PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

General Discussion in Response to the Earth's lithosphere to extension. A Discussion Meeting held at the Royal Society on 20 and 21 May 1998

The Royal Society

Phil. Trans. R. Soc. Lond. A 1999 **357**, 917-920
doi: 10.1098/rsta.1999.0358

General Discussion

Wednesday, 20 May 1998

J. A. Karson (*Duke University, NC, USA*). I would like to ask about oceanic core complexes and continental core complexes formed in very different types of crust and lithosphere and under different rheologies. Why do they have such similar morphology, size and dimensions?

J.-P. Brun (*University of Rennes, France*). I have no answer. But why not call these 'mantle' complexes, because a core complex, as far as I know, is something which is made of crustal material? When Professor Karson asks a question like this, he compares a butterfly with a horse. He is comparing the oceanic lithosphere, where there is an enormous reservoir of the material that can be exhumed, with the continental crust, where this is not the case because the crustal material is finite. Professor Karson's fault can be 2000 km long if he is right. He cannot have this in the Basin and Range, or in the Aegean. I'm not sure whether or not that his question makes sense. So I am not sure that the term 'core complex' is appropriate, if it has the same meaning as for a structural geologist working in the Basin and Range. That is the point.

D. Sawyer (*Rice University, Houston, TX, USA*). I think it's only because they do have the same aspect ratio and the same size that Professor Karson actually relates them geologically to the core complexes on land. That's really his prime line of evidence to draw an analogy between these features, isn't it?

J. A. Karson. Actually, I don't think so. Even before these new images were available, we were suggesting that some of these areas with low-angle normal-fault surfaces, truncating what was clearly strongly thinned crust, were like core complexes.

A. B. Watts (*University of Oxford, UK*). One puzzling thing to me is the association of these highish regions with the nodal deeps. It seems to me that the explanation for the massif is coupled with the explanation for the nodal deeps. Therefore, the notion of the core complex is such that it's got to be treated with caution, because the interpretation involves both the highs and the deeps.

J. A. Karson. Yes, I think that's another good point and one that probably I should have raised in my paper. Basically, going along the flow line, the crust that ends up on top of that massif, starts out in a deep nodal basin and that's an elevation change in a number of places of 4 or 5 km in less than a million years.

Thursday, 21 May 1998

A. Wagner. I want to complain about the environmental destructiveness of mining. I think that the mining industry could improve its ethical behaviour a lot.

R. Hardman (*Amerada Hess Ltd, London, UK*). I think this is really a general environmental point. The world has fairly clear choices to make. Responsibility for the environment is something that we in the oil industry are certainly very conscious of, perhaps much more conscious than the population at large. The restrictions on our activities, both voluntary and legislative, are significant. We are conscious of the impact large populations are having on the environment, and we have got to work to minimize this impact. On the other hand, most of the people that complain about the oil industry impact on the environment; Greenpeace for one, in their complaining use our products. Their boats last year in the west of Shetlands area were fuelled with oil. I believe that one of the reasons they eventually gave up was that the bill for the oil was becoming so large. So we have a paradox and I think that we need to address it together as responsible citizens. We need to look at the effects of mining. Now, I don't know whether you were thinking of onshore mining or offshore mining, but again it doesn't really matter. These are things that we, as a responsible community, should address. Let's take another totally unrelated point: aggregates. It's very difficult for anybody to mine aggregates in this country now. They would probably go to Norway where they don't mind large holes because 95% of the land is uninhabited. It seems to me quite sensible but one has to recognize that there is a cost to the UK balance of payments. There are costs and there are benefits, and we need to balance these while giving environmental concerns full weighting.

J. A. Karson. I think there is a really interesting issue of how rapidly highly extended terrains, whatever you want to call them, develop in continental crust. It has been an issue that has been investigated for a long time. For example, in the western US, where you are at the mercy of various types of argon–argon date, it is clear that these terrains developed relatively rapidly but the resolution with which you can say that is limited by the dating techniques (we are looking at events that occurred in about the mid-Tertiary). It is clear that the highly extended terrains on the ocean floor with associated detachment faults, whether we are going to call them core complexes or not, have developed right on the edge of the median valley where the age of the crust is constrained by magnetic anomalies. Thus, these terrains are clearly forming in less than a million years. Can we date them with better resolution than that? Right now, the answer is no. The very young basaltic material in the middle of the mid-ocean ridge median valleys can be 'dated' now with U-series techniques, but these are only good for a few tens of thousands of years. Then coming from the other direction, some of the earliest papers on mid-ocean ridge igneous products documented them as being very low in potassium; they just don't have the right composition for dating. Even with the best techniques today getting back to 2 Ma old material with argon–argon techniques is difficult, other than in the very best case scenario. So, we have a window where no dating techniques are available and we are reliant basically on the very coarse chronometer available to us through magnetic anomalies. So, even in an oceanic setting, I think we really don't know what the extension rates are, and I think that is a really important point.

J.-P. Brun. I have been working on core complexes on land for more than about 15 years. I have been in the Basin and Range, in the Aegean, in Norway, and in the Variscan Belt, and the core complexes have one characteristic everywhere and that is the rate of exhumation of material. In all cases the rate is exceptionally high. The rocks come from depths corresponding to 10–15 kbar to near-surface in a few million years—1, 2, 3 Ma, whatever the age of the core complex. This is one thing. It doesn't say something directly in terms of strain rate (it's difficult to transform this into strain rate) and rate of process but the rocks come up very, very fast. The second point is that the cooling is very, very rapid because in some core complexes from the Basin and Range and from the Aegean, we can demonstrate that the cooling is higher in some cases, at least in the core of the core complex, than 100 °C Ma^{-1}. This is extremely rapid. The third point is that core complexes, except those recently discovered in the oceanic lithosphere, always develop at early stages of the extension in all mountain belts where they are known; this is true of the Western Cordillera of the United States, the Aegean, the Caledonides, the Variscides and the Appalachians and wherever you want. They are always an early phenomenon in the extension in mountain belts.

R. Hardman. I would like to get back to the question of volcanics and whether the volcanics are just indicators of heat or whether they are fundamental drivers. In other words, is it the rift that causes the volcanics or is it the volcanics that cause the rift?

R. S. White (*Bullard Laboratories, University of Cambridge, UK*). The lithosphere really can't extend significantly anywhere on the Earth without volcanics of some kind being generated. If old continental lithosphere is stretched a relatively small amount, then it is likely that metasomatic melts will be released from the lower lithosphere. If greater stretching occurs, such as on continental margins, then large volume mantle melts, such as picritic basalts, are formed. I don't know of any rift basins where some melting has not occurred. So the first answer to the question is that it is the rifting that causes the volcanism.

But the other side of the coin is that, if a large volume of melt is intruded through the lithosphere and into the crust, then it is likely to change the rheology of the crust markedly and thus to affect the tectonic structure of the rift. In particular, melt generated in the mantle is likely to be at a temperature well above 1000 °C as it enters the crust, whereas the melting point of wet crust may be several hundred degrees Celsius lower than this. If widespread crustal melting occurs, this will certainly change the tectonic response of the crust to stretching. This can be seen occurring on the richly volcanic continental margins, such as those around the North Atlantic, where the margins are both relatively narrow (typically a few tens of kilometres wide), and where continental break-up occurs rapidly (in the space of a few million years); by contrast, the much less volcanic margins, such as those off western Iberia in the North Atlantic, have widths of 100 km or more, and continued stretching over much longer periods, perhaps reaching 20–25 Ma. So in this sense the volcanics control the rift.

Therefore, both statements are true: the rift causes the volcanics and the volcanics may exert strong control over the structure of the rift.

N. White (*Bullard Laboratories, University of Cambridge, UK*). I would like to add a comment about intracratonic basins which Mr Hardman raised when he asked the question about volcanics. Throughout the intracratonic basins in North America, where it looks as if there was extension in the Cambrian, there are lots of signs of small volumes of volcanics in the half-grabens. However, because the stretching factors were so low, typically 1.05–1.1, the volcanics probably represent melts that were derived from the lower part of the lithosphere, so they are metasomatic melts.

R. Hardman. So my question is, if you don't see volcanics, can you be sure it's not a rift basin?

R. S. White. The one major type of sedimentary basin where you don't make melt is a foreland basin. In foreland basins, a depression is generated by flexural loading, and it becomes filled with sediment eroded off the adjacent mountains. There is no particular reason why any melt should be generated in such a setting, and indeed it isn't a rift basin. But in almost every other setting where there are thick sediment accumulations, whether in rift basins or above subduction zones or backarc complexes, volcanism is likely to be found. So it seems likely that if you find thick basinal sediments without any sign of volcanism, indeed the basin was probably not formed by rifting.

N. White. The reason I hesitated is that although you will get melt, its distribution may not be even. Thus, each individual half-graben or graben may not have volcanics in it, but on a regional scale melt products will be present. It is just that the distribution of volcanics within the network of upper crustal rifts is usually not in any sense uniform.

R. Hardman. Are we going to be able to get any better dating? I was very impressed with the fact that when we got ice cores we could work out that the climate changes within about 30–50 years. What about fine-scale dating, is that something we can achieve? Is this something as a group we are going crack? Are we going to get much finer?

N. White. As I understand it, as a background observer, they've got as far as just about the Oligocene with this tuned Milankovitch dating. They have great hopes of getting to the base of the Tertiary reasonably soon and they see no reason why they cannot then rapidly progress through large tracts of the Cretaceous and Jurassic. So there is a great deal of optimism but an enormous of work needs to be done first.

R. S. White. Milankovitch cycles can be seen in the Jurassic, so it is possible to achieve very fine-scale timing even in such old rocks. But, at least at present, it may not be possible to determine the absolute age accurately in such old rocks. So it is possible that you can erect a floating timescale, with fine-scale resolution and precise relative timing, which is nevertheless not well dated in absolute terms.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES