An introduction to paleogeography: What the particle sees

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Paleogeographic maps come in a variety of forms. But it is as reconstructions of past landscapes that they are the most useful. Why? Because it is on these landscapes that the geological record is built. A particle sees topography, rivers, and oceans. It experiences rain and floods and the heat from the sun. It does not see mantle convection nor crustal hyper-extension nor differentiate between a compressional or extensional tectonic setting, at least not directly. How sediment is formed in the hinterland through weathering and erosion, transported and ultimately deposited is a function of what happens at the surface and therefore what that landscape is.

A Google search for the term "paleogeography" reveals a wide range of maps and images. From simple black and white sketches showing past shorelines to maps of depositional systems or the distribution of tectonic plates, to full-color renditions of paleo-elevation and -bathymetry. Many, if not most, are informative, some are aesthetically quite beautiful.

For most geologists, such maps need little introduction. They have a long history of usage in the literature, and today have become something approaching *de rigueur* for conference presentations and corporate montages.

But paleogeography is more than just images in presentations. It is or can be, a powerful tool for managing, analyzing and visualizing geological information, for investigating the juxtaposition and interaction of Earth processes, as well as acting as the boundary conditions for more advanced Earth system modeling with which to better understand how our planet works.

Over the next few months, I will present a series of blogs that will explore paleogeography.

It will be a journey that will take us through the history of paleogeography, a look at how maps are generated, a guide to some of the pitfalls and caveats of mapping, a review of some of the mapping tools available, as well as examples of how paleogeographic maps have been used to solve real-world problems, especially in resource exploration where I have the most experience.

It is a journey that I hope you enjoy and find useful.

In this first blog, I want to set the scene by addressing two simple questions:

What is paleogeography?

and

Why should you care?

The Nature of the Problem: There is simply so much to take in.

If we look at any landscape and the processes responsible for forming it and which are acting on it, such as in the central Pyrenees shown above, we are faced with something of a dilemma: There is simply so much to take in.

For example, if we are teaching field geology in such an area do we focus on the structural evolution, or the stratigraphy, or the depositional systems or the climate, or vegetation or any one of the many components that together comprise the Geological record and the Earth system in this view?

Or do we try and cover all the bases?

Ideally, we want to try and cover everything. But we have limited time. We also do not want to overwhelm all concerned with diverse technical vocabulary and concepts. The risk of losing our audience.

Consequently, we usually focus on a specific field of study.

The same is true in exploration. Whether we are assisting management to make strategic decisions about where to explore or are a member of an asset team identifying and evaluating blocks and then prospects. We need to understand all the components of the Earth system if we are to make informed decisions.

30 years ago, companies would have had an army of in-house specialists on whom they could call for help to do this, and even

more academic experts on retainers. But, those days have long since gone.

Unfortunately, one thing that has not gone is the budget constraints of the commercial world.

Exploration is, by its very nature, a net cost to an energy exploration business.

So, in addition to the scientific challenges, in exploration, we are also faced with trying to extract the maximum value from limited budgets.

So, what do we do?

Finding solutions: Paleogeography as a key tool in the geologist's toolbox

We need a tool with which we can bring together (gather), manage, visualize and interrogate diverse geological information, information which is often sparse (especially in frontier exploration areas), sometimes questionable, and often equivocal.

If we look to history for guidance, we find 19th-century geologists faced with the same problem. A growing volume of diverse geological information and how to deal with it.

Over the preceding 100 years, scientists had tried to encapsulate the contemporary knowledge of the Earth system into a single book or series of books. Humboldt's Cosmos or Lyell's Principles are examples. But this had become next to impossible by the middle of the 19th century due to the sheer volume of information, resulting in an exacerbation of the scientific specialism that we have today. Humboldt's opus itself was unfinished at his death and completed based on his notes.

One solution to this problem was to use maps to distil visually this wealth of information. Ami Boué's maps of the World, more

A particle eroded from the hinterland and transported to its depositional location responds on its journey to processes at the Earth surface.

commonly known through Alexander Keith Johnstons "Physical Atlas of Natural Phenomena" (Johnston, 1856) in the middle of the century., or Élisée Reclus' excellent "The Earth" (Reclus, 1876)

With geology, the problem was exacerbated by the time dimension. This was not simply a matter of mapping the current physical state of the Earth and its processes but how this had evolved over time. The past geography of the Earth. This is Paleogeography.

Paleogeography defined

It is no coincidence that Thomas Sterry Hunt, the author attributed with first coining the term "paleogeography", was also one of the first petroleum geologists, looking for ways to manage and analyze geological data for exploration. (We will revisit this in a later blog).

Paleogeographic maps can summarise a wealth of geological information in a simple, visual way by distilling the record into representations of depositional environments and structures. This then allows additional information to be added and juxtapositions and relationships investigated.

Such maps can also show lithological distribution and character, although strictly speaking facies maps are distinct from paleogeography's in that they represent the product of processes, i.e. the rock record (as do GDEs for that matter), whilst a paleogeography represents the environment and landscape in which and on which those processes act and upon which the geological record is built.

In practice, this definition of paleogeography has become blurred. Facies maps, GDEs (Gross Depositional Environments), and plate reconstructions are all frequently referred to as "paleogeography".

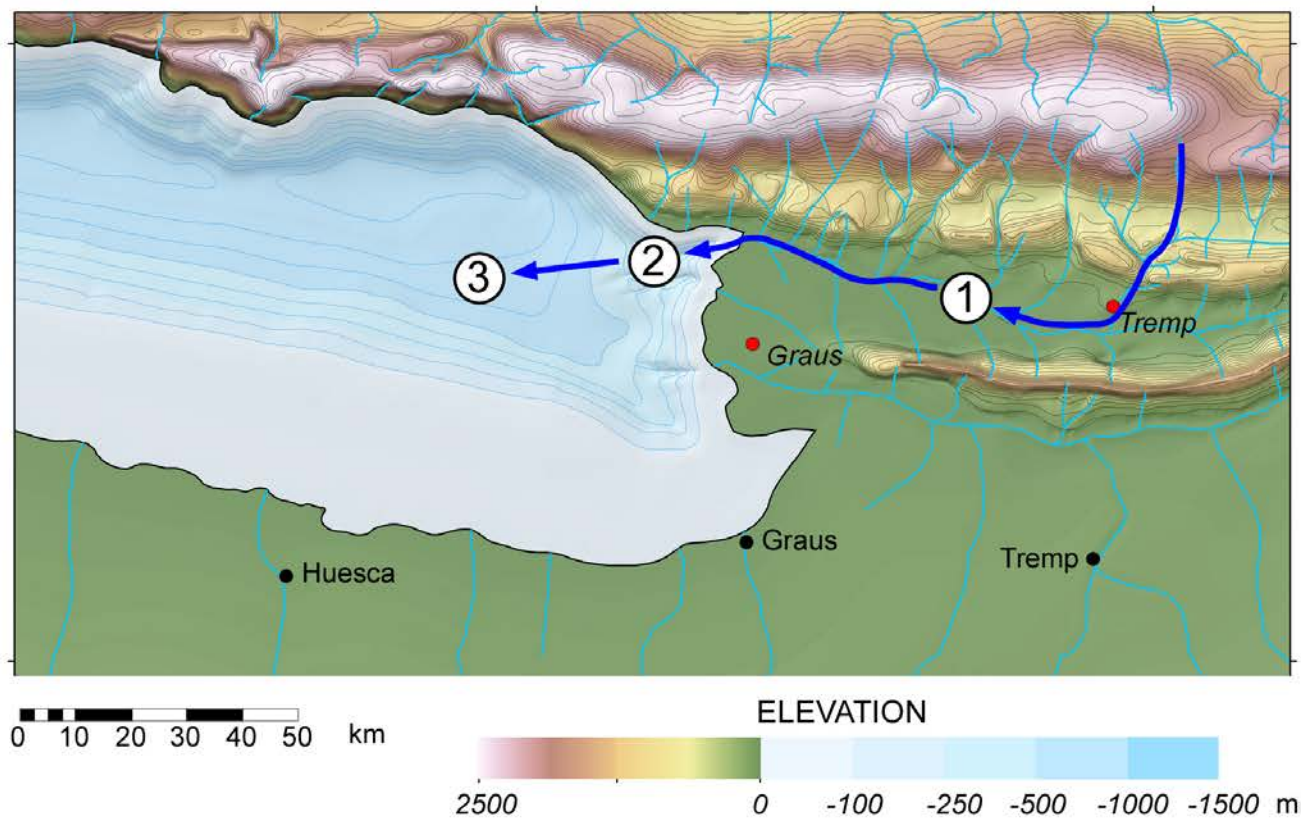
The original definition of paleogeography proposed by Hunt was as a field within geology to describe the "geographical history" of the geological record, which to him included the depositional environments, such as deserts and seas (Hunt, 1873).

This view of paleogeography as being the representation of the depositional environments that comprise a landscape is useful for two important reasons.

First, because it allows us to distinguish between the landscape, the processes acting on the landscape, the processes that created the landscape, and the rock record that is the product of all of the above. This makes the Earth system more manageable. It also means that when building a map we can audit each step (something we will look at another time).

But second, it allows us to deconstruct what the rock record directly responds to. What is important to consider. Where we need to focus our time (and monies). If we think of a sedimentary particle formed in the hinterland through weathering and erosion, transported and ultimately deposited, what does it really 'see' (i.e. respond to – at the risk of personifying clastic particles too much). A particle sees topography, rivers, and oceans. It experiences rain and floods and the heat from the sun. It does not see mantle convection nor crustal hyper-extension nor differentiate between a compressional or extensional tectonic setting, at least not directly.

It responds to the contemporary landscape and the processes acting on it.



The late Ypresian paleogeography for the central Pyrenees showing one transport pathway that takes in the three outcrops shown. From Markwick (2019)

Cenomanian – Turonian section, Steinaker Reservoir. What would a Cretaceous paleogeography meaningfully represent? The transgressive shales or prograding sands or any range of other units or unconformities through the Cretaceous?

Paleogeography defined: the problem of time

We now need to add another component to our definition of what paleogeography is. And that is time.

This is something that was identified by Charles Schuchert, a professor at Yale and colleague of Joseph Barrell, one of the founders of modern stratigraphy.

The Earth is dynamic and landscapes and depositional environments and their products the rock record can change over relatively limited geographic distances and short temporal intervals. For Schuchert, a global Cretaceous map was meaningless, for the very simple reason of what exactly did it represent? A landscape at the beginning of the Cretaceous, the end, the maximum extent of marine conditions, or as more likely, a pastiche of lots of different parts of that Cretaceous record? Schuchert's recommendation was to use the finest stratigraphic intervals possible, which for him were represented by stratigraphic formations.

Kay went further to suggest that ideally paleogeography should represent a "moment in time". Rather like looking at a satellite image. In this definition, paleogeography was a snapshot of the depositional environment and the landscapes at a specific moment. That makes perfect sense, but there is a problem. In the absence of a global correlation tool that can pick out a moment in time, this is next to impossible to achieve, especially over large distances. But it is an aspiration. It is also a reminder to ask of a map, what does it represent? Again, this is something we will return to in a later blog.

In summary

Q. What is paleogeography?

Paleogeography is the representation of the past surface of the Earth, at a 'moment' in time.

Q. Why is it important and why should you care?

Because it allows us to bring together diverse information that will help us better understand the Earth system, whether we are teaching in Spain or faced with deciding on where to explore. Paleogeography gives us the spatial context for gathering, managing, visualizing and analyzing a wide array of geological information in a way that is easy to digest.

At the end of the day, paleogeography is far more than just an image in a presentation.

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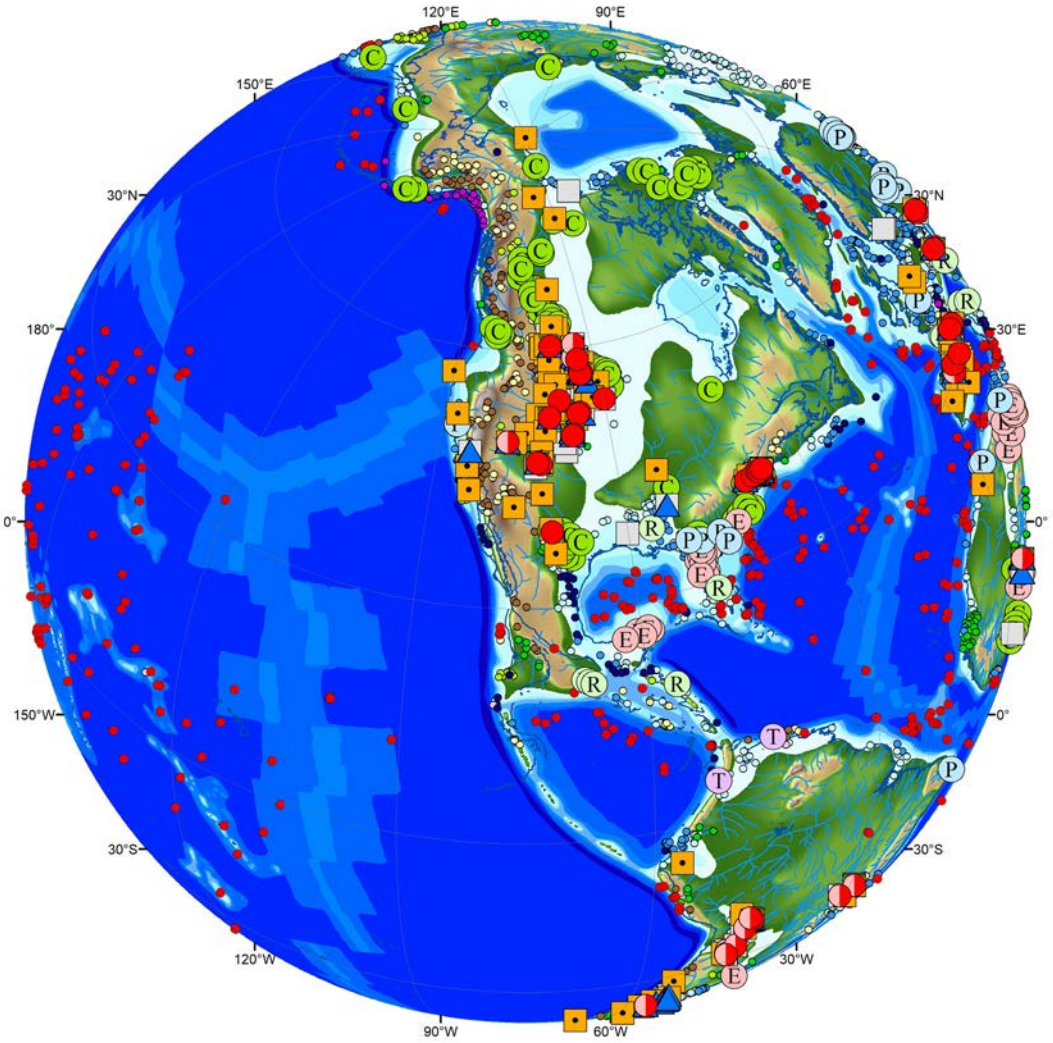
These blogs are based on a lecture course on paleogeography. Readers are also directed to a new paper on paleogeography published in the Geological Magazine: https://www.cambridge.org/core/journals/geological-magazine/article/palaeogeography-in-exploration/444CC2544340A699A01539A2D4C6E92A



Maastrichtian paleogeography showing the distribution of DSDP and ODP sites (small red circles) and vertebrates (Markwick and Valdes, 2004; Markwick, 2007)

About the author

Paul is CEO of Knowing Earth Limited, as well as a Visiting Lecturer at the University of Leeds and Visiting Research Fellow at the University of Bristol. He graduated from St. Edmund Hall, Oxford University in 1987 and received his Ph.D. from The University of Chicago in 1996.

He worked for two years at BP's Research Centre in Sunbury-on-Thames before moving to Chicago, where Paul studied with Professor Fred Zeigler's oil industry-sponsored Paleogeographic Atlas Project. This was followed by a post-doctorate at the University of Reading researching the exploration significance of the paleoclimatic and drainage evolution of southern Africa using computer-based climate models with Professor Paul Valdes. He then moved to Robertson Research International Limited, now part of CGG, as a Staff Petroleum Geologist, where he developed global predictive models of source and reservoir facies. In 2004 Paul moved to Getech Group plc, to set-up the Petroleum Systems Evaluation Group with Dr. John Jacques. From 2006 to 2017 Paul served on the Getech board overseeing the strategic technical direction, which saw the business transition and grow from an academic research group to a multi-million-pound company with four offices, 120 staff and an international client base.

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