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Full Field Fracture Modeling: an Integrated Approach with Application to three Carbonate Fractured Reservoirs

B.D.M. Gauthier
Totalfinaelf
2 Pl. de la Coupole – La Défense 6 – 92078 Paris La Défense Cedex – France – bertrand.gauthier@totalfinaelf.com

The impact of fracture systems on the flow behavior of carbonate reservoirs can range from (1) very restricted to (2) conduit for fluid flow and (3) reservoir impairment. This impact does not depend only on the type of fracture filling but also on fracture geometry, connectivity and density. According to the full field distribution of the fracture pattern, the three above flow behaviors are possible. Consequently, only the characterization and modeling of all fracture parameters at the entire field scale can lead to a comprehensive fracture model. In order to improve field development plans, this model needs to be evaluated against dynamic data.

This paper illustrates a systematic and logical work flow for the (static) characterization of fractured reservoirs. The application of this methodology to three case studies illustrates how it can be used to 1) better understand fracture distribution and its impact on fluid flows; 2) optimize infill drilling and 3) provides imput to the reservoir model.

The static characterization of full field fracture distribution: an integrated approach

Our in-house full field fracture modeling methodology is based the fact that fracture systems are fundamentally discontinuous objects which are defined only at the well scale. Simple extrapolations of well data is thus clearly not adequate. However, fractures are related to the mechanics and the geology of their host rock (tectonic events, rock properties, diagenesis etc). Our basic assumption is that through the geologist judgement, we can relate the Geological Fracture Control Parameters to reservoir attributes, defined at the entire field scale (e.g. with seismic). The main principle of the method is then to model the discriminant relationship between the fracturing (primary) variable and a collection of explicative variables. A full field fracture distribution results which can be used for field development planning. This is done through 4 main steps (Figure1):

1. Fractures families are first defined. For each family, *f*racture frequencies (i.e. inverse of fracture spacing) are computed and form the primary variables about fracturing.
2. Since direct well fracturing data are usually sparse, better known geological, structural or geomechanical factors can explain spatial fracturing trends. Discriminant analysis is used to relate such secondary information to fracture frequency data. Only the first discriminant analysis component (so called geological component) is retained as carrying most of the geological information related to fracturing.
3. The indicator-based simulation method used to simulate fracture frequencies (step 4) allows taking into account a bivariate histogram model that describes the complex relationship between the fracture frequency and the geological component.

4. Finally, sequential indicator simulation (SIS) is used to simulate stochastically the spatial distribution of fracture frequencies. The integration of the geological component is done by cokriging through a Bayesian formalism in which the geological information is converted into soft (probability-like) data. The realizations generated by stochastic simulation are **realistic** equiprobable images of the spatial distribution of fracture frequency which honor well data.

The realizations are used either to quantify the uncertainty about fracturing everywhere within the field, to characterize flow properties of the fracture network or to generate maps that help taking decisions about new well drilling locations. This is illustrated through three case studies.

The Characterization of a Fractured Reservoir: a Multi-disciplinary Approach with Application to an Offshore Abu Dhabi Carbonate Reservoir

This study illustrates a complete and systematic work flow for the characterization of a fractured Middle East carbonate reservoir (Gauthier et al, 2002a). It begins with a standard structural analysis of seismic and well data which defines a structural style and tectonic model. This model is evaluated against the paleo mechanical equilibriums through time computed with a 3D finite-element approach. The resulting deformation attributes are integrated with all known fracture-control parameters and with fracture data interpreted from image logs through our geostatistical method. This leads to probability maps of full field fracture distribution. Then, the role of the present day stress field on fracture permeability, is evaluated with a boundary element approach. Ultimately, the fracture model is confronted and qualitatively validated by production data. In Figure 2A, two probability maps illustrates how the two types of fractures observed in this field were modelled. The first type consists of a diffuse fracture network mainly related to the outer arc doming extension and mainly located at the crest of the field. The second type consists in fracture corridors located in the close vicinity of major (seismic) faults. In this model, the western flank appears less fractured than the central (dome) part and the eastern flank. High fracture frequencies also appear on the north and on the south.

Static and dynamic characterization of fracture pattern in the Upper Jurassic reservoirs of an offshore Abu Dhabi field: from well data to full field modeling

In the oil bearing reservoirs of a mature field in the offshore Abu Dhabi (Gauthier et al, 2002b), the understanding of the fracture network is essential with growing gas and water productions. Fracture characterization and modeling at the full field scale is the key to match the production profile and to optimize infill drilling. The interpretation of fracture data from image logs and cores allows defining accurately the fracture pattern in terms of orientation, typology, density and relation with lithology and faulting. Two main fracture sets are chronologically observed: (i) NW-SE fractures are generally mineralized and clustered around faults of similar orientations; (ii) NE-SW fractures are generally open, homogeneously distributed with their density controlled by the lithology and a few portion located in swarms. The calibration of fracture data with PLT’s in horizontal drains suggests that: (i) the main flow comes from the matrix in porous layers; (ii) in areas without mineralized fractures, wells can be connected to water, either through matrix (permeable layers) or through open NE-SW fractures, particularly in zones of large curvature where a higher fracture density is expected; (iii) in areas with mineralized fractures, water in permeable layers is channelized and tight layers can be vertically connected to more permeable layers by open fractures whereas the lateral flow can be hampered. The application of our full field fracture modeling methodology to this field enables us to optimize the drilling of 4 of infill wells. The results of these wells (Figure 2B) validate the method and result in reducing future log acquisition costs. It also provides qualitative information about the permeability field and permeability anisotropy.

Integrated Fractured Reservoir Characterization: a Case Study in a North Africa Field

In this study, (Gauthier et al, 2002), our approach is applied to a North Africa carbonate field that is not considered strictly as a fractured reservoir but where the dominant NW-SE fracture-set plays a determinant role on flows in the southern and to a less degree northern parts of the field. It is demonstrated that lithology (dolomitic streaks) and faulting are the main factors controlling this fracture-set. Dolomitic facies and faults are more frequent in the South and both contribute to the better productivity of the southern wells. The good fracturing predictions along a well drilled more recently validate, partly at least, this model (Figure 2C).

The fracture-frequency model cannot be used directly for flow simulation but needs to be incorporated in a more integrated reservoir model (Figure 2D). Especially, fracture-frequency maps are used, in combination with other reservoir constraints (e.g. lithology) to control the local density of fractures for the stochastic simulation of discrete fracture networks (DFN). DFN models are then calibrated in terms of equivalent flow properties to match well test data and to derive dual porosity-permeability parameters for reservoir simulation (Daniel et al, 2001).

References

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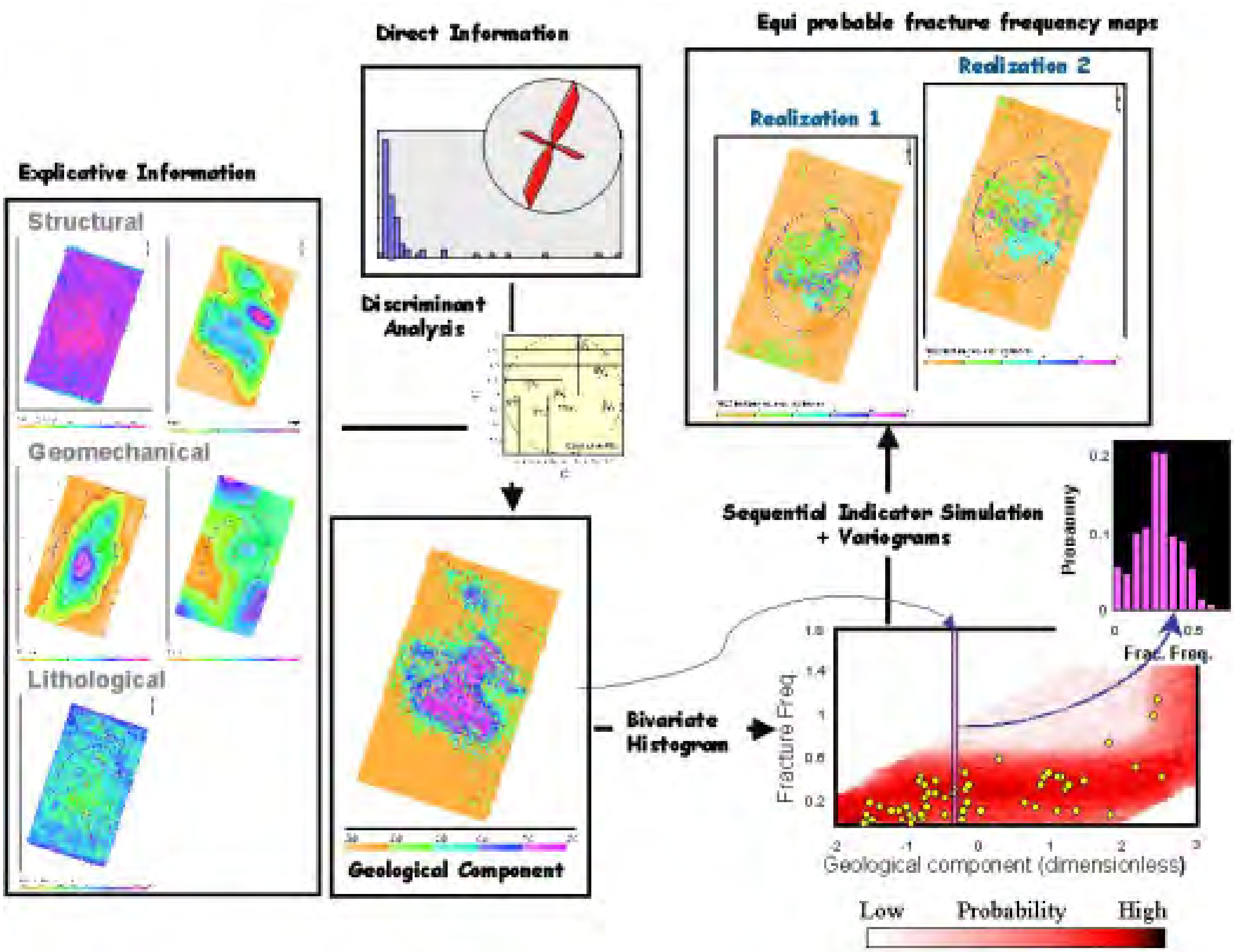
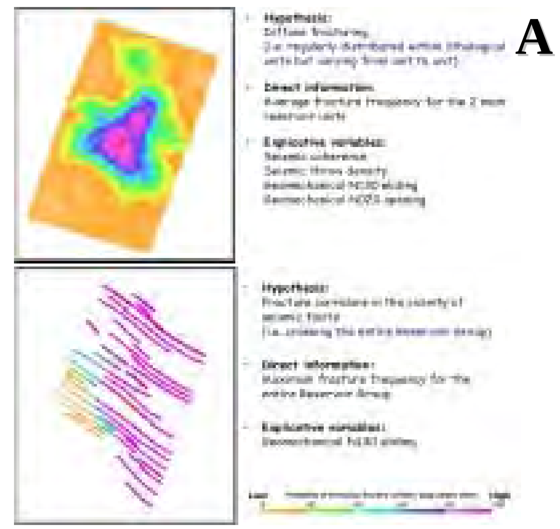
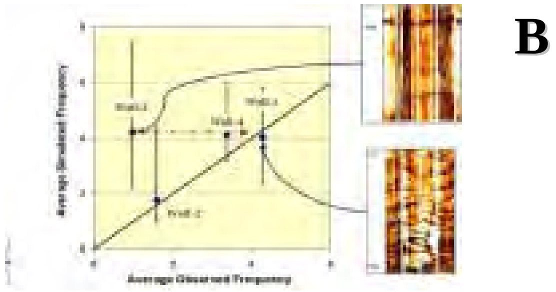


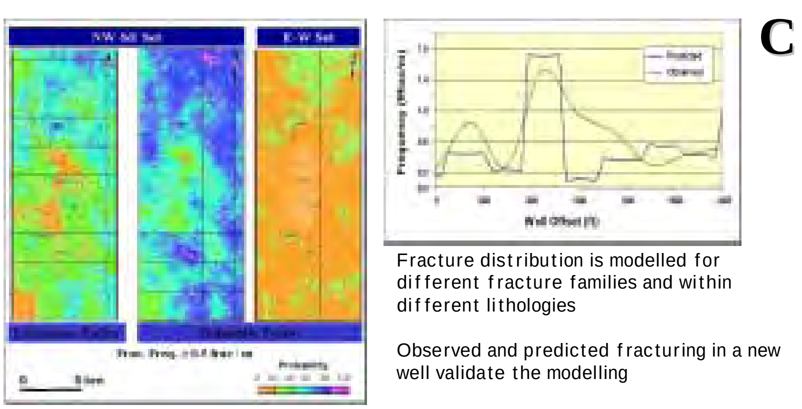
Figure 1: Systematic workflow for the full field modeling of fracture distribution



Modelling of a diffuse fracture system and fault related fracture corridors. *After Gauthier et al, 2002a*



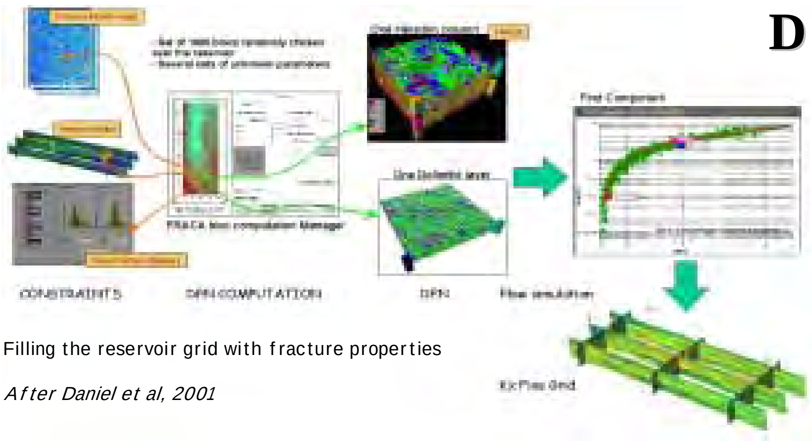
Observed and predicted fracturing in 4 new wells validate the modelling and allows fracturing in Well 3 has been underestimated due to poor image log in bad hole conditions. *After Gauthier et al, 2002b*



Fracture distribution is modelled for different fracture families and within different lithologies

Observed and predicted fracturing in a new well validate the modelling

After Gauthier et al, 2002c



Filling the reservoir grid with fracture properties

After Daniel et al, 2001

Figure 2: Application of the full field fracture modeling in three case studies