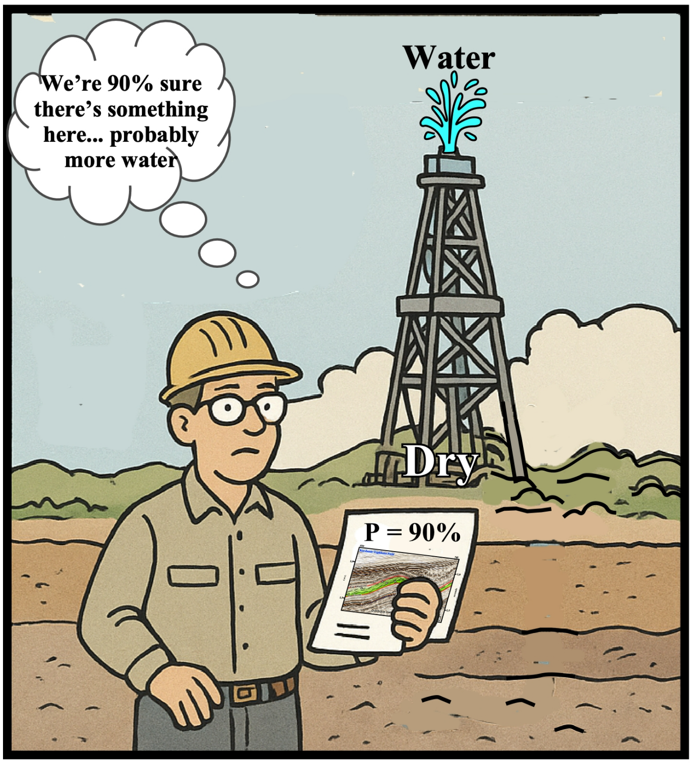
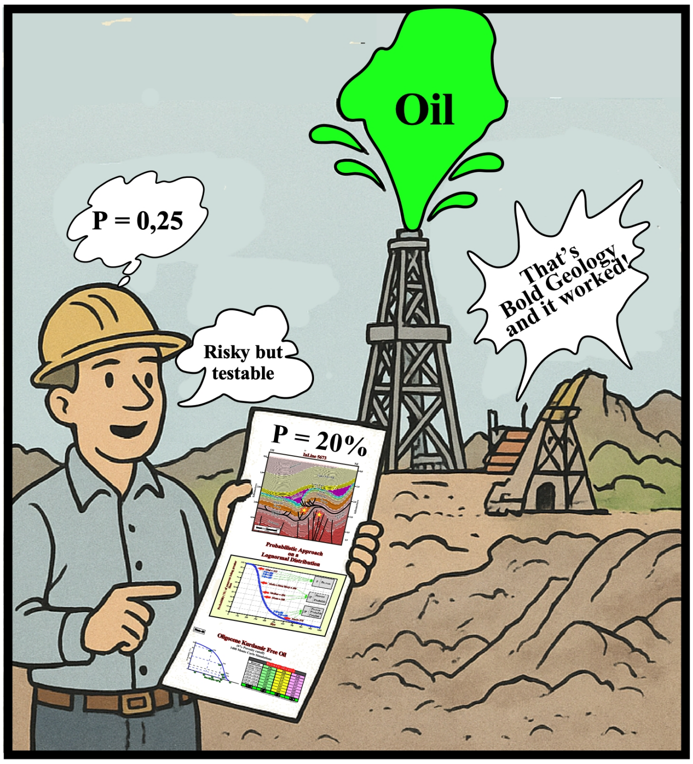
Probability and Versimilitude
in
Petroleum Geology

High Probability



High Verisimilitude



High probability doesn't mean high value.
Scientific boldness, not caution, drives discovery

CCramez, June 2025

Caption of the cover:

Left Panel (High Probability):

"High Probability, Low Informational Value"
This well targets a conventional structural trap with high confidence - the type often chosen because it's familiar, well-bounded, and easy to justify. However, its high probability reflects low geological risk **but also low scientific content**. The outcome is predictable - in this case, **water** - and adds little new insight into the petroleum system.

Right Panel (High Verisimilitude):

"Low Probability, High Scientific Value"
This well tests a **mixed structural–stratigraphic- hydroidynamic trap** informed by seismic inversion, facies modeling, and hydrodynamic analysis. Although its formal probability is lower, it represents a **bold, falsifiable hypothesis** with strong internal coherence. The result - **a successful oil find** - validates the geological reasoning and demonstrates that **scientific merit often lies in riskier, more informative models**.

Takeaways for Managers

For effective exploration decision-making in an oil company, it is essential to clearly distinguish between the **probability assigned to a geological hypothesis or to specific petroleum parameters**, and the **scientific value** of that hypothesis.

While *probability*—both in its **mathematical sense** (as defined by probability theory) and its more **heuristic sense** (used as a practical estimate or rule of thumb) - is a useful tool for managing uncertainty, it should not be confused with **verisimilitude**. Verisimilitude refers to how close a hypothesis comes to the truth, which depends on its **boldness**, **testability**, and **empirical content**—not simply on how likely it appears to be.

A **high probability** may reflect caution, familiarity, or consensus - but not necessarily **scientific depth, originality, or predictive power**. In contrast, some of the most valuable hypotheses in petroleum geology are those that are **less probable**, yet far **richer in content** and more **vulnerable to falsification**. These are the hypotheses that truly drive understanding forward.

Recognizing this distinction helps managers and policymakers:

- ➡ Better evaluate competing geological models,
- ➡ Prioritize targeted data acquisition and technical studies,
- ➡ And allocate exploration resources to ideas that offer genuine scientific advancement- even if they involve higher uncertainty.

In summary, **clarity about what "probability" means—and what it does not—helps avoid costly misinterpretations**, and promotes decisions grounded in the scientific method rather than in mere consensus or apparent likelihood.

1) Background

In the context of petroleum exploration, there is a frequent and consequential confusion between the **probability** of a geological hypothesis and its **scientific quality** - or what philosophers of science refer to as its **verisimilitude** (truthlikeness). This confusion often leads to misinterpretation in technical discussions and strategic decision-making.

In practice, the term ***probability*** is commonly used not in the strict mathematical sense defined by probability theory, but rather as a shorthand for expressing **confidence**, **credibility**, or the perceived **soundness** of a geological model. However, it is important to emphasize that **a high probability does not necessarily indicate that a hypothesis is scientifically stronger or more informative**.

As Karl Popper has shown, the **value of a scientific hypothesis lies not in how likely it appears, but in how much it tells us — and how exposed it is to being proven wrong**. A hypothesis that makes bold, risky predictions carries **greater empirical content**, and therefore greater scientific value, than one that is so cautious or vague that it cannot be meaningfully tested.

The aim of this memorandum is to remind policymakers involved in exploration decisions in the WesternZagros Resources that **a high assigned probability should not be mistaken for scientific reliability**. On the contrary, some of the most valuable hypotheses in petroleum geology are those that - while less probable in the formal sense — offer the clearest, most testable insights about the subsurface. Recognizing this distinction is essential for sound risk assessment and resource allocation.

2) Probability

In its strict mathematical sense, **probability** is a formal measure - **a number between 0 and 1** - that expresses how likely an event is to occur within a clearly defined **sample space**. It follows a set of rules known as the **Kolmogorov axioms,** which ensure consistency and logical coherence in risk evaluation..

A **probability space** is the mathematical framework used to describe uncertainty in a rigorous way. It consists of three components:

- **Ω** (*omega*): the **sample space**, which is the complete set of all possible outcomes of a given experiment or process. For example, in the case of rolling a die, the sample space is $\Omega=\{1,2,3,4,5,6\}$.
- **F**: a **σ-algebra** (sigma-algebra) of subsets of Ω. These subsets represent the **events** we are interested in - that is, the outcomes or combinations of outcomes to which we can assign probabilities. A σ-algebra is a collection of subsets that includes:
  - the sample space itself (Ω),
  - the complement of any event,
  - and any countable union of events.

  This structure ensures that probability calculations remain logically consistent, even when dealing with complex or infinite event combinations.
- **P**: a **probability measure**, which is a function that assigns a number between 0 and 1 to each event in **F**, representing the likelihood of that event occurring.

Formally, the probability function is written as: $P:F\to[0,1]$ and it must satisfy the **three Kolmogorov axioms**:

Axioma 1: Non-negativity - $P(A) \geq 0$ for all events $A \in F$ (meaning A is an element of F).

The probability assigned to any event must be a **number greater than or equal to zero**. In other words, you can't have a negative probability. For instance, you roll a six-sided die and you let A, i.e., the die shows a 3, then

$$P(A) = ⅙ = 0{,}166... \text{and clearly: } P(A) \geq 0$$

If someone said: "The probability of getting a 3 is –0,2 . That would violate the non-negativity axiom and would be nonsense mathematically.

Axioma 2: Normalization: P(Ω) = 1 (meaning the probability that something happens is 1)

When you perform an experiment (like tossing a die or drilling a well), some outcome in the defined space must occur. So the total probability - **when you consider all possible outcomes together** - must be 1, or 100 %.

Example: Let's say a geologist classifies the possible outcomes of drilling a well:

A: Gas found B: Oil found. C: Water found D: Dry hole

Then: Ω = {A,B,C,D}

If these are all the only possible outcomes, the sum of their probabilities must equal 1: **P(A) + P(B) + P(C) + P(D) = 1**

Even if some probabilities are very small (e.g., dry hole = 0,9), the total always adds up to 1.

Axioma 3: Additivity: If A∩B=∅ (meaning A and B have no elements in common), then P(A∪B) (meaning probability of any outcome in that union) **= P(A) + P(B)**

If event A and event B cannot happen together (i.e. they have no outcomes in common), then the probability that either A or B happens is simply the sum of their individual probabilities.

Example: Tossing a die let's define **two events:**

A: **The die shows an even number** → A = {2,4,6}

B: **The die shows a 3** → B = {3}

These are disjoint: **they have no outcomes in common**, i.e. **A∩B =** ∅

So: P(A∪B) = **P(A) + P(B)**.

If the die is fair: **P(A) = 3/6 = 0,5** and

P(B) = ⅙ ≈ 0,167

Then: **P(A∪B) = 0,5 + 0,167 = 0,667**, that is to say, the probability that **either an even number comes up or the number 3 comes up** is about **0,667**, or

66,7 %. The events are disjoint, i.e., **mutually exclusive** because tgey **cannot happen at the same time** — they have **no elements in common**

In addition to its formal mathematical definition, **probability can be interpreted in different ways depending on context** — particularly in scientific practice and decision-making under uncertainty. The main interpretations include:

- **Classical (Frequentist or Statistical):**
  Probability is understood as the **limit of the relative frequency** of an event occurring over a large number of repeated trials.
  For example, P = 1/6 means that in the long run, the event is expected to occur once in every six trials.

- **Bayesian:**
  Probability represents a **degree of belief** or confidence in a proposition, given existing knowledge and evidence. This belief is updated systematically using **Bayes' Theorem** as new information becomes available.

- **Logical:**
  Probability is viewed as a **logical relationship between propositions**, based on the infor-mation available and principles of logical symmetry. This approach aims to formalize rational degrees of belief in an objective way.

- **Propensity:**
  Probability is interpreted as a **physical tendency or causal disposition** of a system to produce a certain outcome. For instance, a perfectly symmetrical die is said to have a 1/6 propensity of landing on any one of its faces.

3) Verisimilitude

The verisimilitude or truthlikeness, that is to say, the degree to which a **scientific theory or hypothesis approximates the truth**, is a central concept in the K. Popper philosophy of science. It explains how **science progresses**, even though all the hypotheses remain, in principle, **conjectural and falsifiable.**

However, in science — and particularly in petroleum geology — the word *probability*, when used in the sense of **probability calculation**, has **nothing to do with the scientific quality of a hypothesis**. According to Karl Popper, the quality of a hypothesis lies in its **improbability**, which reflects the **boldness and testability** of its claims. This improbability serves as a measure of the hypothesis's **empirical content**, and is therefore a key factor in assessing its scientific value. Let's see how K. Popper explains all that :

Karl Popper makes an important distinction between **"probability" in the mathematical sense** and the **scientific value of a hypothesis**.

When Popper refers to a "probable" conjecture, he insists that the term *probable* **should not be interpreted in the mathematical sense** - that is, as defined within the framework of probability theory. For Popper, using **mathematical probability** to judge the **quality** of a scientific hypothesis is misleading.

In his view, **the probability of a hypothesis, in the sense of probability theory, has nothing to do with its scientific merit**. A hypothesis may have a very high mathematical probability and yet be trivial or uninformative. For example:

> ***"The source rocks are rich in oragnic matter"*** is a highly probable geological statement - but from a scientific standpoint, it is **uninformative**, because it tells us nothing new or unexpected.

Popper's key insight is that **only the improbability of a hypothesis - in a logical sense - can serve as a measure of its content**. The more a hypothesis rules out possible outcomes, the more **risky**, **bold**, and **informative** it becomes. In other words, **scientific progress depends on bold conjectures that can be rigorously tested and potentially refuted**.

Example:

➡ **Hypothesis 1**: *"The reservoirs rocks are either a carbonates or sandstone"*
→ Hypothesis extremely probable, but trivial; it adds no new knowledge.

➡ **Hypothesis 2**: *"the reservoir rocks are the porous carbonates of the undaforms"*
→ Hypothesis less probable, but far more specific, informative, and testable - hence of greater scientific value.

Summing up:

A) The **scientific quality of a hypothesis does not come from its probability** (in the mathematical sense).

B) On the contrary, a scientifically valuable hypothesis is often **improbable**, because it makes strong, specific claims that **can be tested and potentially refuted**.

C) It is this **testability and falsifiability** that gives a hypothesis its strength in scientific reasoning.