Introduction

Effective exploration is based on the method of Play-Based Exploration (PBE) which places the geological play concept at the heart of exploration and thus helps to identify and rank opportunities (Doust, 2010). A crucial aspect in this approach is the mapping of elements that constitute the play and combining them to identify the play fairway. This is typically done with Combined Common Risk Segment (CCRS) maps (Shell, 2014). The extent of each play element is divided into segments with similar probability characteristics whose boundaries reflect changes in either geology or confidence (data quality and/or density). Subsequently, play elements are multiplied/stacked to yield a play probability map.

The stacking of play element maps may lead to confusion between risk (evidence of possible success or failure) and uncertainty (low confidence about a possible outcome) and to the loss of underlying information from individual or critical play elements. The difficulty to estimate a certain risk for a segment comes from the challenge to predict the extent of an element and therefore to represent its spatial uncertainty. When interpreting data, the geologist usually draws the most probable extent of a geological feature. However, this feature also has an estimated minimum and maximum extent depending on data availability and conceptual arguments. Here, we try to quantify this spatial uncertainty on a map.

Method

The extent of a play element requires probability distributions in areas where data is lacking or insufficient to make a deterministic estimation. Play elements are represented by vector data or shapefiles that are encoded as a series of X-Y coordinates. For each point of the shapefile, a normal vector can be determined. Each point is then shifted along its normal vector according to a beta distribution. If the shapefile represents the most likely extent of the geological element, the limit of the shapefile represents the peak of the probability distribution. Therefore, only low and high estimates are required to determine the lower and upper bound of the extent. The probability distribution is zero around the most likely extent, the maximum would have a positive value (as the normal vector is directed outwards), and the minimum a negative value (Figure 1).

![Figure 1](image.png) Probability distribution attributed to part of a play element polygon applied in the direction of the normal vector. Here, the beta distribution is defined with the minimum at -20 units, the mode at 0 and the maximum at +80.

Hydrocarbon charge is sometimes difficult to represent as a play element. This is usually done by basin modeling which attempts to simulate the process of migration (Hantschel and Kauerauf, 2009). Prospects close to a source rock kitchen have a higher chance to be charged than prospects that are farther away. We implemented the Fast Marching Method (FMM) (Sethian, 1996) which allows to calculate the propagation front of flow lines within the migration area (Figure 2). By defining probability distributions of migration distances, we can represent the uncertainty of lateral migration. The distribution is a truncated normal distribution with a mean on the maximum efficient migration distance.
and a standard deviation to define the uncertainty on that value. Such a distribution represents all factors that influence migration, such as hydrocarbon generation and retention, carrier bed heterogeneity, potential migration losses etc.

**Figure 2** Left: Map representing the distance of migration in a fetch area. Colours represent distance from source. White polygon to the left corresponds to mature kitchen area or source rock, and white polygon to the right corresponds to area where hydrocarbons may be accumulated in traps. Right: probability distribution of migration distance.

Uncertainty of play fairways can be measured using the principle of information entropy $H$ which is defined as the sum of all products of probabilities $p$ for each possible outcome $i$ of $n$ total possible outcomes with its logarithm (Shannon, 1948). The application of information entropy to a spatial context follows directly from the concept that a discrete sub-region identified with a position vector $r = (x, y)$, can be considered as a random variable $X(r)$, with a set of $n$ possible exclusive outcomes (Wellmann, 2012):

$$H(X(r)) = - \sum_{i=1}^{n} p_i(r) \log_2 p_i(r)$$

A pixel of a grid or a map should validate the following assumptions:

- If no uncertainty exists at a specific location, then the measure is zero
- The measure is strictly greater than zero when uncertainty exists
- If several outcomes at a location are probable and all are equally likely, uncertainty is maximal
- If an additional outcome is considered, the uncertainty cannot be lower than without the outcome

**Application**

An example is given here from a fictive basin that has experienced two main tectonic events, an early extensional rift event and a late compressional event (Figure 3).

**Figure 3** Schematic section through fictive basin example: deep lacustrine source rock (purple), shallow marine source rock (blue), delta front deposits (yellow), clastic lobe-shape fans (orange), reef carbonates (light blue). Also indicated are the depth of the oil window (green line), depth of the gas window (red line) and depth where source rocks are overmature (grey line). Not to scale.
Figure 4 (A) Play element maps of carbonate reef in blue and delta lobe reservoir facies in orange; Schematic cross section A-A’ is shown in Figure 3. (B) Cap rock extension in grey including hashed eroded parts. (C) Play element map of postrift source rock and (D) play element map of synrift source rock. Blue areas show presence of source rock, grey areas show extensions of migration area to charge reservoir rocks. Green, red and black lines indicate beginning of oil, gas and overmature window. Dashed lines indicate maximum extensions. Hashed areas indicate erosion. (E) Probability map and (F) entropy map of play fairway for the combined carbonate and clastic plays.

The rifting event led to the formation of horsts and grabens within which the deposition of a lacustrine source rock occurred. It was followed by the deposition of a marine source rock above the unconformity, followed by the deposition of a prograding deltaic system indicated by delta foresets and prodelta fans, whereas carbonate reefs formed in the outer rim of the delta. The subsequent compressional tectonic
event then folded the previous deltaic sequence. Figures 4A and 4B show maps of reservoir and cap rock play elements whereas maps of extent and maturity of source rocks as well as migration areas of the two different source rocks are given in Figures 4C and 4D. Solid lines indicate most-likely extent of the play elements whereas maximum extent is indicated by dashed lines.

Spatial probability distributions are assigned to the play element extensions as shown in Figure 1 and stochastic realizations are generated for each play element which are then stacked to yield a probability map of the play fairway of the two combined reservoir facies (Figure 4E). 500 realizations result in a play surface distribution with a minimum and maximum extent of 78400 and 122000 area units. Underlying probabilities can be queried for any position of each play element, for example which source rock charges a given reservoir.

An entropy map is generated from these probability maps (Figure 4F), according to the Shannon equation above, which has values ranging from 0 to 2 where the highest value corresponds to highest uncertainty where all outcomes are equally likely. Possible outcomes are: 1) all elements present, 2) one of three elements missing, or 3) two or all elements missing. For example, at position (X 300, Y 580) uncertainty is high because two elements, carbonate reservoir and cap rock, may be missing. Similarly, at position (X 400, Y 150) uncertainty is high because carbonate reservoir facies and charge may be missing.

**Conclusions and outlook**

Geological probability depends strongly on play fairway uncertainty that can be measured applying the principle of information entropy to play element maps that carry probabilistic limits. This enables ranking total uncertainty based on multiple properties of the play that are expressed with their individual spatial uncertainties and spatial dependencies. A natural extension of our work includes the application of Bayesian inference on the play with new information such as a well or seismic data. The impact on the play can be used to quantify the value of such new information. Additional play surface means additional yet-to-find volumes and potentially unlocking nearby prospects. The procedure developed here can also be applied to other types of map dependent resources such as estimates of geothermal plays or mineral resources.

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**References**


