

From Stone to Star

A view of Modern Geology

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Jupiter is a giant planet, the largest in the solar system. It is three hundred times larger than the Earth, but its mass is only 3.18 times that of Earth which gives it a density of 1.33 (as we have seen that of the Earth is 5.3)..

This is indeed a garbled fragment of a text, nonsense piled upon nonsense. What is meant by three hundred times larger than the Earth? I guess it refers to volumes, but the right figure in that case is thirteen hundred times that of the Earth, and its mass is in fact a hundred times the figure cited, which indeed gives the quoted density (which has no connection with the data presented, which would instead suggest 0.05!). Is the author confused, is it the result of a number of typos maybe perpetrated by the translation, and if so what other less obvious nonsense does the book contain? Admittedly the entire segment can be excised from the book without any loss of coherence, nothing depends on it, the only thing the reader needs to know are the correctly cited densities. Allègre is a controversial geochemist mainly because of his political activities, he served as cultural minister during the Socialist prime minister Jospin for three years until 2000 but has lately gravitated towards the conservative Sarkozy camp. He is not shy to stray from his area of expertise and expound on such matters publicly. He advised for evacuation of the neighborhood of the volcano la Soufrière in Guadeloupe during a pending eruption against a noted volcanologist. The authorities decided to err on the side of caution but it turned out that the major damage was caused by the unnecessary evacuation. Allègre later had his adversary fired, but maybe for other reasons. He has lashed out against mathematics and written a tract against Plato, which has been viewed as a broadside against conceptual thought. Furthermore he has recently come out as a climate change denier with connection to the petro industry. His scientific credentials are otherwise impeccable the recipient of many an international award. The story he has to tell about the history of the Earth is a truly fascinating one involving a synthesis of many natural science disciplines. Basically it is a forensic exercise trying to reconstruct the past from the subtle and intermittent traces it leaves in the present. It is science in the sense that the public and politicians can understand. It is based on a simple question, what happened to the Earth, which most curious people can appreciate? And it involves a lot of people all over the world doing structured investigations following exacting criteria of objective scientific observation and testing. In fact the author in the end dedicates the book not to the theoreticians, no matter how fertile their imaginations, but the anonymous workers in laboratories all over the world doing exacting and often tedious work united by, as he puts it, a common spirit. Indeed what strikes the mathematician is the simplicity of the concepts, and hence their explicability to a general public contrasting with the complexity of their implementation. A nuclear chain reaction is simple in principle but exceedingly complicated to bring about

in practice. Or more relevant to the present subject, separation of isotopes through their differential deflection in magnetic fields is a very simple idea, but to actually do it in practice is fraught with a host of technicalities which a reader would as well not become privy to. This separation of an idea from its technicalities is not as distinct in mathematics, where without at least some familiarity with the latter the idea itself does not make sense. It is that state of affairs which presents an almost insurmountable hurdle in the popularization of mathematics where we consequently have no separation between theoreticians and experimenters. One consequence of this must be that at a meeting of geologists most participants can actually understand and appreciate the various talks and assess the state of art, while in mathematics most participants are just confused and the attendance at a talk is more a question of politeness than a desire for genuine instruction.

The prevailing philosophy of geology formed at the end of the 18th century and the beginning of the 19th and is known as uniformitarianism and with Hutton and Lyell as the main proponents¹. Hutton is known for his saying 'no vestige of a beginning, no prospect of an end' thus suggesting a time of endless duration characterized by the cycles of orogeny (the lift resulting in mountains) and erosion (the obliteration of the same). Lyell emphasized that the mechanisms that drove geological changes, such as volcanoes and erosion by flowing water, were the same then as now, and thus that geology should be a question of extrapolation of known processes and not the invocation of miracles and catastrophes. This encouraged a more 'scientific' attitude, meaning shying away from religious concerns, such as the history of the universe as presented in Genesis and concentrating on technical matters such as systematic mappings of geological features and correlations of different strata across locations. The stratigraphic reading of the record goes back to the Dane Steno and Descartes, and the shortcut through fossils was regularly employed by the early 19th century². Thus in particular the historical event of evolution has never been controversial in the scientific community only the mechanism that drives it. The French naturalist Cuvier studied it in depth and believed that species were exterminated by catastrophes and new ones were created, his compatriot and contemporary Lamarck had a far more sophisticated theory that foreshadowed that of Darwin, but was rejected as being merely speculative and hence 'unscientific'³. By the end of the 19th century there was a firm understanding of a relative ordering of geological ages back to the precambrian era, i.e. for the period of which there were fossils remains. Before that there was in the words of Hutton no vestiges of a beginning. However, the notion of an endless time did not square with the basic physical principles of limited energy. The huttonian cyclical process could not have been going on for ever, what could have powered it? Thus there was a renewed

¹ By a coincidence Lyell was born the same year (1797) as Hutton died, just as Newton was born the same year as Galileo died, at least if we stick to the old Julian calendar (o.s. versus n.s.)

² One of the pioneers was the British geologist Smith doing indeed systematic geological mappings. Without this shortcut location in time for isolated specimen not embedded in a sequence would be impossible. In fact it provides an illustration in geology of the principle which in mathematics turns theorems into definitions

³ This may to a large extent explain Darwin's reluctance to go public. Ironically it was his mentor Lyell who urged him to do so, although Lyell did not believe in Natural selection but he was putting principles above beliefs and opinions.

interest in absolute dating (and in the words of the author, without an absolute chronology no real disclosure of history is possible) which had already been considered in the 17th century. In particular there was an interest to gauge the time elapsed since Cambrian times during which natural selection had taken place. Kelvin made some estimates based on known physical sources of energy, such as gravitational contraction, of how long the Sun could have been shining at its present brilliance, thus giving an upper bound. The figures he came up with were far too short by geological standards. The geologists were quite familiar with the snail pace of sedimentation and had a different sense of scale. This led to a contradiction between classical physics and geology which was not resolved until the discovery of radioactive decay. This happened at the dawn of the new century and the rest is history. Radioactivity not only gave the clue to energy production but also furnished the geologists with clocks which would revolutionize the discipline. And indeed science progresses by asking questions, and not any questions but questions for which there exists tools to answer, and the predominant tool is radioactive dating which runs as a unifying theme throughout the whole book. As the author points out the fact that it is technically possible to measure frequency distribution to four significant digits is exactly what was needed not only to be provoked to put relevant questions but also to answer them. Thus it is important that a clear and logical presentation of the principles behind as well as a revelation of the tacit assumptions are given. Admittedly the book is not a textbook but a popular account, a 'vulgarization' as the French put it, yet this does not excuse fuzziness. To ignore technical details which may only overwhelm and confuse the casual reader is one thing, but accounts with logical holes is quite another and only frustrate the concerned reader. Natural science is as already noted a forensic undertaking and its presentation could well benefit from being in the form of a detective story.

To take some concrete examples. The isotope ^{238}U is radioactive it decays eventually to ^{206}Pb a stable non-radioactive element. The half-life is known fairly accurately and on the order of four and a half billion years. If we have a rock which has a fairly high concentration of ^{238}U we can determine its age by finding out the ratio between it and its end product ^{206}Pb . This depends on the tacit assumption that when the rock was formed, meaning when the present atoms came to make up the configuration the presence of ^{206}Pb was negligible. Why can we make such an assumption? As far as I can tell, but there is no discussion of this only general hints elsewhere in the book, the accumulation of uranium in the rock is due to some chemical process, as the chemical properties of uranium and lead are rather different, there is no reason to assume that lead should have partaken in the process, thus being a rare element any accidental contamination with it must be rather unusual. With those assumptions in place the rest is straightforward. The ratio R of lead to uranium will be given by $\frac{e^{-\lambda t}}{1-e^{-\lambda t}}$ when R, λ are known we easily solve for t . Now there are other clocks, another isotope ^{235}U decays to ^{207}Pb which gives a check, and of course an irresistible one, if the two estimates do not agree there is trouble and we need to go back and seriously rethink matters and question both the underlying principles as well as accidental technical snags. If on the other hand there are regular confirmations the double check will eventually be seen as redundant and instead a possible shortcut presents itself. It is suggested that the ratio of the two lead isotopes should suffice. However, this is not borne out mathematically, you certainly need additional information as to the initial ratio

between the two uranium isotopes, which is impossible to get, as all uranium on Earth has not been produced at the same time (experts on nuclear reactions in the interior of stars may otherwise come up with a figure). Or is that another tacit assumption?

Another example is the classical one by Urey. It concerns the ratio of the isotopes ^{18}O and ^{16}O studied in the shells of marine creatures. It claims first that this ratio is much lower for polar caps than for sea water. But why is that? The ice from the polar caps come from seawater, or is the latter not thoroughly mixed? A big thing is made by that ratios of isotopes are unaffected by chemical reactions and hence survive a lot of activity, but not all activity is chemical, there is also a fair amount of mechanical. Is evaporation mechanical? Are heavier water molecules (meaning containing heavier oxygen nuclei) less likely than normal ones to evaporate and hence being underrepresented in the caps? Furthermore he claims that as a consequence a big polar cap lowers that ratio $^{18}\text{O}/^{16}\text{O}$ in the seas and a small cap raises it. Why? I would think the opposite. Is there anything I have missed? The conclusion is very puzzling and he leaves the reader in the lurch. Is this another typo or a bad translation?

Such key explanations are just the kind of thing readers may take home with them. There are a lot of other explanations in the book, or rather more in the nature of narratives lying out a sequence of steps with no compelling logic to really bind them together. Those do not stay with you but quickly fade from memory. Still the book has the advantage over most other popular books, it does not sweeten the pills with a lot of anecdotes but sticks to the science which is allowed to speak for itself and thus goes some way to bridge the gap between the 'vulgar' account and the one intended for the intelligent layman which means not shying away from technicalities when those are crucial but ignoring them when routine, and basically putting the reader on the same level as the author thus being more of a conversation than a lecture.

Now what story does the author tell? In its main outlines there is consensus and the story has been known for some fifty years with the revolution brought about by continental drift caused by tectonic activity being accepted in the 60's capping it off. However, when it comes to details they undergo modification over time, boring it would be otherwise, so the account given based on the state of art at the end of the 80's is clearly out of date, but this is of minor concern, the true subject of the book not being the history of the Earth *per se*, but the evolution of modern geology, which means the emergence of new techniques.

That the Earth consists of many layers has been known for over a century. The relative modest flattening of the Earth and its rather high density significantly higher than that of its surface rocks indicate the existence of a dense core the composition of which has been assumed to be iron. Refined means of investigations have been supplied by seismology developed rapidly at the turn of (the last) century. From this we conclude that the core is surrounded by a mantle and finally this is enclosed in a thin skin known as the crust, the only one we have direct contact with save for the exception of the occasional ejecta of volcanoes giving us samples of the mantle. The crust is at the thinnest below the oceans, providing the seafloor, which geologically is rather young being continually recycled every 200 million years or so, while the crust constituting the continents is more protected containing rocks, such as in western Greenland and in Australia, whose age is close to that of the Earth itself. Then one may also include the atmosphere in the layering

of the planet, although it does not consist of rocks. Initially there were two theories as to the formation of the Earth, one referring to a heterogenous accretion in which the core was formed first then different material started to accumulate, the other to a homogeneous one in which the differentiation came later, in particular the iron core (more precisely an alloy with some amount of nickel) formed by the heavy iron converging to the center and the loss of potential energy resulting in a heating of the planet. Incidentally the inner core is no longer assumed to be liquid, the pressure is too high for the temperature, but the inner core is surrounded by a liquid one. As to the formation of the Earth the nebular hypothesis of Kant and Laplace is still in effect although modified in its details. Through an incredible luck we are able to get our hands on pieces of that primordial nebula in the form of stones falling from the sky. The fact that those stones actually come from the sky was initially greeted by skepticism and incredulity by those considering themselves hard-headed and what we now would call scientific. When we get our hands on them we naturally subject them to chemical and isotopic analysis and radio-active dating, what else could we do? Incidentally some of those meteorites have come from other planets more specifically Mars a fact established by isotopic fingerprinting. Those investigations point to a rather precise chronology. The Sun formed some 50 million years before the Earth, the formation of the Earth may have taken some 20 million years, a rather brief moment in the geological time scale. The creation of the Moon is still a mystery and the idea that it is made out of the Earth has not been rejected. There is the above mentioned layered differentiation of the Earth, the formation of the crust the filling of the oceans the appearance of the continents. The early history of the Earth is far more violent than the succeeding which is more or less the same adhering to the paradigm of Hutton, a testimony to a geologically active Earth (as opposed to the Moon) driven by eternal heat not yet dissipated. The one remarkable thing to note is the contamination of a nitrogen atmosphere with oxygen during the last tenth of the Earth's history, a consequence of the appearance of life, or more specifically the development of photosynthesis.

And how do we know? It is only through the phenomenon of isotopes and well regulated radioactive decay? Reality as opposed to fiction is accessible through parallel channels each complementing and corroborating each other. In this case there seems to be only one channel. Had it not existed would that have doomed us to permanent ignorance? The history of Earth is an objective phenomenon and not one contingent upon a particular avenue of inquiry, although that might be the post-modernistic opinion. How many things will for ever be barred to us because the necessary tools of investigation simply are not there? Or should we refer to Hilbert's famous dictum as to mathematics, to the effect that anything worth knowing will eventually be known. Otherwise will what leaves no trace as well never have existed as the pragmatists assure us?

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