# Effect of the geothermal fault roughness on the permeability field and the fracture opening field

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***Abstract***

The aim of this article is to establish a basic document for scientists in order to correct the correlation functions and also to deepen the spatial display techniques on the filtrations of the geological data. The opening field of a rough fracture is generated in a Matlab algorithm. The Hurst coefficient controls the roughness of the fracture. The prefigured factor controls the accuracy of the validation of the power law associated with the Hurst coefficient that one can perceive the average amplitude of the opening. The permeability field associated with this surface could be deduced by the identification of Darcy's law at the integration of the velocity field of the flow along the axis of the opening.

*Key words: Geothermal fault, effect of roughness, permeability, opening field, Hurst's Function*

***Résumé***

L'objectif de cet article est d'établir un document de base pour les scientifiques afin de corriger les fonctions de corrélation et aussi d'approfondir les techniques d'affichage spatial sur les filtrations des données géologiques. Le champ d'ouverture d'une fracture rugueuse est généré dans un algorithme de Matlab. Le coefficient de Hurst contrôle la rugosité de la fracture. Le pré-facteur mis en évidence contrôle la précision de la validation de la loi de puissance associe au coefficient de Hurst que l'on peut percevoir l'amplitude moyenne de l'ouverture. Le champ de perméabilité associe à cette surface a pu en être déduit par l'identification de la loi de Darcy à l'intégration du champ de vitesse de l'écoulement selon l'axe de l'ouverture.

## 1. INTRODUCTION

In most cases, there is a lot of difficulty in the temperature and the pressure fields setting up out of the flow in the geothermal faults. In addition, programs on the correlation of geological data are almost unstable in the event of major changes, and permeability in fractures is also required to create a flow simulation.
A first numerical representation of permeability field in a fault has been proposed by A. Jupe [Jupe et al, 1995] as part of the European HDR (Hot Dry Rock) geothermal project. It consists in schematizing the flow in an open fault with complex geometry by the circulation of a Newtonian fluid between two parallel planes possessing the same thermo-hydraulic properties as the real fracture. The Bouchaud's work [Bouchaud et al, 1997] shows that many surfaces of natural fractures can be perceived as self-affine functions.

Our objective is to know all opening influence parameters of the faults and to deepen the techniques of spatial displays on the geological data. To do this, we will use the method of the self-affine function, the principle of numerical analysis and that of the correlation functions of Hurst according to the law of powers. By varying the Hurst coefficient without changing the size of the fracture, one can deduce to what extent the correlated field of permeability is dependent on the roughness. Any influence of the fault size or the verification of the effectiveness of the playing program will be corrected and discussed.

## 2. FRACTURES AND GEOTHERMAL ENERGY

### 2.1. Geothermal energy

Geothermal energy comes from the Greek word geo (earth) and thermos (hot), geothermal energy consists in exploiting the heat stored in the subsoil of our planet. Geothermal energy is defined as the exploitation of the heat stored in the earth's crust, originating both in the cooling of the terrestrial nucleus and above all in the natural disintegration of the radioactive elements contained in the deep rocks. Geothermal energy is present everywhere on the surface of the globe. It is manifested by the geothermal gradient (elevation of temperature with depth) which is on average 3.3 ° C per 100 m at the Earth's scale. This geothermal gradient comes from the geothermal flux equal to an average of 60 MW / m². Local variations of geothermal gradient are nevertheless observed. They are related to the age of the geological formations and their composition. Geothermal energy can be used for heating, cooling, or generating electricity through different technologies. The possibility of implementing each of these technologies depends on the local geological and hydro-geological context.

### 2.2. Different geothermal resource

In the case of the use of geothermal energy for the production of heat, a geothermal system consists of a heat source, associated with a heat sampling device enabling it to be transferred for use. The heat source is characterized, on the one hand, by its temperature level (in ° C) and by the nature and characteristics of the medium concerned.
The temperature depends on the depth and the local geothermal gradient. In the case of the underground environment where heat is to be considered, it may consist of permeable or impermeable, compact, porous or cracked rocks.
When the geological formations are sufficiently porous and / or cracked and gorged with water, they are called "aquifers" or "groundwater" or designated as "reservoirs". The physical characteristics of these aquifers allow the collection of water in sufficient quantity by capture.
The aquifers formations are found in sedimentary geological layers (chalk, limestone, sand, etc.), crystalline or volcanic.
The superficial aquifers of the deep aquifers are then distinguished. Deep aquifers are found in sedimentary basins over a hundred meters and may reach depths exceeding two thousand meters for some.

### 2.3. Flow in the fracture

A fault is a planar land break with relative displacement of the compartments thus separated. Groundwater flows result from the interactions between the fluid and the rock from which the aquifer is formed. In fractured media, the rock is almost impermeable and water can only flow through the fractures (Figure 1). The observations of the natural environment reveal a complexity both geometric, linked to the network of fracture, and hydraulic, by the organization of the flows in this network. Heterogeneity is present at all scales. At the scale of the fracture, its shape, its opening and its roughness induce spatially variable hydraulic properties. The flows depend on the distribution of the fracture lengths, the orientations, the openings and the way in which the fractures are organized. For a critical study of methods of characterizing flows in fractured media.

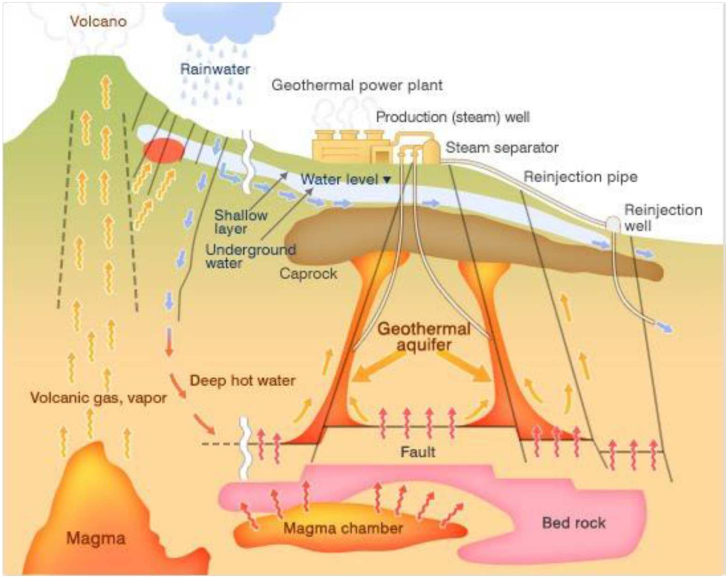


*Figure 1: Systems of a hydrothermal circulation in a fault (Guoni Axelsson, 2014)*

## 3. FRACTURE, FAULT AND PERMEABILITY

### 3.1. Description of the principle of operation

Synthetic fracture is a fracture defined by a model. The geometry of synthetic faults (Figure 2) remains simple and unrealistic given the heterogeneity of the fractured rocks. However, this non-triviality of the geometric properties of the faults has a real impact on the hydraulic and thermal circulation in the fault network.

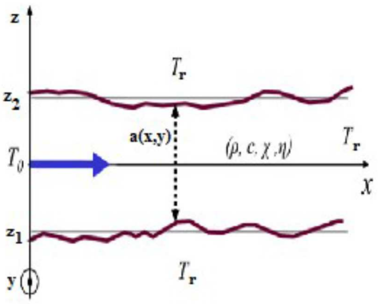


*Figure 2: Diagram of a fracture having a variable opening a(x,y)*

In the case of this study, we are limited to the effects of the variation of the opening of a fracture. The study of Méheust and Schmittbuhl [Meheust et al, 2000] made it possible to demonstrate experimentally the influence of the self-affine fluctuations of the real fault openings.
Our numerical study is based on the generation of a synthetic rough surface that we want as close as possible to reality. Measurements of the 3D topography of a rough surface can be carried out by different procedures using laser technology in the laboratory or in the field.

**3.2. Conditions and parameters necessary**

Table 1 shows the list of the properties of the fault studied and Table 2 shows the list of the properties of the fractured rock.

*Table 1: List of the properties of the fault studied*

| Properties of the fault | | | |
|---|---|---|---|
| Properties | Order of magnitude | Materials | Places |
| Roughness [mm] | 0.1-0.9 | Roughometer | On ground or in Laboratory |
| Opening [mm] | 10-20 | Measure | On ground or in Laboratory |
| Geometry | Study vertical | - | On ground or in Laboratory |

*Table 2: List of the properties of the fractured rock*

| Properties of the rock | | | |
|---|---|---|---|
| Properties | Order of magnitude | Materials | Places |
| Porosity [Pa] | 2.2.108 | Pycnometer | Laboratory |
| Density [kg m3] | 3800 | Gamma densimeter | Laboratory |
| Permeability [m2] | 10-8 - 10-7 | Gravimeter | Laboratory |

In the reference frame (0, x, y, z) or the z-axis is perpendicular to the main plane of the fracture (x, y), a surface of equation z = f (x, y) is said to be self-affine if The scaling of an intermediate coefficient λ is isotropic in the plane and anisotropic according to z

$$x \rightarrow \lambda dx, y \rightarrow \lambda dy \; et \; z \rightarrow \lambda^{\zeta} dz \quad (1)$$

With ζ the coefficient of Hurst or roughness says

From this we deduce a certain number of behavior related to the definition of the Hurst coefficient. If we assume that a scale transformation in the reference case of a system has two parallel plates is written as

$$x \rightarrow \lambda dx, y \rightarrow \lambda dy \; et \; z \rightarrow \lambda \, dz \quad (2)$$

Then the Hurst's coefficient can be understood as one of the factors of the difference between the real shape of the opening field (assuming that the fracture is a self-refining object) and that of the reference case above. Our numerical study is based on this law of power (1) since we seek to synthesize fracture surfaces closest to the observed measurements.
It is important to note that | ζ | <1 thus the self-affine transformation of a surface diverges along the z axis for small scales. Hence it is necessary to define a characteristic filtering length lc in the algorithm for generating a random opening field whose fluctuations with respect to the reference case are correlated by the power law (1). This also implies that the size of the model plays an important role in defining the roughness of a fracture.

### 3.3. Numerical resolution of the problem

The first step of the numerical study consists in generating a permeability field correlated according to the power law with a Hurst exponent. The algorithm for generating the field is formulated in a Matlab code. It is subdivided into a main program and a function generating the random and correlated fields of opening and permeability. The steps of the algorithm are shown schematically in figure 3.

It is therefore essential to explain the transition from a generation of an auto-affine rough surface to that of a field of self-affine permeability along a plane. This is the analogy made in equation (3) and Darcy's law is

$$k = \frac{-a^3}{12\eta} \qquad (3)$$

With a (x, y), the random field of random and correlated opening of the correlated fracture
And η, the dynamic viscosity of the arbitrary fluid.

This relation constitutes the remarkable equivalence between variables of fluid mechanics such as permeability or viscosity and those of the porous medium such as the opening of the fracture.
The synthesis of the opening field is based on a classical approach to simulation of fractures with complex geometry developed by the work of A. Jupe [Jupe et al, 1995]. The fracture medium is modeled by a network of faults whose geometry of each is summarized to two parallel plates but with the same properties as the real medium.

The parameter is called the aperture field a (x, y) as the difference between the surfaces of the fracture facing each other. In the reference case we have a constant opening field a (x, y) = A, this is the starting point of our model. The fracture surface is cut according to a grid of dimension (nx, ny). The parameters nx and ny correspond to the number of elements of the fracture opening matrix. They are chosen even to improve the spatial correlation with the Hurst power law.

To simulate a self-affine topography, we add a random fluctuation of amplitude note Z (x, y) to the field of opening A. We assimilate the set of random amplitudes Z (x, y) to a white noise in the the Matlab program. This perturbation Z (x, y) is then spatially correlated according to the scale transformation (1) and thus connected directly to the roughness coefficient ζ.
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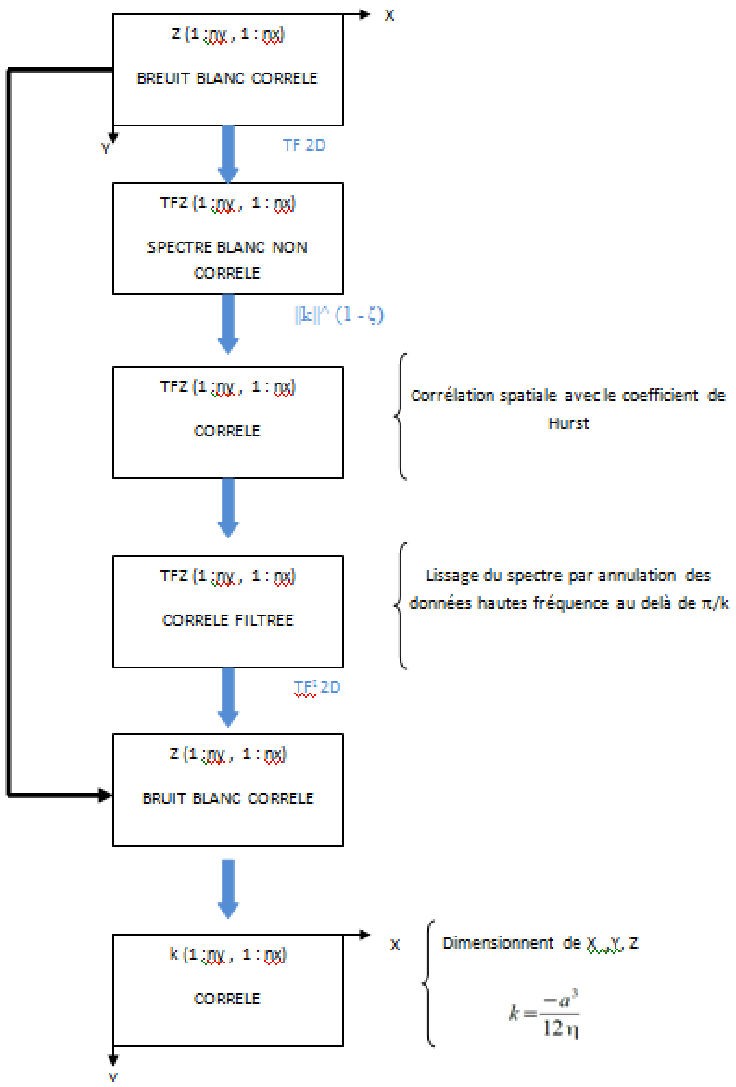


*Figure 3:"Illustration of the various stages of the algorithm of generation of the field"*

In practice, this spatial statistical correlation is carried out in the Fourier domain in two dimensions, and summarizes the multiplication of the white spectrum by the factor || k || ^ (1 - ζ) with k, the wave number. We then reduce to two parameters ζ and Z the generation of the opening field for a fracture of size (lx, ly).

The spectrum is then smoothed out by suppressing high frequency data exceeding the critical spatial filtering frequency $\pi$ / lc. The work of A. Neuville point out that the length lc plays on the divergence of the law of Hurst in small scales [Neuville et al, 2010]. Thus the characteristic length must be between nx and ten times this value. The high-pass filter is nothing other than the brutal application of a gate function in the Fourier domain.

The correlated random opening field is obtained by a return in the spatial domain by an inverse 2D transform of Fourier. We take only the real part in the Matlab program to avoid any problem of phase shift. The flow permeability field is deduced from the dimensioned and filtered opening field Z and from equation (3). It is concluded that the permeability of the fracture thus depends indirectly on the coefficient of roughness $\zeta$ as well as the complex geometry of the fracture.

## 4. RESULT AND INTERPRETATION

### 4.1. Random opening field and permeability correlated

The visualization of the synthetic fields of opening and permeability makes it possible to appreciate qualitatively the influence of the coefficient of roughness. A complementary statistical study with the generation of a number of synthetic surfaces would be necessary to study the influence of the parameter on the geometric aperture field quantitatively.

In figure 4, the correlation and aperture fields are shown for a particular value $\zeta = 0.3$ and for $\zeta = 0.5$; It should be noted that beyond the visualization of the effect of roughness on a fracture and its field of permeability, figure 4 illustrates the simulation of the rough surfaces of two different types of rocks,

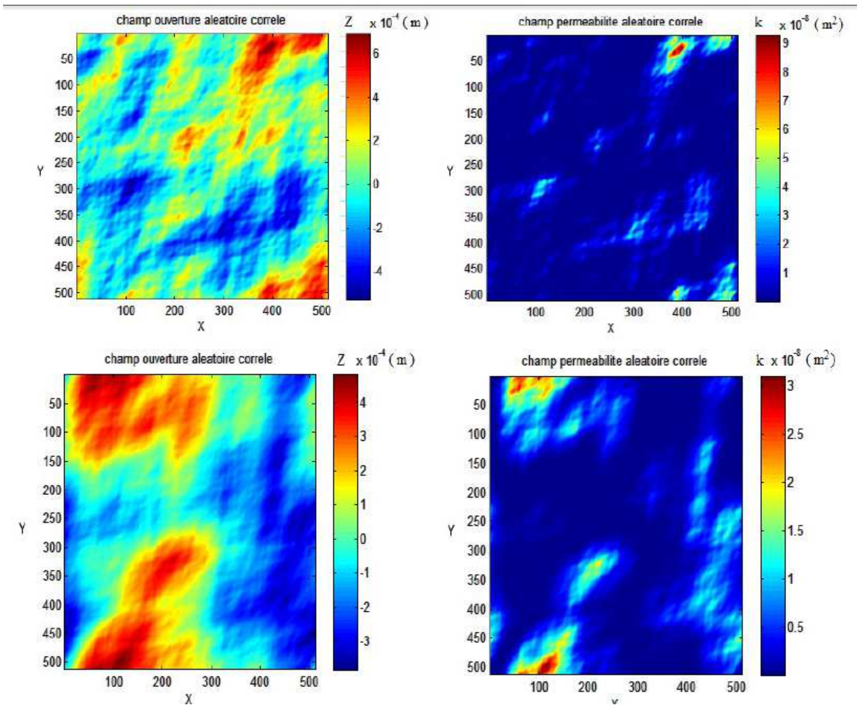


*Figure 4: Representation 2D of the fields of opening and permeability*

**4.2. Characterization of roughness**

After the visualization of several correlated fields of opening, it appears necessary to assure us of the isotropy of the law of Hurst in the Fourier domain.

In a first step, it is verified that there is no spreading effect in the Fourier domain. The two components of the wave number must be equalized in order to avoid an anisotropy of the Hurst law. There is no apparent dissymmetry between the expressions of the axes kx and ky in the code of the function of generation of the two fields. To ensure that the absence of spreading is graphic, the equation of a circle with the representation of the values of the axes kx and ky is associated in Figure 5. If there was a difference in scale between the two components, the two figures should not overlap. As can be seen in figure 5, there is no spreading phenomenon.

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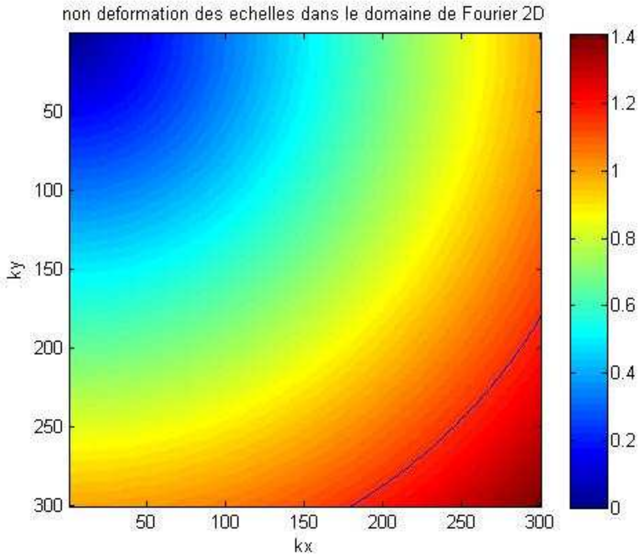


*Figure 5: Non deformation of the scales in the field of Fourier 2D*

**4.3. Precision of the correlation of the spectrum white**

In order to ensure the accuracy of the correlation, the white spectrum (likewise for the random phase) of correlated aperture must follow a power law || k || ^ (-1 - ζ) or a linear law in Logarithmic scale according to several 1D profiles following the kx axis, the ky or oblique axis. We propose a program of interpolation of the logarithm of the auto-affine transformation of the variables kx and ky with the correlated white spectrum.

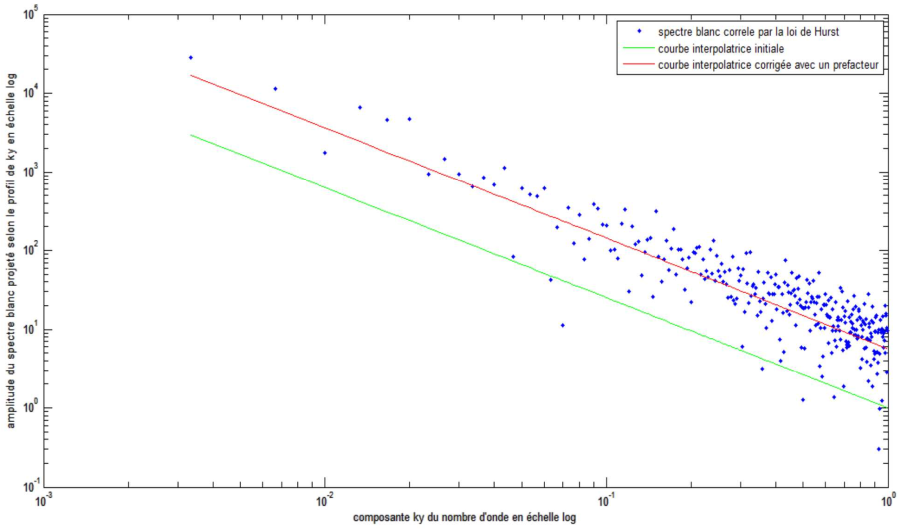


*Figure 6: Linear Interpolation of the correlated white spectrum*

The error variable of a factor has to be introduced in the Matlab code in order to superimpose at best the shape of the two straight lines. The influence of this factor is illustrated in Figure. 6. Here, it is found that a prefactor error value of 2 is necessary for a correct estimation of the roughness law. This error is mainly due to the non-normalization of the opening field. The generation of the fields was finally retained. This deviation with the interpolation line is no longer to be taken into account because the function contains a normalization step. The search for this error has therefore made it possible to highlight the importance of standardization in the characterization of the Hurst coefficient.

**5. DISCUSSION**

The opening field for a fault in a granitic basement logically tends to approach the reference case since $\zeta$ (0.3) $<\zeta$ (0.8) $<1$. This explains the greater presence homogeneities (the same for the zones of values Constants) of the open fields and permeability of the fracture.

A similar method of superposition could be used to ensure the circular and thus isotropic decay of the Hurst law. Nevertheless, the correlated spectrum of Hurst's law is attenuated very rapidly, which does not facilitate the definition of the equation of a circle to be superimposed on the spectrum.

There are other methods for characterizing the Hurst coefficient. These alternative methods are explained in the work of T. Candela [Candela et al, 2009]. As for our numerical studies, the estimate of the roughness is based on the comparison of the fixed Hurst coefficient as input variable by the user and that extracted from the 1D profile by linear interpolation of the power law with the spectrum of Opening synthesizes. The difference results from the fact that the method for generating the fracture profiles takes place in the Fourier 1D domain.

## 6. CONCLUDING REMARKS

A numerical model of the rough geothermal fracture opening has been proposed in order to understand the setting up of random permeability field and the correlated random opening field. A horizontal fault of variable section with variable roughness was chosen.

Our numerical study is based on the generation of a synthetic rough surface that we want as close as possible to reality. Measurements of 3D topography of a rough surface can be carried out by different procedures using laser technology in the laboratory or field.

Other methods of characterization of the Hurst coefficient are possible as the correlation by the standard deviations of the surface with the roughness factor consists in estimating the average field of fracture profiles 1D. Each profile being constituted by N points cutting an axis x each point of which separates by a distance $\Delta x$ and associated with an opening $\Delta L$. For an $\Delta x$ between the size of the increment and the length of the axis, the standard deviation of $\Delta L$ is calculated. In this case, since the Hurst law is written $\Delta x\ \zeta$, the roughness extracted from the 1D profile will not be affected by prefactor error in the same way for the deviation of the power law with the Hurst exponent.

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