Still *Set in Stone*: A Response to Stephen Moreton
Paul Garner

This is a response to Dr Stephen Moreton's critical review of the *Set in Stone* DVD posted on the Amazon website. Although it is not our intention to get embroiled in lengthy discussions with internet critics, especially those so ready to impute dishonourable motives to us, some response to Dr Moreton's comments is in order.

Introductory comments
Stephen Moreton is an inorganic chemist with a PhD from Edinburgh University and an accomplished mineral collector. He is also something of a crusader for atheism, as a simple Google search will reveal. He has had articles published by humanist organisations such as the Australian Skeptics and is associated with the self-styled British Centre for Science Education. Moreton makes many claims about our supposed "hidden agenda", but seems rather more reticent when it comes to declaring his own. This is significant because too often his criticisms of our programme seem driven by his philosophical commitment to outdated paradigms than by engagement with the evidence that we presented. This is not unusual within the discipline of geology. The mindset of researchers does affect what they see in the field and how the observations are interpreted. Geology needs to be taught in a way that recognises the importance of philosophical commitments. There is a tendency today to accept that Derek Ager was right about some punctuated geological events, but there is still resistance to his explanation of why geologists have misread the rock record:

> "... I have been trying to show how I think geology got into the hands of the theoreticians who were conditioned by the social and political history of their day more than by observations in the field. ... In other words, we have allowed ourselves to be brainwashed into avoiding any interpretation of the past that involves extreme and what might be termed 'catastrophic' processes." (Ager 1981, p.46)

The place to address brainwashing is in education, but it cannot be done properly without the critical evaluation of alternative hypotheses proposed to explain evidence.

Significantly, Moreton concedes that *Set in Stone* (in his words) "contains only a few items that might be taken as straightforward fibs". This grudging admission suggests that he has struggled to find something to criticise in our documentary, and may explain the oddly conspiratorial nature of his review in which he criticises us mostly for *not* saying things that he evidently rather wishes we had. Nevertheless, Moreton suggests that we deliberately left out of our presentation facts that would undermine the arguments we were making. We reject this accusation. Of course, it is impossible to be anything other than selective when making an hour-long documentary about a topic as wide-ranging as earth history, but we do not believe that our programme is unfair or unrepresentative. Where catastrophist scenarios have been challenged (such as in the debate concerning Derek Ager's reinterpretation of the Sutton Stone) we specifically pointed this out. What is more, a significant proportion of the programme anticipated some of the most serious challenges to catastrophism (such as the deposition of mudstones and chalks) and addressed them. Of course more could be said on all the topics we covered, but we deny that we have "lied by omission". In fact, it is somewhat ironic that Moreton accuses us of this when, as we shall see, he is himself guilty of ignoring inconvenient data on more than one occasion.

First, let us deal with the more substantive scientific criticisms that Moreton makes.

Granites

Moreton concedes that the segregation, ascent and emplacement of granite magmas are processes now known to take place rapidly. Twenty years ago he may well have been telling us that this was quite impossible. Nevertheless, he says that the production of granite magmas by the partial melting of source rocks must have been slow, with timescales on the order of millions of years. He even makes the absurd claim that Snelling "invented" the idea of accelerated radioactive decay in order to account for the required thermal regime. This is simply not true. The hypothesis of accelerated nuclear decay was not invented to account for the production of granite melts; it was proposed to account for a range of radioisotopic data including the systematically discordant dates derived from different radiometric methods, the high retention of radiogenic helium in crustal rocks despite rapid rates of helium leakage and the timescale implications of short-lived parentless polonium radiohalos in a variety of geological settings. How does Moreton account for these data? He does not tell us. Besides, accelerated nuclear decay is only one possible mechanism that might account for the rapid production of granite melts. Large quantities of granitic magma can also be generated by the transfer of heat between basaltic magmas and the sialic crust into which they are intruded (Bergantz 1989). Models suggest that this mechanism can generate a melt layer two-thirds the thickness of the basaltic intrusion in only 200 years, at a temperature of up to 950^{o}C (Huppert and Sparks 1988). Petford et al. (2000, p.669) conclude that "dynamic models that operate on timescales of months to centuries are replacing the once-prevailing view of granitic magma production as a slow, equilibrium process that requires millions of years for completion."

Moreton continues to assert that the rapid cooling of large igneous intrusions is impossible, although he acknowledges that many variables affect cooling rates, often dramatically. He relies heavily on radiometric dating and on current measurements of heat conduction, which are irrelevant to heat transferred by convection in hydrothermal fluids under catastrophic conditions. He correctly notes the crucial importance of rock permeability in providing pathways for convecting fluids, but wrongly considers this to be a problem in the case of deep-seated granitic intrusions. He is evidently unaware of the detailed discussion of the permeability of granites and the effects on cooling times in Snelling and Woodmorappe (1998). Joints and microfractures occur almost ubiquitously throughout granitic terrains (Secor 1965; Bauer and Handin 1983). In fact, it is rather difficult to find granites with low permeability as those working in the nuclear waste storage industry have discovered (Green and Mair 1983). Even presently impermeable granites were once very permeable and under cathodoluminescence display evidence of former networks of micro-sized apertures (Sprunt and Nur 1979).

Moreton claims that the ore bodies associated with large igneous intrusions can only be explained by long-lived hydrothermal cells. However, ore formation is known to occur extremely rapidly given appropriate conditions. For example, the Ladolam deposit of Lihir, Papua New Guinea, one of the most massive gold accumulations known, could have formed in only 55,000 years at present-day deposition rates (Simmons and Brown 2006). But much higher gold concentrations found in the associated fluid inclusions suggest that the deposit might have accumulated in as little as 50-60 years, and mining geologist Greg Hall is reported as saying, "My gut feeling looking at Lihir is that it formed in the same time it took Mount St Helens to blow up – a month, a day, maybe as short as 5 hours" (McKenna 2007). Likewise the formation of the massive graphite deposit associated with Ordovician magmatism in the English Lake District has been described as "catastrophic, that is, it occurred in a geologically very short period of time" (Ortega et al. 2010). Indeed, one of the

researchers studying this ore deposit has speculated that its formation might have been rapid even when measured on the human scale, taking perhaps only seconds (Wilkinson 2012).

Moreton also refers to the work of Lorence Collins on the origin of granites, but fails to point out that Collins' views on granite formation are somewhat idiosyncratic and not held by the majority of professional geologists.

Flood basalts

Moreton grudgingly concedes that flood basalt provinces testify to the rapid production of immense volumes of lava that engulfed huge areas. But once again he accuses us of ignoring things that he thinks we ought to have addressed, in this case features he believes demonstrate "long periods of quiescence between each flow."

Specifically, Moreton draws attention to the Interbasaltic Bed at the Giant's Causeway, conventionally interpreted as a laterite, the product of prolonged chemical weathering between the Lower and Upper Basalts. Moreton cites a maximum present day rate of laterite formation of 58 m/Ma, and asserts that the Interbasaltic Bed (which reaches a maximum of 30 m thick) must have taken around three million years to form. However, even if the Interbasaltic Bed is a laterite (and not the product of hydrothermal reactions between hot lava and water) it is unwise to assume that present day formation rates are necessarily similar to those that operated in the past. Extensive flood basalt provinces have no modern day counterpart and it seems reasonable to think that chemical weathering rates in such environments may also have been unparalleled. It is certainly possible to conceive of much higher rates of weathering with greater volumes of groundwater flow and surface runoff, higher water temperatures and differences in water pH. For instance, Kirkwood and Nesbitt (1991) have shown that naturally acidified waters can double or even triple weathering rates.

As it happens, fossil soils, *in situ* organic accumulations and weathered horizons seem to be uncommon in ancient flood basalt provinces. Tyler (2003a) describes the Ardtun Leaf Beds sandwiched near the base of a basalt lava sequence on the Isle of Mull in the Inner Hebrides (like the Giant's Causeway part of the Tertiary North Atlantic Province). However, there is essentially no evidence of plant regrowth during the succeeding volcanic episode, suggesting the absence of significant hiatuses. Interbeds between lava flows in the Columbia River Basalt Group of Washington and Oregon are uncommon and thin when they do occur (Woodmorappe and Oard 2002). Sedimentary layers between basalt flows are also absent in many of the thickest sections of the western Deccan Traps of India (Karmarkar 1978). Where horizons of organic material exist it is usually in the form of detritus and litter that is unlikely to be *in situ*.

Of course, the main point made in our documentary is the obvious discontinuity between the flood basalts of the past and modern basaltic volcanism. Even if Moreton is right and occasional lengthy hiatuses could be documented between major accumulations, this in no way detracts from this crucial observation.

Mam Tor

Moreton agrees with us that the Mam Tor sandstones were deposited rapidly by turbidity currents. However, he objects to our suggestion that the intervening mudstones might also have been deposited rapidly, despite evidence showing that mudstones can also be produced by turbidity currents (Piper 1972). Of course, if the radiometric dates for the Carboniferous are correct, then each of the Mam Tor mudstones must represent a quiescent period on the

order of 10,000 years duration. Moreton draws attention to occasional casts of trails and burrows on the soles of the sandstone beds (which no one disputes), but that is far from demonstrating the kind of extensive bioturbation that ought to have resulted over long timescales. Moreton also highlights the presence of fossil invertebrates (as we did in the programme), although this makes the absence of extensive bioturbation even more mysterious from a conventional perspective. Certainly the evidence seems insufficient to establish that the goniatite-bivalve faunas represent normal sea floor communities that persisted for thousands of years.

Moreton says that further evidence against short timescales is found in the neighbouring rocks. He refers to carbonate reefs, but this begs the question of whether they are actually *in situ* growth structures. Mud mounds similar to those found in the Carboniferous of Derbyshire typically lack an organic framework and may have been rapidly precipitated by microbial activity. Some similar structures have even been interpreted as allochthonous blocks (Boling et al. 2011). Others may not be true reefs at all but simply piles of transported debris. Indeed, Moreton acknowledges that much of the fossil material in the Carboniferous limestones of Derbyshire is broken and fragmented, which is consistent with transport in a high energy environment. Moreton says there are some intact crinoids but they also testify to rapid burial since field observations and laboratory experiments show that crinoids quickly disarticulate after death (Meyer 1971; Liddell 1975).

Radiometric dating

Moreton says that nearly all the references on radiometric dating that we cite in our booklet concern the K-Ar method and that most date from the sixties and seventies when researchers were testing the method and identifying its pitfalls. He implies that the problem of excess argon in young lavas is now fully recognised and accounted for by researchers. However, as recently as 1991 Dalrymple stated (p.91): "The K-Ar method is the only decay scheme that can be used with little or no concern for the initial presence of the daughter isotopes. This is because ^{40}Ar is an inert gas that does not combine chemically with any other element and so escapes easily from rocks when they are heated. Thus, while a rock is molten the ^{40}Ar formed by decay of ^{40}K escapes from the liquid." But this statement is clearly at odds with the work we cited, some of which, ironically enough, was by Dalrymple himself! Of course, other dating systems (Rb-Sr, Sm-Nd, U-Th-Pb, Lu-Hf, Re-Os) have problems of their own and these have been discussed at some length by Snelling (2009, pp.795-864).

Radiocarbon

Moreton claims that the presence of radiocarbon in samples that are supposedly millions of years old can be readily explained by subterranean neutron capture reactions. He says that this has been known for a decade and accuses us of "brazenly" omitting this information in order to deceive our audience. However, Moreton himself has to omit crucial information in order to make his point, since Baumgardner (2005) dealt with the neutron capture hypothesis in technical and quantitative detail and demonstrated that it is woefully inadequate to account for the radiocarbon found in diamonds, coal and other fossil samples. The quantities of uranium and nitrogen are simply insufficient to generate the amounts of radiocarbon that are measured in fossil materials. Either Moreton has not actually read the work that he is criticising or he has chosen to ignore the fact that his objection was answered several years ago.

Chalk

Moreton takes us to task for saying that "chalky sediments" are currently accumulating in the deep ocean. Chalk, he points out, is calcium carbonate which cannot precipitate at depths below about 4.5 km. Nevertheless about half of the deep ocean floor is covered by oozes, consisting mainly of calcium carbonate and containing innumerable microscopic shells. These shells are the remains of microorganisms that lived in the surface waters and whose remains sank through the water column upon death and accumulated on the ocean floor. There is indeed a level in the ocean below which the rate of dissolution of the calcium carbonate exceeds the rate of input from above, which is the 4.5 km "calcium compensation depth" to which Moreton alludes. But above this level calcium carbonate rich oozes certainly do build up, especially on the tops and flanks of submarine mountains. So Moreton's objection basically boils down to a quibble about whether a depth of 4.5 km counts as "the deep ocean".

Furthermore, Moreton's objections to rapid chalk formation in his 2009 paper seem to us to be based on implausible assumptions (e.g. that all the calcium carbonate in the chalk must have been in solution in the oceans simultaneously) and ignore published work concerning coccolith productivity and episodic blooms. Moreton also contends that the presence of volcanic ash bands in the Chalk is a problem for catastrophist scenarios since the falling ash ought to have blended in with the chalk as it accumulated. In fact, I have observed ash layers in the Cretaceous Chalk of north Norfolk that appear to grade wispily into the overlying sediment and I think it is likely that petrographic studies will reveal a greater input of volcaniclastic material scattered throughout the Chalk than is currently recognised.

Siccar Point

Moreton objects to our claim that the unconformity surface at Siccar Point is remarkably planar and that there is little evidence of differential erosion between the hard sandstones and the less resistant mudstones. He says that the rocks underlying the unconformity are highly uneven, just as would be expected if they had been subjected to slow weathering and erosion. We invite readers to take a look at the photographs in David Tyler's (2003b) article, 'Revisiting Hutton's unconformities' on the Biblical Creation Society website. There is an evident contrast between the highly irregular surface produced by modern erosion and the general absence of differential weathering on the unconformity surface. Moreton says that the relief on the unconformity surface can be "as much as 20 cm" but that makes our point for us: the relief produced by modern erosion far exceeds 20 cm! In one place Moreton says there is "vertical variation in height of the underlying rocks" of more than a metre, although it is not clear whether he is referring to differential weathering between the sandstones and mudstones or to the topography of the unconformity surface. Yes, there is relict topography on the unconformity surface and some sandstone beds were more resistant to erosion than adjacent layers, but the overall impression is one of striking contrast with the kind of relief being produced by present day processes. Moreton also draws attention to deposits at the unconformity surface which he interprets as patches of calcrete requiring prolonged exposure in an arid environment. We think detailed chemical, petrographic and field studies of these deposits would be valuable to see whether alternative explanations are possible. Calcium carbonate enriched horizons can probably be formed in the subsurface by circulating groundwater. Similar horizons are common in the Old Red Sandstone of Scotland and Moreton claims that each one requires a protracted break in deposition. However, even assuming that these deposits have been correctly interpreted as calcretes, it is known that multiple calcrete horizons can be formed during a single subaerial exposure event (Rossinsky et al. 1992).

Relying on the unreliable

In a number of places Moreton offers no critique of his own and no citations to the published literature. Instead he links to a non-peer-reviewed polemical website, TalkOrigins (TO). Here are a few brief comments on those topics.

Helium leakage from zircons. Moreton does not mention the fact that Humphreys has repeatedly responded to criticisms of his helium diffusion work such as those on the TO website (e.g. Humphreys 2010a and most recently Humphreys 2010b responding to Loechelt 2010). In addition, Humphreys (2011) has presented a new analysis of argon retention in feldspars that supports the original helium diffusion age for zircons in the same borehole.

Salt in the oceans. TO claims that the "missing" salt can be explained by the alteration of basalt on the ocean floor. However, while it is true that the sodium-bearing mineral albite forms near the mid-ocean ridges where sea water reaches high temperatures, the process of sea-floor spreading eventually moves the albitized ocean floor away from the mid-ocean vents and into cooler sea water. When the albite gets into cooler water, it decomposes into the mineral chlorite and releases the same amount of sodium back into the sea water. The net effect on sodium in the ocean water is zero.

Sediment in the oceans. TO states correctly that sediment thickness in the oceans increases with the age of the ocean floor. However, the claim that "there is about 150 million years' worth of sediment at the continental margins" is simply an assertion and no supporting data is provided.

Erosion rates. TO says that although old mountains are being destroyed by erosion, there are also forces creating new mountains. Of course this does not explain the persistence of very old mountain ranges such as the Caledonides of western Europe and the Appalachians of North America. Furthermore, sedimentary layers of various ages seem to be well-represented in mountainous regions; we would expect the erosion associated with millions of years of continual uplift to have eradicated them. TO also suggests that present day erosion rates are anomalously high, but rates would have to have increased several hundredfold in order to resolve the problem raised in our DVD, and from a conventional perspective that seems improbable.

Fossil graveyards. TO points out that some fossil graveyards may accumulate over a long period of time, such as carcasses around a tar pit or near a river crossing on a seasonal migration route. Of course this is true, but each case must be evaluated according to the evidence. Some fossil graveyards originally assumed to be the product of gradual accumulation have been shown by careful investigation to have formed catastrophically. A good example is the *Edmontosaurus* bone bed in the Upper Cretaceous Lance Formation of Wyoming described by Chadwick et al. (2005). Although this bone bed was originally regarded as the product of episodic accumulation of carcasses in a fluvial environment over a long period of time, the evidence now gathered at the site favours a catastrophic mass mortality event (Chadwick et al. 2006). TO further claims that some fossil graveyards contain too many carcasses (e.g. the Karoo Formation) or too much biomass (e.g. coal) for a young world, but both claims have been shown to be false (Woodmorappe 1986; Woodmorappe 2000; Schönknecht and Scherer 1997).

Rapid coal formation. TO says that while long time periods may not be necessary to form coal itself, they are necessary to account for the geological contexts in which coal is found

(including the underlying root and soil horizons). But there is a great deal of evidence that coal seams were formed from vegetation that was transported and rapidly deposited (Nevins 1976; Scheven 1981). Even the root-bearing horizons in coal-bearing sequences usually interpreted as fossil soils show evidence of having been transported into place (Schultz 1958; Rupke 1969; Scheven 1996).

Ad hominem attacks

Finally, Moreton engages in some gratuitous *ad hominems*, including repeating Alex Ritchie's disgraceful attacks on the integrity of Andrew Snelling while failing to inform his readers that Snelling responded to Ritchie on the TrueOrigin website almost fourteen years ago (Snelling 1998). The irony is that the presenters in the DVD have better credentials in geology than Moreton himself, who, to our knowledge, has no graduate or postgraduate qualifications at all in the earth sciences.

Conclusion

It is necessary to distinguish between evidence-based approaches to reconstructing earth history and the specific conceptual models for integrating these evidences into a coherent narrative. Our DVD focuses on the evidences that must be explained by any model of earth history. In an educational context, this is the issue that needs facing because model building cannot get far if the evidences themselves are misunderstood. Unfortunately, Moreton seems committed to fighting a rear-guard action to perpetuate worn-out paradigms, an approach that is likely to hamper education. His critique consists of unwarranted extrapolations of present day rates into the geological past, assertions presented without evidence and a failure to consider alternative hypotheses. He makes unfounded accusations of dishonesty and yet selectively omits crucial information himself. In some cases it is evident that he has not even read the scientific work that he is seeking to criticise. We intended our documentary to raise questions, promote thought and encourage further investigation. We think we have succeeded in that aim and that Moreton's efforts to refute our case have failed. We stand by the arguments we have presented.

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