		SL1	SL2	SLNS	
no	n	mean	disp	mean	stdev	min	max	term	mean	stdev	distribution	K / S	chi-sqr	P10	P10	P10	
1	8	346/26	53	0.6	0.5	0.2	1.6	100	0.6	0.5	normal	96	77	4.1	0	0.8	
2	10	177/23	17	0.59	1.17	0.1	3.9	90	0.28	0.725	log norm	99	36	4.6	0.8	0.5	
3	18	218/34	19	0.55	0.54	0.1	1.8	100	0.22	0.3	log norm	91	70	7.7	2.4	0.5	
4	11	264/43	51	1.39	0.79	0.3	2.5	100	1.31	0.764	normal	83	54	0.5	8.1	0.5	
5	3	033/41	48	0.27	0.15	0.1	0.4	100	0.25	0.06	log norm	100	92	0.5	0	0.2	
NS	19	067/22	63	1.07	0.53	0.4	2.4	57.9	0.82	0.528	normal	79	92	0	0	2.9	
	69	**= TOTAL n**									**AVERAGE SIMULATION FIT**	**91.3**	**70.2**	**16.4**	**3.2**	**1.8**	**P10 SUM**
																21.4	**TOTAL P10**

1066 = TOTAL n FOR ALL SETS AVERAGE OF ALL SIMULATED FITS 93.5 69.0

TABLE DR2. TCW DISCRETE FRACTURE NETWORK MODEL CALIBRATION DATA AND RESULTS

Abbriviations: intersects. and ints. = interactions along scan line, no. = number, DFNM Discrete Fracture Network Model, na = not analyzed
P10 = fracture intensity or number of fractures per unit line length and P32 = fracture density in fracture area per unit volume which reduces to P10

285S

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL1	00/347	347/36	3.61	13.31	48	46.0	-4	47	-2
SL2	36/077	347/36	3.31	7.25	24	23.1	-4	27	11
SL3	00/290	290/90	1.85	3.78	7	7.4	6	7	0
		Totals	**8.77**		**79**	**76.5**		**81**	**3**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4	set 5
1.7	1.1	1.3	1	0.01

Total P32 for DFN Model	**5.1**
Number of fractures in 15m DFN model	**3679**

LAMBERT

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL1	10/150	060/10	3.66	14.19	52	52.3	1	54	3.8
SL2	10/200	200/70	2.85	9.46	27	29.5	9	26	3.7
SL3	60/232	052/82	7.05	1.56	11	2.5	-345	1	90
		Totals	**13.6**		**90**	**84.3**		**81**	**-10**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4
2.2	0.8	1	0.5

Total P32 for DFN Model	**4.5**
Number of fractures in 15m DFN model	**4738**

HARRINGTON

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL6	00/034	034/90	1.94	12.4	24	21.3	-11	25	4.2
SL10	87/027	027/87	1.16	11.2	13	11.5	-11	14	7.7
SL11	00/310	310/90	1.40	15*	21	25.9	23	21	0
		Totals	**4.5**		**58**	**58.7**		**60**	**3**

* scan line length truncated to model size

Simulated Fracture Intensities (P32)

set 1a	set 1b	set 2	set 3
0.55	0.31	0.45	1.15

Total P32 for DFN Model	**2.46**
Number of fractures in 15m DFN model	**2860**

285N

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL4	00/010	010/90	1.0	6.20	6	6.8	12	6	0
SL5	00/100	100/90	1.5	9.10	14	13.9	-0.4	12	-16
SL7	25/271	115/48	2.2	3.16	7	4.9	-44	7	0
		Totals	**4.7**		**27.0**	**25.6**		**25.0**	**-7**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3
0.2	0.9	0.5

Total P32 for DFN Model	**1.6**
Number of fractures in 15m DFN model	**1248**

LEGAULT PEAK EAST

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL6	25/330	330/90	3.19	5.33	17	10.4	-63	15	-13
SL9	00/145	325/90	1.13	16.00	18	18.5	3	17	-6
SL10	90/055	325/90	2.97	4.71	14	13.5	-4	14	0
		Totals	**7.3**		**49**	**42.4**		**46**	**-6**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3
0.85	1.4	0.07

Total P32 for DFN Model	**39.11**
Number of fractures in 15m DFN model	**1092**

NOBEL

						100 Realizations		Best Single DFNM	
scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	average simulated no. of ints.	relative percent error	simulated number of intersects	relative percent error
SL07	90/330	330/90	1.80	5	9	3.9	-57	8	-11
SL08	10/140	140/72	1.87	14.42	27	23.6	-13	22	-19
SL09	00/050	230/50	1.40	15*	21	23.0	9	14	14
		Totals	**5.1**		**57**	**50.5**		**44**	**-23**

Simulated Fracture Intensities (P32)

set 1a	set 1b	set 2	set 3
0.35	0.1	0.9	1

Total P32 for DFN Model	**2.35**
Number of fractures in 15m DFN model	**2380**

TABLE DR2. TCW DISCRETE FRACTURE NETWORK MODEL CALIBRATION DATA AND RESULTS CONTINUED

GREEN

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
SL05	70/200	098/70	2.33	6	14	11.7	-17	14	0
SL06	35/112	112/66	1.33	15*	20	21.2	6	22	10
SL07	10/120	300/85	1.33	15*	20	20.5	2	20	0
		Totals	**4.99**		**54**	**53.4**		**56**	**4**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4
0.55	0.3	0.75	0.41

Total P32 for DFN Model **2.01**
Number of fractures in 15m DFN model **2905**

JUNCTION RANCH-PARADISE HILLS FAULT ZO
GRID 1

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
G1 SL1	00/081	081/52	30.2	0.992	30	30.0	0	30	0
G1 SL2	52/171	081/52	10.8	1.110	12	13.4	11	11	-8
EW	00/159	159/61	19.9	1.005	20	17.2	-17	18	-10
		Totals	**41**		**42**	**43.4**		**41**	**-2**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3
21	0.8	6

Total P32 **27.8**
Number of fractures in 2m DFN model **1969**
Projected number of fractures in 15m DFN mode **~125,000**

JUNCTION RANCH-PARADISE HILLS FAULT ZON
GRID 2

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
G2 SL1	00/070	070/53	19.1	0.995	19	20.1	6	19	0
G2 SL2	53/160	070/53	18.0	0.998	18	17.3	-4	15	16.6
EW	00/159	159/61	19.9	1.005	20	18.2	-10	20	0
		Totals	**57**		**57**	**55.6**		**54**	**-5**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4
6	8	6	7.2

Total P32 for DFN Model **27.2**
Number of fractures in 2m DFN model **1644**
Projected number of fractures in 15m DFN model **~121,000**

JUNCTION RANCH-PARADISE HILLS FAULT ZO
GRID 3

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
G3 SL1	00/159	159/61	19.9	1.005	20	na	na	na	na
G3 SL2	61/249	159/61	22.1	0.997	22	na	na	na	na
		Totals	**42**		**42**	**0.0**		**0**	**0**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4	set 5
na	na	na	na	na

Total P32 for DFN Model **0**
Number of fractures in 15m DFN model **na**

CONIFER-ASPEN PARK FAULT ZONE GRID 1

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
G1 SL1	00/170	170/60	17.5	1.946	34	31.2	-9	35	2.9
G1 SL2	60/260	170/60	11.3	1.235	14	14.1	1	13	-7.1
		Totals	**28.8**		**48**	**45.3**		**48**	**0**

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4	set 5
3.7	3.5	9	0.5	0.5

Total P32 for DFN Model **17.2**
Number of fractures in 2m DFN model **1881**
Projected number of fractures in 15m DFN model **~130,000**

CONIFER-ASPEN PARK FAULT ZONE GRID 1
WITH G2 NS SET

scan line number	scan line orient	face orient	P10	scan line length	observed number of intersects.	100 Realizations average simulated no. of ints.	100 Realizations relative percent error	Best Single DFNM simulated number of intersects	Best Single DFNM relative percent error
G1 SL1	00/170	170/60	17.5	1.946	34	35.2	3	33	-3
G1 SL2	60/260	170/60	11.3	1.235	14	14.5	4	13	7
G2 NS	00/118	118/50	2.8*	1.8*	5*	21.0	-4	5	0
		Totals	**29**		**48**	**70.7**		**54**	**13**

* Based on 19 intersections along a 6.65m scan line giving 2.9 intersections per meter

Simulated Fracture Intensities (P32)

set 1	set 2	set 3	set 4	set 5	set g2 ns
3.7	3.5	9	0.5	0.5	3.6

Total P32 for DFN Model **20.8**
Number of fractures in 2m DFN model **1820**
Projected number of fractures in 15m DFN mode **~130,000**

TABLE DR3. FRACTURE INTENSITY AND AQUIFER HYDRAULIC DATA FROM PREVIOUS WORK IN T

Cubic Law $T \sim 10^6 (b)^3$

Hicks, 1987

Estimated Fracture Intensities (joints per meter

P10 ysp	P10 gneiss	P10 all metamorphic rocks	
0.06	0.06	0.06	**min**
6	6	6	**max**

Lawrence, 1990

Estimated Transmissivities (T)

T (gpd/ft)	T (m^2/s)
3	4.31E-07
9300	1.34E-03
max	1.34E-03
min	4.31E-07

Folger, 1995

Estimated Transmissivities (T)

T (m^2/day)	T (m^2/s)	
3	3.47E-05	
6	6.94E-05	
11	1.27E-04	
3	3.47E-05	
0.07	8.10E-07	
0.9	1.04E-05	
120	1.39E-03	
0.2	2.31E-06	
0.4	4.63E-06	
0.8	9.26E-06	
2	2.31E-05	
7	8.10E-05	
14	1.62E-04	
15	1.74E-04	
12	1.39E-04	
1	1.16E-05	
160	1.85E-03	
0.7	8.10E-06	
0.5	5.79E-06	
	1.85E-03	**max**
	8.10E-07	**min**

Hydraulic Aperture (b) Estimates

b (σm)	
380	
240	
110	
200	
190	
120	
60	
100	
570	
360	
160	
300	
570	**max**
60	**min**
233	mean
195	median

Porosity (n) Estimates

n (liters)	n#(m^3)	
0.19	0.00019	
0.12	0.00012	
0.06	0.00006	
0.01	0.00001	
0.57	0.00057	
0.36	0.00036	
0.16	0.00016	
0.03	0.00003	
5.70E-01	5.70E-04	**max**
1.00E-02	1.00E-05	**min**

TABLE DR4. TCW DICRETE FRACTURE NETWORK (DFN) MODEL POTENTIAL POROSITY RESULTS

V_f = total fracture volume, n_p = total fracture network potential porosity in DFN model

METAMORPHIC ROCKS

location and DFN model size	DFN model density (m^2/m^3)	DFN model volume (m^3)	Vf @ 10σm (m^3)	Vf @ 100σm (m^3)	Vf @ 1mm (m^3)	n_p @ 10σm (%)	n_p @ 100σm (%)	n_p @ 1mm (%)
285S								
2m	5.10	8	4.08E-04	4.08E-03	4.08E-02	0.0051	0.051	0.51
5m	5.10	125	6.38E-03	6.38E-02	6.38E-01			
10m	5.10	1000	5.10E-02	5.10E-01	5.10E+00			
15m	5.10	3375	1.72E-01	1.72E+00	1.72E+01			
285N								
2m	1.607	8	1.29E-04	1.29E-03	1.29E-02	0.0016	0.0161	0.1607
5m	1.607	125	2.01E-03	2.01E-02	2.01E-01			
10m	1.607	1000	1.61E-02	1.61E-01	1.61E+00			
15m	1.607	3375	5.42E-02	5.42E-01	5.42E+00			
LAMBERT								
2m	4.517	8	3.61E-04	3.61E-03	3.61E-02	0.0045	0.0452	0.4517
5m	4.517	125	5.65E-03	5.65E-02	5.65E-01			
10m	4.517	1000	4.52E-02	4.52E-01	4.52E+00			
15m	4.517	3375	1.52E-01	1.52E+00	1.52E+01			
LEGAULT PEAK								
2m	2.31	8	1.85E-04	1.85E-03	1.85E-02	0.0023	0.0231	0.231
5m	2.31	125	2.89E-03	2.89E-02	2.89E-01			
10m	2.31	1000	2.31E-02	2.31E-01	2.31E+00			
15m	2.31	3375	7.80E-02	7.80E-01	7.80E+00			
					AVERAGE	**0.0034**	**0.0338**	**0.3384**
					MAX	**0.0051**	**0.0510**	**0.5100**
					MIN	**0.0016**	**0.0161**	**0.1607**

INTRUSIVE ROCKS

location and DFN model size	DFN model density (m^2/m^3)	DFN model volume (m^3)	Vf @ 10σm (m^3)	Vf @ 100σm (m^3)	Vf @ 1mm (m^3)	n_p @ 10σm (%)	n_p @ 100σm (%)	n_p @ 1mm (%)
HARRINGTON								
2m	2.46	8	1.97E-04	1.97E-03	1.97E-02	0.0025	0.0246	0.246
5m	2.46	125	3.08E-03	3.08E-02	3.08E-01			
10m	2.46	1000	2.46E-02	2.46E-01	2.46E+00			
15m	2.46	3375	8.30E-02	8.30E-01	8.30E+00			
NOBEL								
2m	2.01	8	1.61E-04	1.61E-03	1.61E-02	0.0020	0.0201	0.201
5m	2.01	125	2.51E-03	2.51E-02	2.51E-01			
10m	2.01	1000	2.01E-02	2.01E-01	2.01E+00			
15m	2.01	3375	6.78E-02	6.78E-01	6.78E+00			
GREEN								
2m	2.35	8	1.88E-04	1.88E-03	1.88E-02	0.0024	0.0235	0.235
5m	2.35	125	2.94E-03	2.94E-02	2.94E-01			
10m	2.35	1000	2.35E-02	2.35E-01	2.35E+00			
15m	2.35	3375	7.93E-02	7.93E-01	7.93E+00			
					AVERAGE	**0.0023**	**0.0227**	**0.2273**
					MAX	**0.0025**	**0.0246**	**0.2460**
					MIN	**0.0020**	**0.0201**	**0.2010**

FAULT ZONES

location and DFN model size	DFN model density (m^2/m^3)	DFN model volume (m^3)	Vf @ 10σm (m^3)	Vf @ 100σm (m^3)	Vf @ 1mm (m^3)	n_p @ 10σm (%)	n_p @ 100σm (%)	n_p @ 1mm (%)
JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 1								
2m	27.78	8	2.22E-03	2.22E-02	2.22E-01	0.028	0.278	2.780
5m	27.78	125	3.47E-02	3.47E-01	3.47E+00			
10m	27.78	1000	2.78E-01	2.78E+00	2.78E+01			
15m	27.78	3375	9.38E-01	9.38E+00	9.38E+01			
JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 2								
2m	27.17	8	2.17E-03	2.17E-02	2.17E-01	0.027	0.272	2.720
5m	27.17	125	3.40E-02	3.40E-01	3.40E+00			
10m	27.17	1000	2.72E-01	2.72E+00	2.72E+01			
15m	27.17	3375	9.17E-01	9.17E+00	9.17E+01			
CONIFER-ASPEN PARK FAULT ZONE								
2m	21.00	8	1.68E-03	1.68E-02	1.68E-01	0.021	0.210	2.100
5m	21.00	125	2.63E-02	2.63E-01	2.63E+00			
10m	21.00	1000	2.10E-01	2.10E+00	2.10E+01			
15m	21.00	3375	7.09E-01	7.09E+00	7.09E+01			
					AVERAGE	**0.0253**	**0.2532**	**2.5333**
					MAX	**0.0278**	**0.2778**	**2.7800**
					MIN	**0.0210**	**0.2100**	**2.1000**

TABLE DR5. TCW DISCRETE FRACTURE NETWORK MODEL (DFNM) POTENTIAL PERMEABILITY RESULTS

All DFNMs run with uniform b = 100σm and T=1e-6m^2/s

First column indicates DFNM size & flow direction (e.g. 2mtb is a two meter DFNM with top to bottom flow, ew=east to west, ns=north to south).
For each DFNM outflow face: Q=mass flux, I=hydraulic gradient, A=cross-sectional area, K=hydraulic conductivity, k=potential permeability.
Fracture intensity is in units of m^2/m^3 and volume is in units of m^3.

location, DFNM size, and flow direction	Q (m^3/s)	I	A (m^2)	K (m/s)	k (m^2)	geometric mean k	log k	k normalized to min	max	min	direction of k max	direction of k min	fracture intensity	volume
285N														
2mtb	2.4E-07	0.05	4	1.2E-06	1.2E-13	-18.6	-12.9	1.2E+17	1.2E-13	1.0E-30	tb	ew	1.607	8
2mew	0.0E+00	0.05	4	0.0E+00	1.0E-30		-30.0	1.0					1.607	8
2mns	2.4E-07	0.05	4	1.2E-06	1.2E-13		-12.9	1.2E+17					1.607	8
5mtb	5.2E-07	0.02	25	1.0E-06	1.1E-13	-13.1	-13.0	1.9	1.1E-13	5.5E-14	tb	ew	1.607	125
5mew	2.7E-07	0.02	25	5.4E-07	5.5E-14		-13.3	1.0					1.607	125
5mns	3.9E-07	0.02	25	7.9E-07	8.0E-14		-13.1	1.5					1.607	125
10mtb	8.4E-07	0.01	100	8.4E-07	8.6E-14	-13.2	-13.1	1.9	8.6E-14	4.6E-14	tb	ew	1.607	1000
10mew	4.5E-07	0.01	100	4.5E-07	4.6E-14		-13.3	1.0					1.607	1000
10mns	7.1E-07	0.01	100	7.1E-07	7.2E-14		-13.1	1.6					1.607	1000
15mtb	1.0E-06	0.0067	222	6.8E-07	7.0E-14	-13.3	-13.2	1.8	7.0E-14	3.9E-14	tb	ew	1.607	3375
15mew	5.7E-07	0.0067	222	3.8E-07	3.9E-14		-13.4	1.0					1.607	3375
15mns	8.7E-07	0.0067	222	5.9E-07	6.0E-14		-13.2	1.5					1.607	3375
LAMBERT														
2mtb	2.5E-07	0.05	4	1.3E-06	1.3E-13	-13.0	-12.9	1.6	1.3E-13	8.0E-14	tb	ew	4.517	8
2mew	1.6E-07	0.05	4	7.8E-07	8.0E-14		-13.1	1.0					4.517	8
2mns	2.2E-07	0.05	4	1.1E-06	1.1E-13		-13.0	1.4					4.517	8
5mtb	1.2E-06	0.02	25	2.4E-06	2.5E-13	-12.9	-12.6	3.7	2.5E-13	6.7E-14	tb	ew	4.517	125
5mew	3.3E-07	0.02	25	6.6E-07	6.7E-14		-13.2	1.0					4.517	125
5mns	4.9E-07	0.02	25	9.8E-07	1.0E-13		-13.0	1.5					4.517	125
10mtb	3.4E-06	0.01	100	3.4E-06	3.4E-13	-12.6	-12.5	2.0	3.4E-13	1.7E-13	tb	ew	4.517	1000
10mew	1.7E-06	0.01	100	1.7E-06	1.7E-13		-12.8	1.0					4.517	1000
10mns	2.0E-06	0.01	100	2.0E-06	2.0E-13		-12.7	1.2					4.517	1000
15mtb	4.4E-06	0.0067	222	3.0E-06	3.0E-13	-12.7	-12.5	1.8	3.0E-13	1.7E-13	tb	ew	4.517	3375
15mew	2.5E-06	0.0067	222	1.7E-06	1.7E-13		-12.8	1.0					4.517	3375
15mns	3.0E-06	0.0067	222	2.0E-06	2.1E-13		-12.7	1.2					4.517	3375
LEGAULT PEAK														
2mtb	1.3E-13	0.05	4	6.7E-13	6.8E-20	-14.8	-19.2	1.0	2.6E-13	6.8E-20	ew	tb	2.31	8
2mew	5.2E-07	0.05	4	2.6E-06	2.6E-13		-12.6	3.9E+06					2.31	8
2mns	3.3E-07	0.05	4	1.7E-06	1.7E-13		-12.8	2.5E+06					2.31	8
5mtb	3.2E-08	0.02	25	6.4E-08	6.5E-15	-13.3	-14.2	1.0	1.6E-13	6.5E-15	ew	tb	2.31	125
5mew	7.8E-07	0.02	25	1.6E-06	1.6E-13		-12.8	24.4					2.31	125
5mns	6.4E-07	0.02	25	1.3E-06	1.3E-13		-12.9	19.8					2.31	125
10mtb	1.6E-07	0.01	100	1.6E-07	1.7E-14	-13.2	-13.8	1.0	1.5E-13	1.7E-14	ew	tb	2.31	1000
10mew	1.5E-06	0.01	100	1.5E-06	1.5E-13		-12.8	9.1					2.31	1000
10mns	1.4E-06	0.01	100	1.4E-06	1.4E-13		-12.9	8.5					2.31	1000
15mtb	2.6E-07	0.0067	222	1.8E-07	1.8E-14	-13.2	-13.7	1.0	1.2E-13	1.8E-14	ew	tb	2.31	3375
15mew	1.8E-06	0.0067	222	1.2E-06	1.2E-13		-12.9	6.7					2.31	3375
15mns	1.6E-06	0.0067	222	1.1E-06	1.1E-13		-13.0	5.9					2.31	3375
285S														

TABLE DR5. TCW DISCRETE FRACTURE NETWORK MODEL (DFNM) POTENTIAL PERMEABILITY RESULTS CONTINUED

location, size,						**geometric**		**k norm**			**direction of k**			
flow direction	**Q (m^3/s)**	**I**	**A (m^2)**	**K (m/s)**	**k (m^2)**	**mean k**	**log k**	**to min**	**max**	**min**	**max**	**min**	**intensity**	**volume**
HARRINGTON														
2mtb	2.7E-07	0.05	4	1.4E-06	1.4E-13	-13.1	-12.9	2.3	1.4E-13	6.0E-14	tb	ew	2.46	8
2mew	1.2E-07	0.05	4	5.8E-07	6.0E-14		-13.2	1.0					2.46	8
2mns	1.6E-07	0.05	4	7.8E-07	7.9E-14		-13.1	1.3					2.46	8
5mtb	6.5E-07	0.02	25	1.3E-06	1.3E-13	-12.9	-12.9	1.3	1.3E-13	1.0E-13	tb	ns	2.46	125
5mew	5.1E-07	0.02	25	1.0E-06	1.0E-13		-13.0	1.0					2.46	125
5mns	5.0E-07	0.02	25	1.0E-06	1.0E-13		-13.0	1.0					2.46	125
10mtb	1.2E-06	0.01	100	1.2E-06	1.3E-13	-13.0	-12.9	1.6	1.3E-13	8.0E-14	tb	ew	2.46	1000
10mew	7.9E-07	0.01	100	7.9E-07	8.0E-14		-13.1	1.0					2.46	1000
10mns	9.5E-07	0.01	100	9.5E-07	9.7E-14		-13.0	1.2					2.46	1000
15mtb	1.8E-06	0.0067	222	1.2E-06	1.3E-13	-13.0	-12.9	1.6	1.3E-13	7.9E-14	tb	ew	2.46	3375
15mew	1.2E-06	0.0067	222	7.8E-07	7.9E-14		-13.1	1.0					2.46	3375
15mns	1.4E-06	0.0067	222	9.6E-07	9.8E-14		-13.0	1.2					2.46	3375
NOBEL														
2mtb	3.6E-07	0.05	4	1.8E-06	1.9E-13	-13.0	-12.7	2.5	1.9E-13	7.4E-14	tb	ew	2.01	8
2mew	1.5E-07	0.05	4	7.3E-07	7.4E-14		-13.1	1.0					2.01	8
2mns	1.5E-07	0.05	4	7.5E-07	7.7E-14		-13.1	1.0					2.01	8
5mtb	5.3E-07	0.02	25	1.1E-06	1.1E-13	-13.2	-13.0	2.7	1.1E-13	4.0E-14	tb	ew	2.01	125
5mew	2.0E-07	0.02	25	3.9E-07	4.0E-14		-13.4	1.0					2.01	125
5mns	2.4E-07	0.02	25	4.8E-07	5.0E-14		-13.3	1.2					2.01	125
10mtb	1.0E-06	0.01	100	1.0E-06	1.1E-13	-13.1	-13.0	2.0	1.1E-13	5.3E-14	tb	ew	2.01	1000
10mew	5.2E-07	0.01	100	5.2E-07	5.3E-14		-13.3	1.0					2.01	1000
10mns	6.3E-07	0.01	100	6.3E-07	6.4E-14		-13.2	1.2					2.01	1000
15mtb	1.5E-06	0.0067	222	1.0E-06	1.0E-13	-13.2	-13.0	2.0	1.0E-13	5.0E-14	tb	ew	2.01	3375
15mew	7.3E-07	0.0067	222	4.9E-07	5.0E-14		-13.3	1.0					2.01	3375
15mns	9.0E-07	0.0067	222	6.0E-07	6.2E-14		-13.2	1.2					2.01	3375
GREEN														
2mtb	1.9E-07	0.05	4	9.6E-07	9.8E-14	-13.1	-13.0	1.8	1.0E-13	5.4E-14	ew	ns	2.35	8
2mew	2.0E-07	0.05	4	1.0E-06	1.0E-13		-13.0	1.9					2.35	8
2mns	1.0E-07	0.05	4	5.2E-07	5.4E-14		-13.3	1.0					2.35	8
5mtb	5.3E-07	0.02	25	1.1E-06	1.1E-13	-13.0	-13.0	1.8	1.2E-13	6.0E-14	ew	ns	2.35	125
5mew	5.9E-07	0.02	25	1.2E-06	1.2E-13		-12.9	2.0					2.35	125
5mns	2.9E-07	0.02	25	5.9E-07	6.0E-14		-13.2	1.0					2.35	125
10mtb	9.6E-07	0.01	100	9.6E-07	9.8E-14	-13.0	-13.0	1.1	1.2E-13	8.5E-14	ew	ns	2.35	1000
10mew	1.2E-06	0.01	100	1.2E-06	1.2E-13		-12.9	1.4					2.35	1000
10mns	8.4E-07	0.01	100	8.4E-07	8.5E-14		-13.1	1.0					2.35	1000
15mtb	1.3E-06	0.0067	222	9.0E-07	9.2E-14	-13.0	-13.0	1.0	1.0E-13	9.1E-14	ew	ns	2.35	3375
15mew	1.5E-06	0.0067	222	9.8E-07	1.0E-13		-13.0	1.1					2.35	3375
15mns	1.3E-06	0.0067	222	8.9E-07	9.1E-14		-13.0	1.0					2.35	3375
JUNCTION RANCH-PARADISE HILLS FAULT ZONE GRID 1														
2mtb	4.3E-06	0.05	4	2.1E-05	2.2E-12	-11.9	-11.7	3.2	2.2E-12	6.8E-13	tb	ew	27.78	8
2mew	1.3E-06	0.05	4	6.7E-06	6.8E-13		-12.2	1.0					27.78	8
2mns	3.6E-06	0.05	4	1.8E-05	1.8E-12		-11.7	2.7					27.78	8
10mtb	ated - extrapolated				1.6E-11	-10.9	-10.8	1.9	1.6E-11	8.7E-12	tb	ew	27.78	1000
10mew	ated - extrapolated				8.7E-12		-11.1	1.0					27.78	1000
10mns	ated - extrapolated				1.2E-11		-10.9	1.4					27.78	1000