Massive solar eruptions and their contribution to the causes of tectonic uplift

Robert J. Johnson

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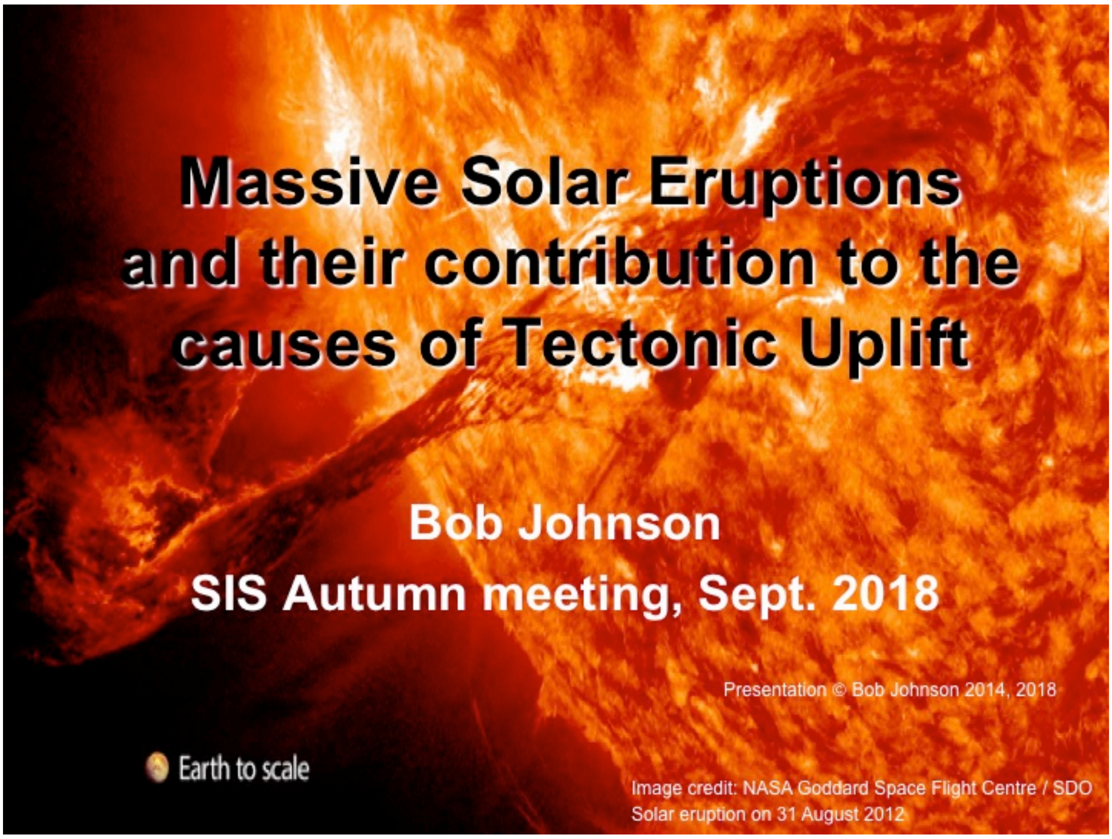
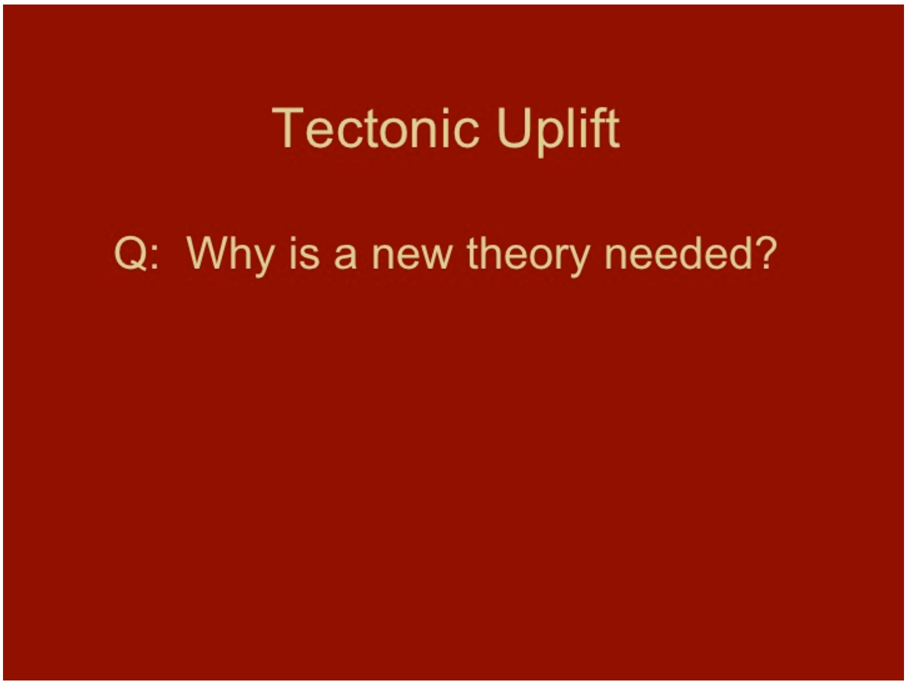
Text in orange (and references in brackets) were omitted from the talk.
Notes and references follow the text and slides.



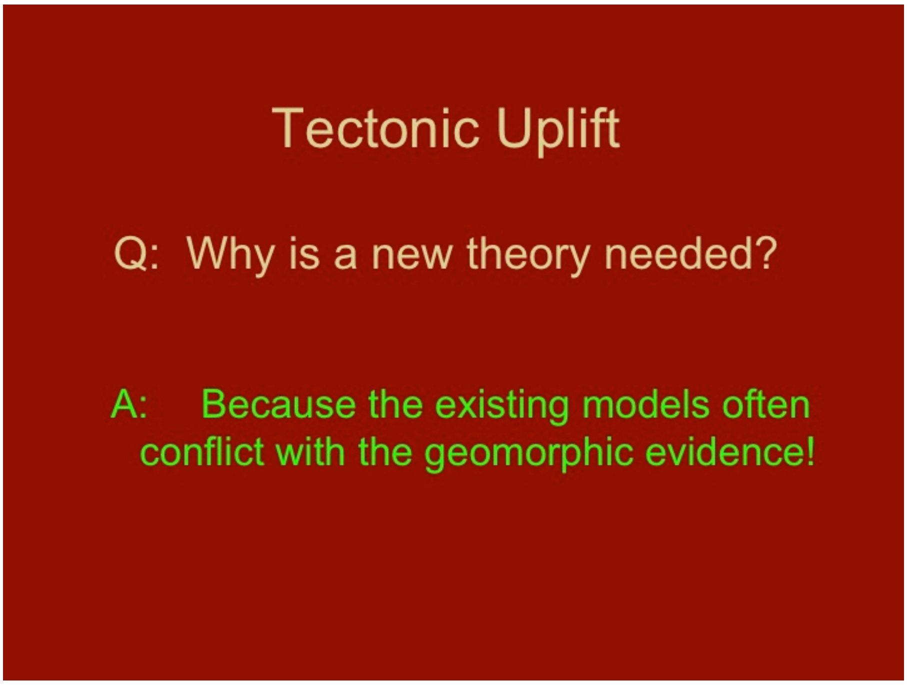
Introduction

Proponents of the Electric Universe have suggested a catastrophic origin for various geological features: from mountains to canyons; from dendritic ridges to river systems; and from dunes to craters. But geologists explain many of these features with uniformitarian models; only the craters require a catastrophic meteor strike. There doesn't seem to be any obvious role for electricity in most cases. But perhaps electrical discharges arising from massive solar eruptions may have played a part in the past?

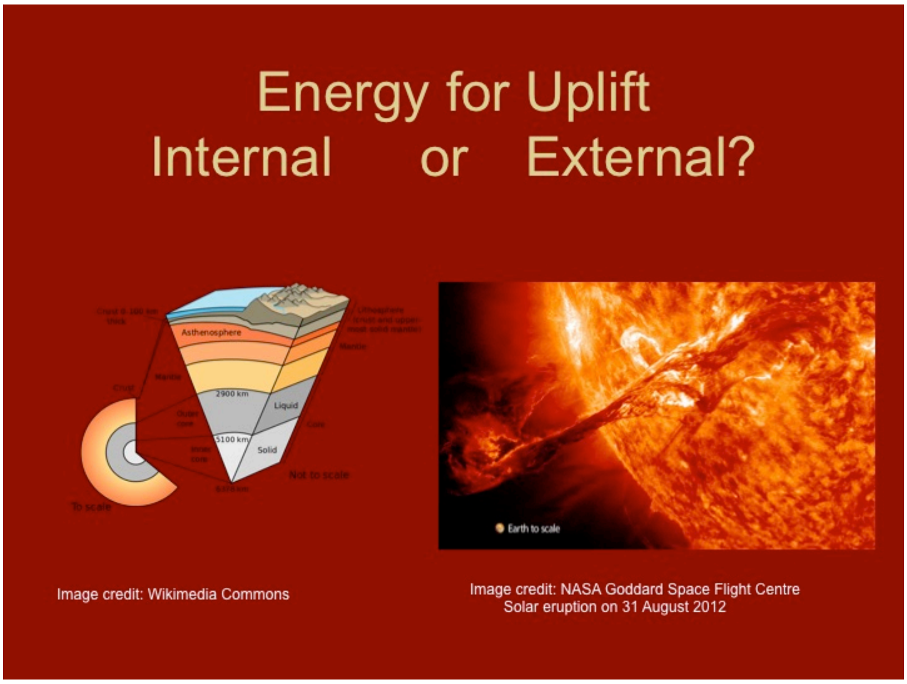
Let's take the origin of mountains as an example. The process of mountain formation is known as tectonic uplift.



There are many theories of uplift, of which plate tectonics represents the majority consensus. Taken together, these models apparently explain how the various different mountain ranges came into being. Why is a new theory needed?



The answer is that Plate Tectonics, and many of the other theories of uplift, conflict with the geomorphic evidence in the rocks. The models require a series of events and processes to have happened, but the geology of the rocks shows that the strata often can't have gone through the processes demanded by the models.

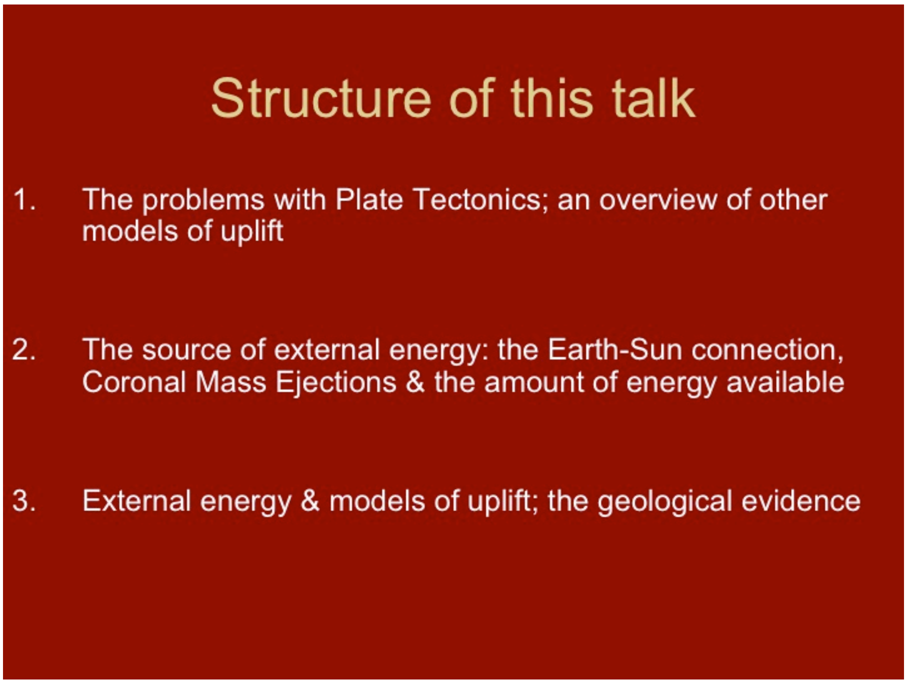


Many of these conflicts arise from the assumption that the source of energy for uplift is the molten mantle inside the Earth. The models have to explain how rocks on the surface of the continental crust get enough heat from the mantle, which is about 30 to 50 km below the surface.

An external source of energy would remove this requirement and allow many of the existing models of uplift to fit the geological evidence. I suggest that this external energy was contained in Coronal Mass Ejections in past eras.

In this talk I'll explain how that model works. But if you're waiting for me to rescue Plate Tectonics then you'll be disappointed; that's not one of the models which can be saved by an external source of energy.

Structure of this talk



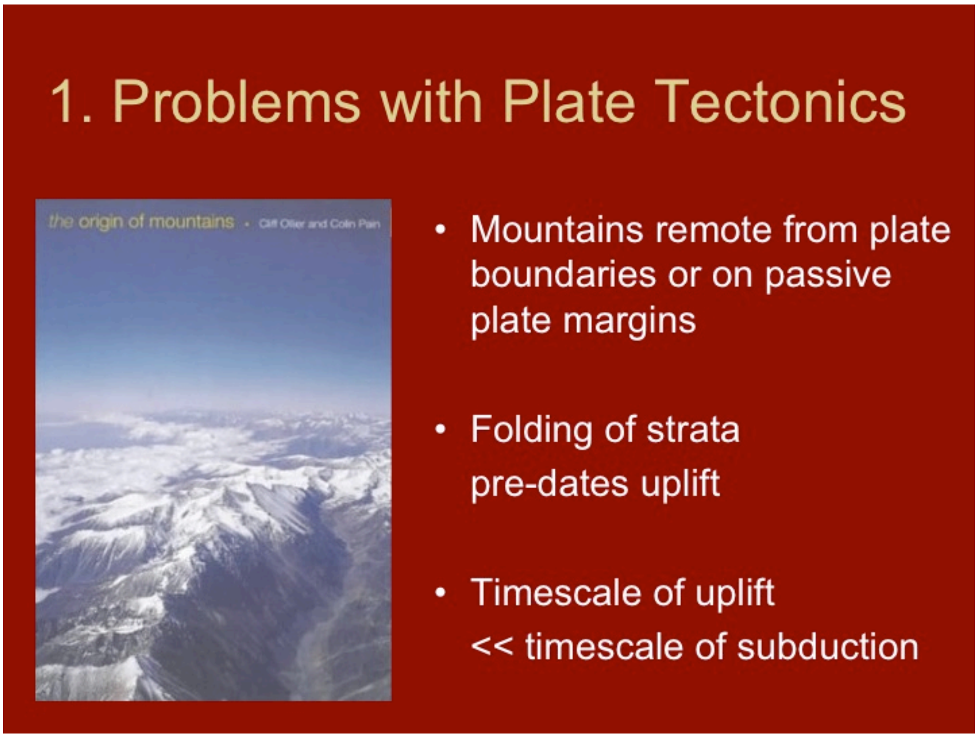
This talk is in three parts:

Part I will look briefly at the problems with Plate Tectonics and give an overview of the other models of uplift.

Part II will look at the source of external energy: we'll consider the Earth-Sun connection, Coronal Mass Ejections, and the amount of energy available.

Part III will look at how this energy relates to models of tectonic uplift, and show how an external source of energy fits the geological evidence.

Let's start off with Plate Tectonics.



The cause of uplift

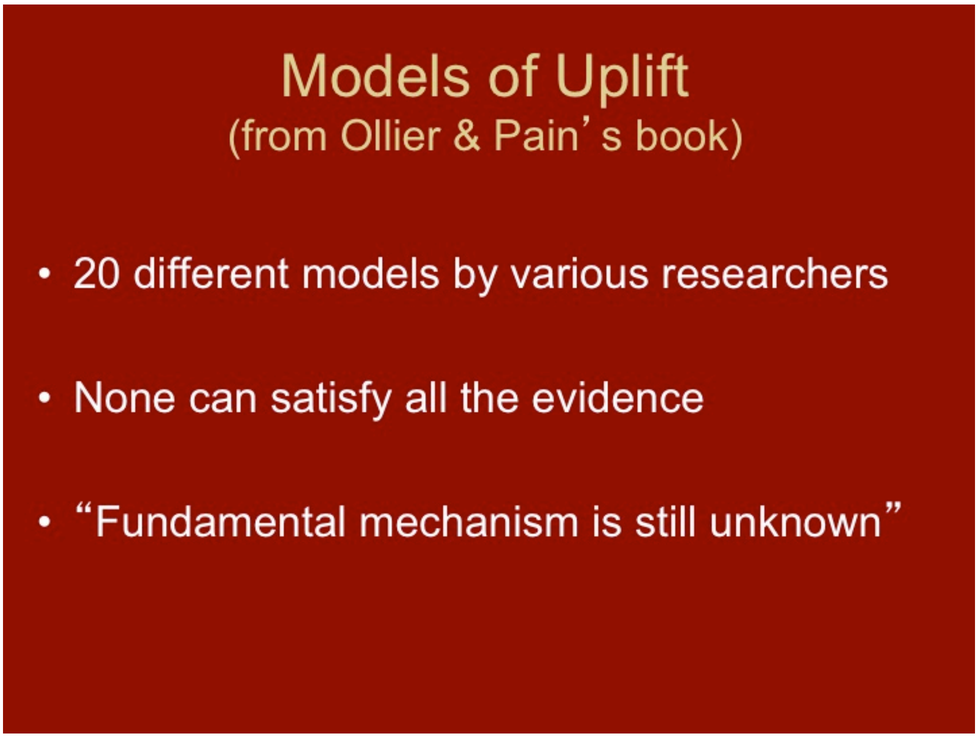
The cause of uplift is still a matter of debate. Ollier & Pain's book *"The Origin of Mountains"* is an eloquent demonstration that the 'one size fits all' theory of Plate Tectonics does not agree with the evidence in many instances, and requires "Procrustean" adjustments to the evidence to force it to fit the theory.

The principal problems include: mountain ranges remote from plate boundaries or on passive plate margins; the folding of strata caused by subduction often pre-dates the uplift; and the timescale of uplift is much shorter than the timescale of subduction by colliding plates.

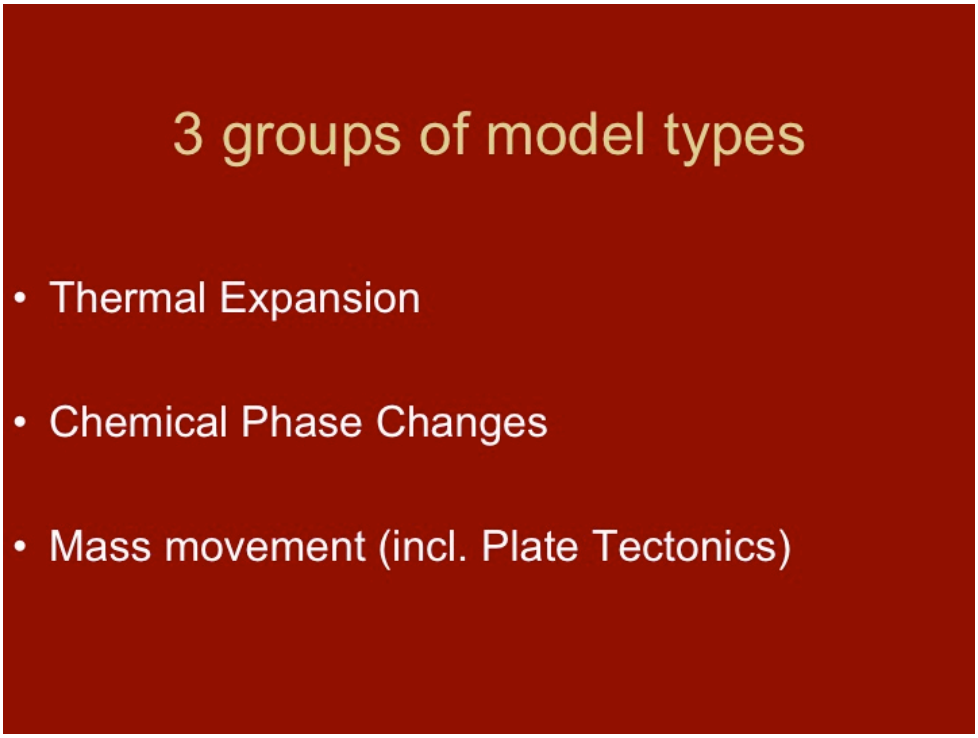
Some Types of Uplift

- Simple Plateau (Colorado Plateau)
- Tilt Block (Sierra Nevada)
- Passive margin warp (Eastern Australia)
- Isostatic uplift (Himalayas)
- Broad swell (Alps & Apennines)
- Symmetrical plateau + graben (Andes)

What's more, uplift comes in many different forms. Here are a few examples from around the world. As you can see, they're all very different! The number of variables seems to preclude a single explanation, and that's why so many other models of uplift have been proposed by various researchers.



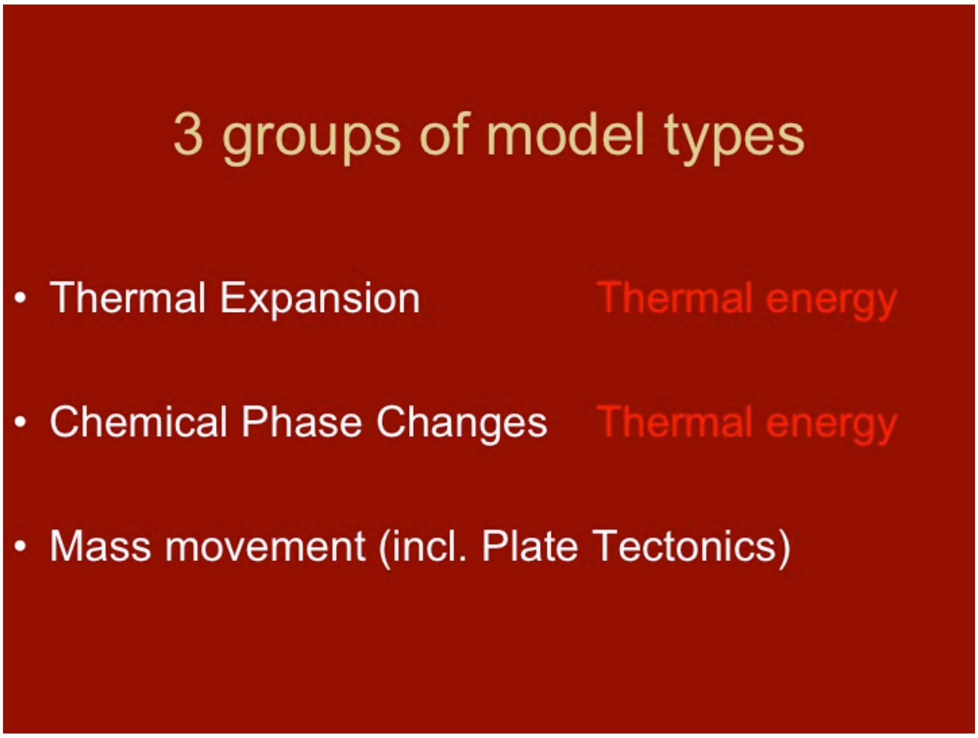
Ollier & Pain list twenty different models, none of which is able to satisfy all the evidence (*ibid.* Table 12.2, p 308). The authors conclude that the fundamental mechanism of uplift is still unknown.



Using Morgan & Swanberg’s (1985) analysis of the causes of uplift of the Colorado Plateau, we can arrange Ollier & Pain’s more general list into three similar groups: thermal expansion; chemical phase changes; and mass movement, including plate tectonics.

Many of the models in the first two groups assume that uplift is an isostatic response to mass deficiency occurring at depth; in other words, the rocks become lighter and simply float upwards on the dense mantle below.

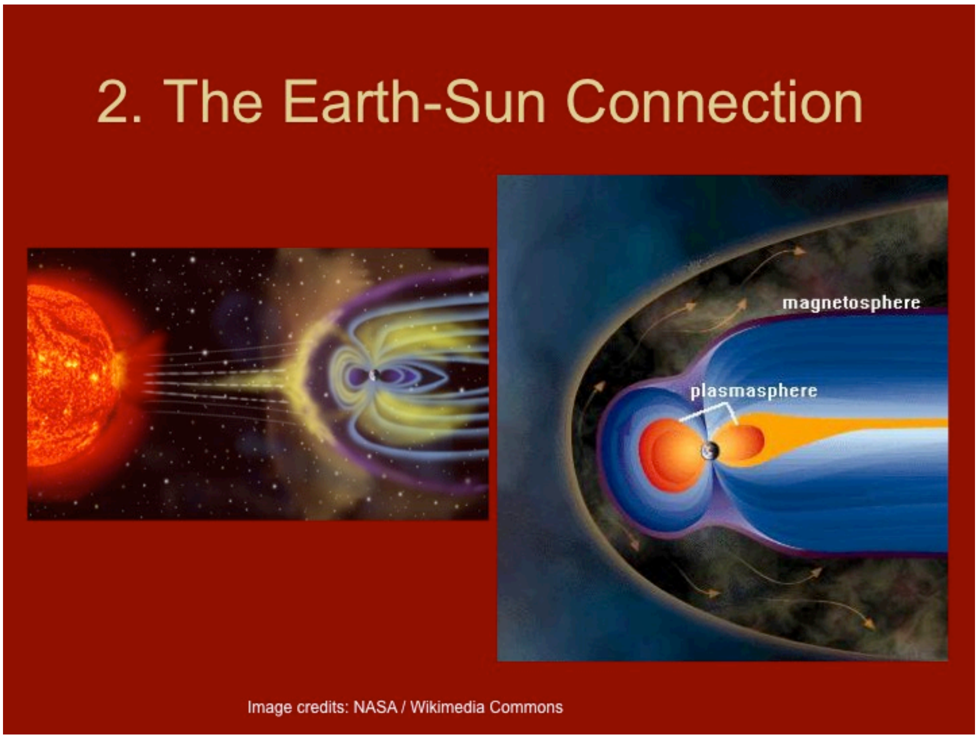
Various causes are hypothesised in order to explain this mass deficiency. Thermal expansion models postulate that there is a reduction in density due to heating of the crust. Phase change models rely on the reduction in density caused by changes in the minerals.



The factor common to models in the first two groups is thermal energy. Increased temperature is fundamental to the thermal expansion group; and the rate of chemical reactions is temperature-dependent; they can happen quickly if the rock is partially melted.

So how are we going to get the external source of thermal energy into the rocks?

That brings us to Part 2 of this talk.



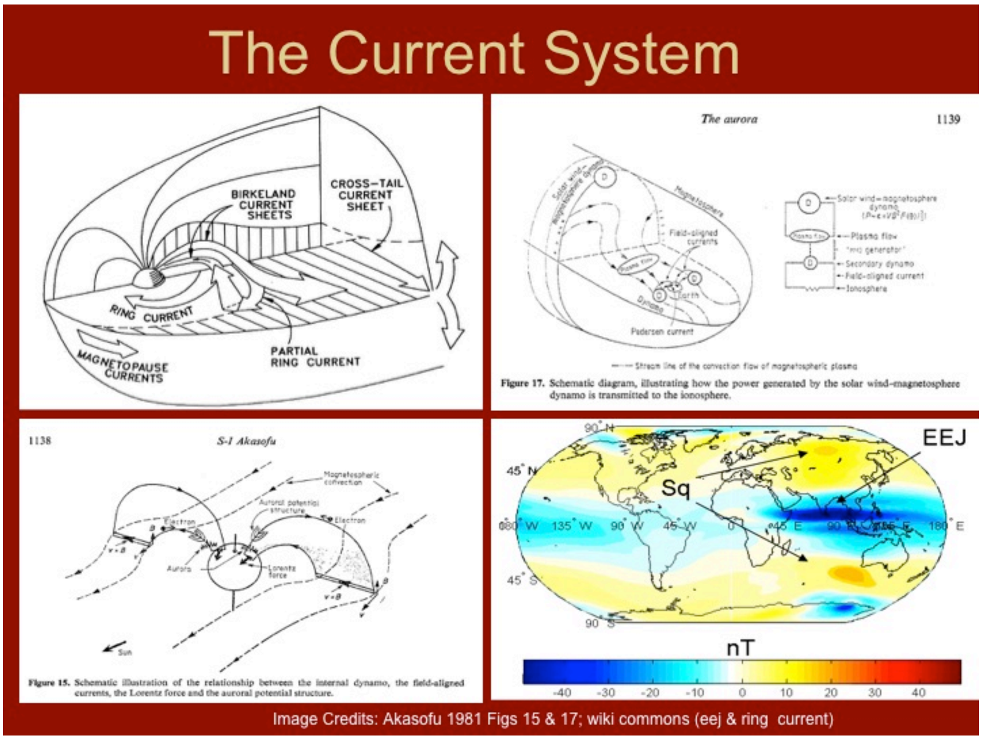
The Earth-Sun Connection

a. The present day

I hardly need to explain the Earth-Sun Connection to everyone here today but a brief summary might be useful for what comes later, so please bear with me.

The Sun itself is a magnetised body which continuously emits plasma in the form of the solar wind which carries a portion of the Sun's magnetic field with it into the heliosphere; this is referred to as the Interplanetary Magnetic Field, or IMF. The point is that the solar wind has both kinetic energy and magnetic energy.

The Earth is also a magnetised body; the Earth's dipole field extends out into interplanetary space forming a donut-shaped magnetosphere following the dipole field lines, which get dragged out into a long tail on the night side. Within the magnetosphere, the Earth's field dominates the magnetic environment.



Under normal conditions, the interaction of the IMF and the Earth's magnetic field deflects the solar wind around the magnetosphere; this involves a change in the magnetic field the wind contains. This in turn generates electric currents in the magnetopause according to Lenz's Law which, in effect, states that any change to a magnetic field will be resisted by the generation of an electric current whose magnetic field opposes the original change.

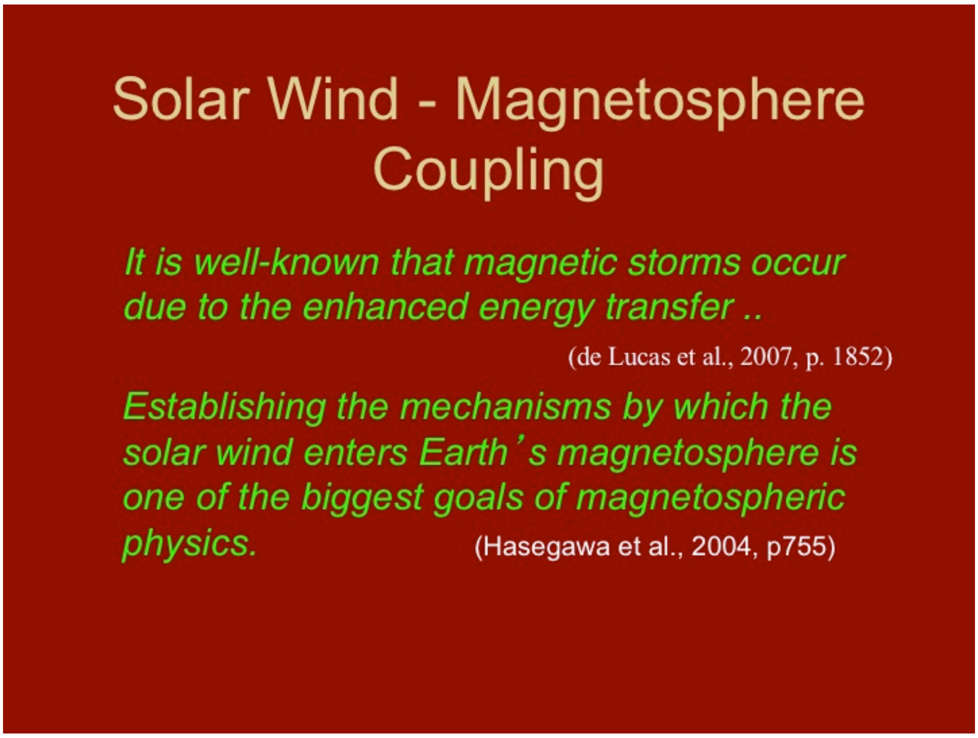
These currents in the outer boundary of the magnetosphere cause other currents in the inner regions comprising the plasmasphere and the ionosphere. The most important of these for our purposes is the Ring Current in the outer plasmasphere. Currents in the equatorial plane of the plasmasphere flow into the ionosphere along the dipole magnetic field lines to the polar regions where they cause the aurorae.

Other currents, such as the equatorial electrojet, flow in the remainder of the ionosphere. Finally, Telluric Currents in the surface of the Earth are induced in response to the various currents in the ionosphere above.

The energy in this complex series of currents is dissipated as Joule heating, particle acceleration in the auroral regions, and kinetic motion in the currents themselves. The proportion of energy normally dissipated in induced Telluric Currents in the Earth's surface is extremely small, in part because the atmosphere is an insulating layer which prevents direct current linkages like those in the plasma layers above (Gold, 1959).

So far, I've only mentioned the 'quiet Sun' conditions. The system becomes significantly more complicated during the frequent solar eruptions in which the Sun emits large quantities of additional energy from coronal magnetic storage in sunspot regions (Emslie et al*.*, 2005, p3).

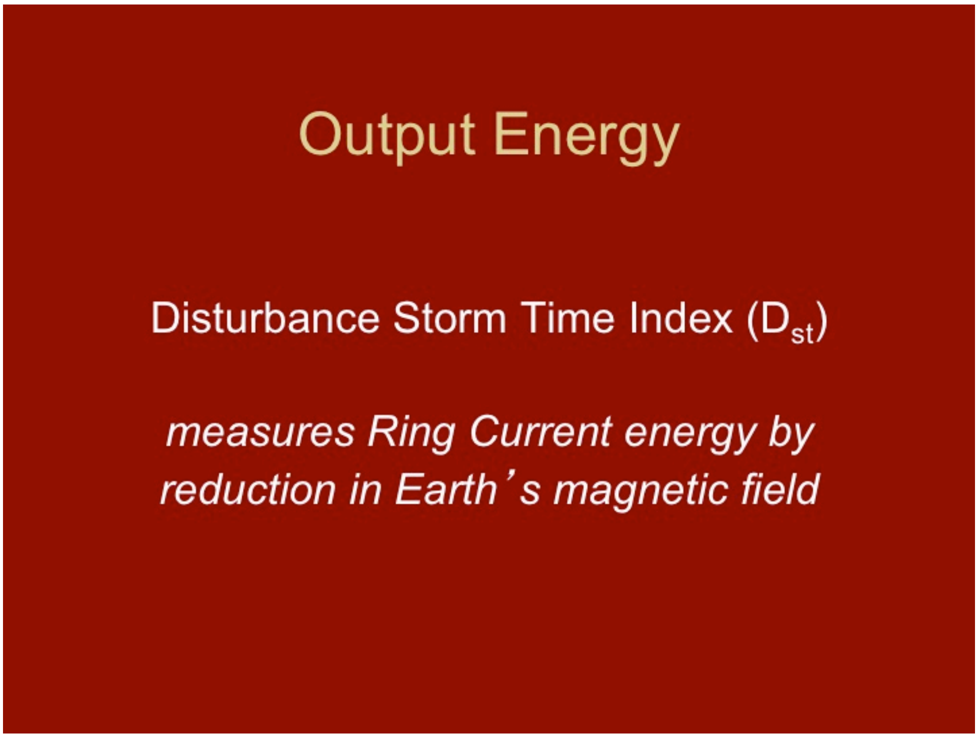
These change the magnetic and kinetic energies of the solar wind, and magnify the normal current systems. These enhanced effects deliver more energy to the magnetosphere and result in 'magnetic storms' measurable on the surface of the Earth itself.



b. Solar Wind – Magnetosphere Coupling

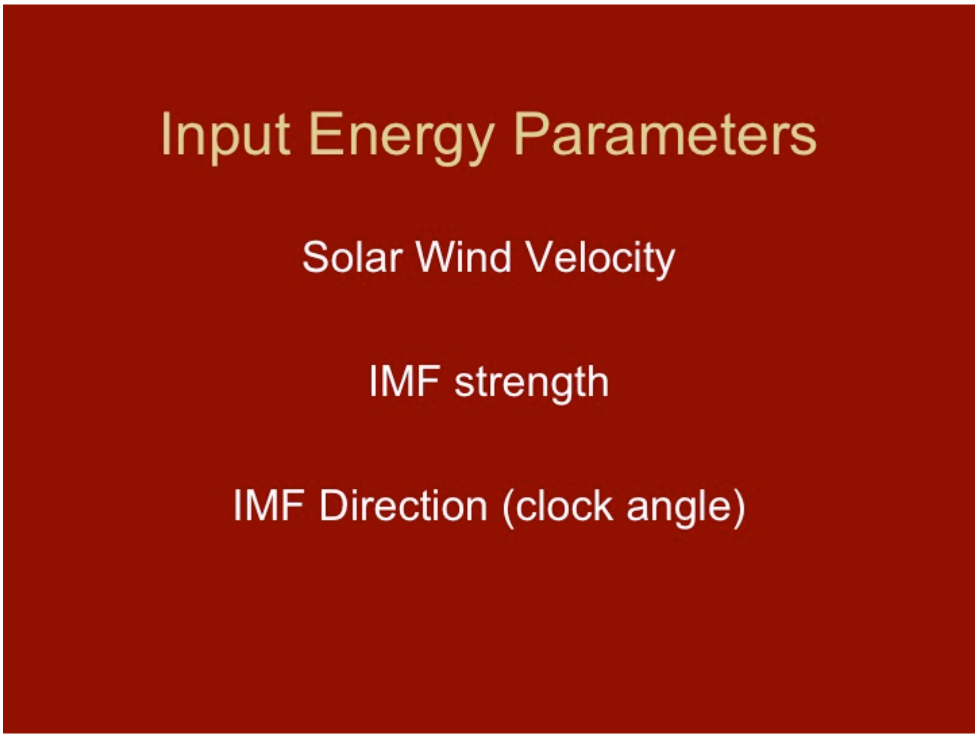
The process of transfer of energy from the incoming solar wind to the Earth's immediate environment is known as 'Solar Wind – Magnetosphere Coupling' and "…it is well-known that magnetic storms occur due to the enhanced energy transfer ..” (de Lucas et al., 2007, p. 1852). However, exactly how this occurs is still under investigation. "Establishing the mechanisms by which the solar wind enters Earth's magnetosphere is one of the biggest goals of magnetospheric physics." (Hasegawa et al., 2004, p755).

A key objective of these studies is to identify the 'geoefficiency' of the coupling mechanism, that is the percentage of the available 'input energy' in the solar wind which is actually 'output' to the magnetosphere (Guo et al., 2011, p. 8).



The 'output' is monitored indirectly by various Earth-based parameters of which the Disturbance Storm Time Index, or D_{st} , is the most relevant for our purposes. This index gives information about the strength of the Ring Current and the intensity of the magnetic storm by measuring the reduction in the horizontal component of the Earth's dipole field.

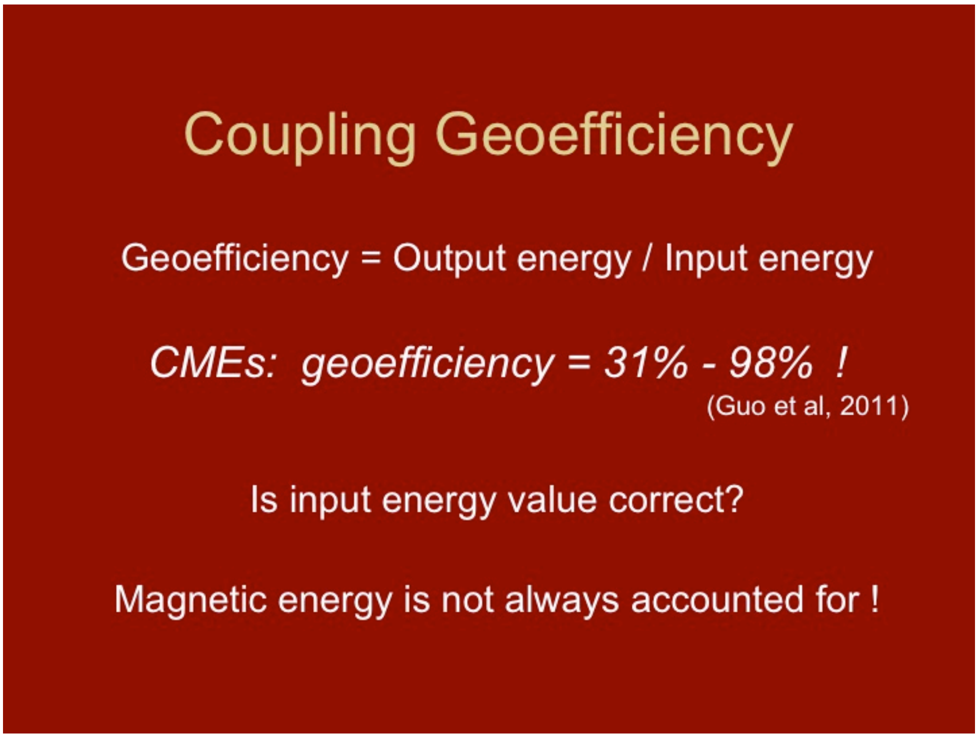
Using the D_{st} index allows estimates to be made of the amount of 'output' energy delivered to the Ring Current but this alone is not enough to estimate the geoefficiency. The key problems lie in the facts that the level of the 'input' energy available for coupling is not known for certain, nor is the coupling mechanism itself fully understood.



The relevant parameters, or ‘drivers’, for the available input energy are the solar wind velocity, the IMF strength, and the clock angle between the IMF and the Earth’s own magnetic field (Guo *et al,* 2012). A southward IMF is known to be the most geoeffective but the precise influence of each of the drivers is a matter of considerable debate. Akasofu et al. (1981) listed thirteen different formulae (other than their own) that have been proposed so far.

It is generally accepted that: “…the major mechanism of energy transfer from the solar wind to the Earth’s magnetosphere is magnetic reconnection following Dungey’s model” (Tsurutani et al., 2003, p. 2). However this is disputed by some researchers. For example, Troshichev and Janzhura (2012) argue that this mechanism is “fundamentally incorrect” (ibid., p79). In contrast, Scurry & Russell (1991) argue that non-reconnection models cannot readily explain the increase in storm activity when the IMF is directed southwards.

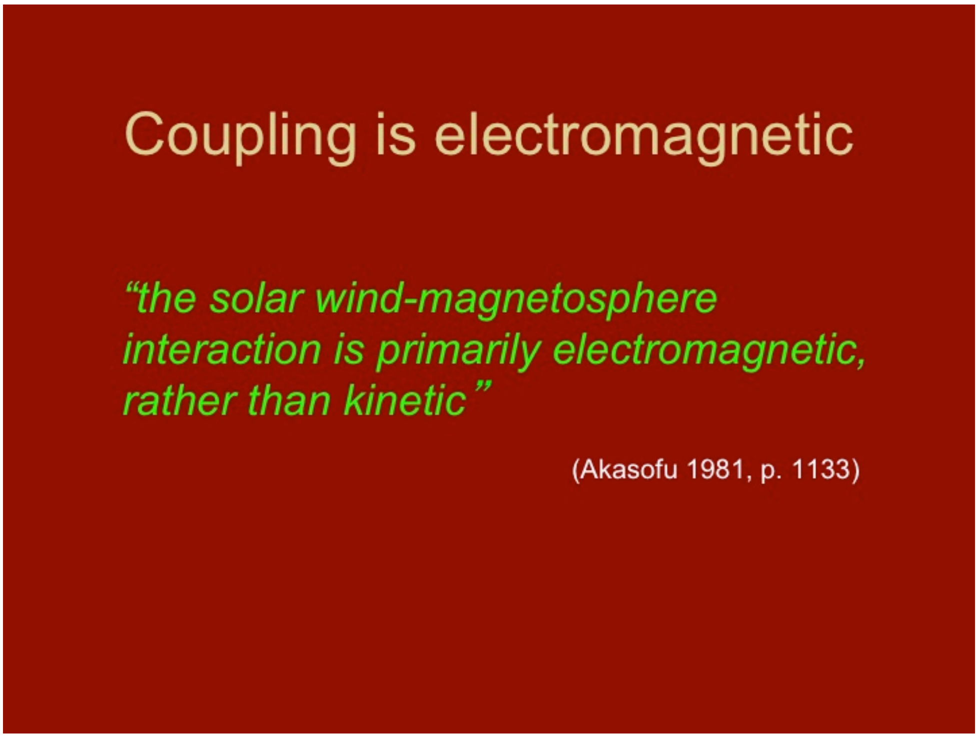
They also pointed out that the best correlation occurred assuming a delay of ~ 1 hour. This comment highlights another contentious issue: whether the magnetic effects are an ‘instantaneous driven process’ or whether they are delayed by energy storage in the magnetotail which is later released to the plasmasphere. (Wolfe et al., 1984, p. 261).



Whichever mechanism is right, the coupling efficiency is not constant. According to Guo et al*.,* (2011) for CMEs, the geoefficiency varies between 31% and 98%, based on the Akasofu ε parameter of input energy (ibid., p9). However, de Lucas et al. (2007) found that the ε parameter significantly underestimates the available input energy.

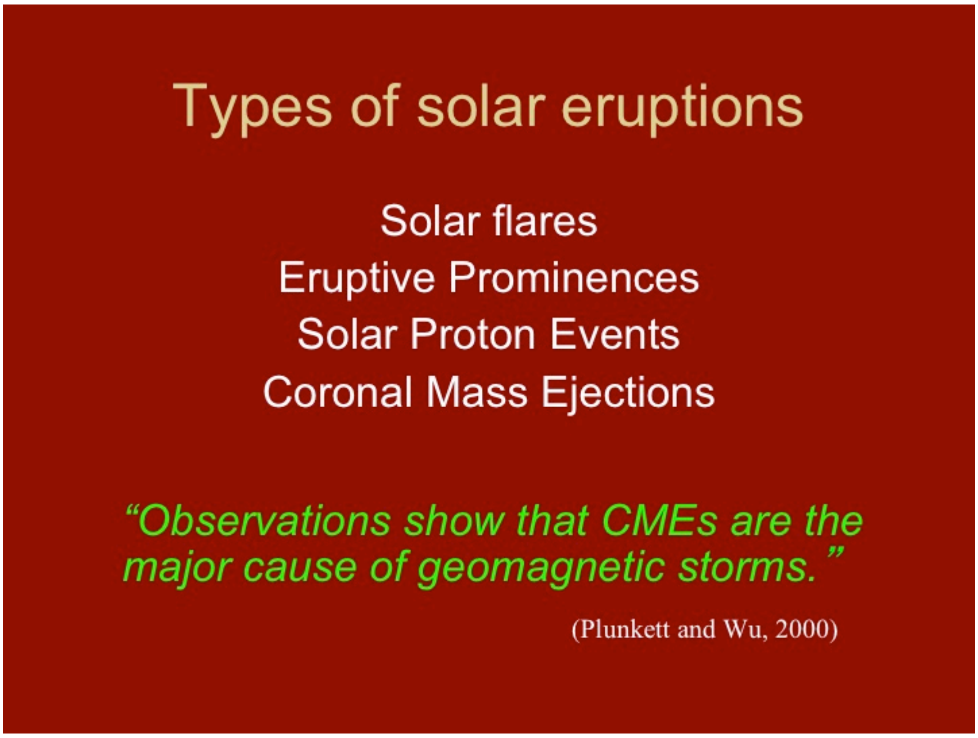
Although the strength of the IMF is known to be important, the magnetic energy in a CME is not always accounted for in the energy budget (Emslie et al., 2005). This can result in an underestimation of the total input energy and it may be a contributing factor in the widely-varying calculated geoefficiencies of different events.

I mention these issues to show that the coupling mechanisms are still very uncertain. Scurry and Russell (1991) suggest that the studies are "fraught with ambiguities" (ibid., p. 9541). Guo et al. (2011) go further: they say "In fact, we do not even know the details of how and where the transfer takes place." (ibid*.,* p. 5)



Nevertheless, one conclusion is reasonably certain. According to Akasofu “…the solar wind-magnetosphere interaction is primarily electromagnetic, rather than kinetic.” (ibid, 1981b, p. 1133)

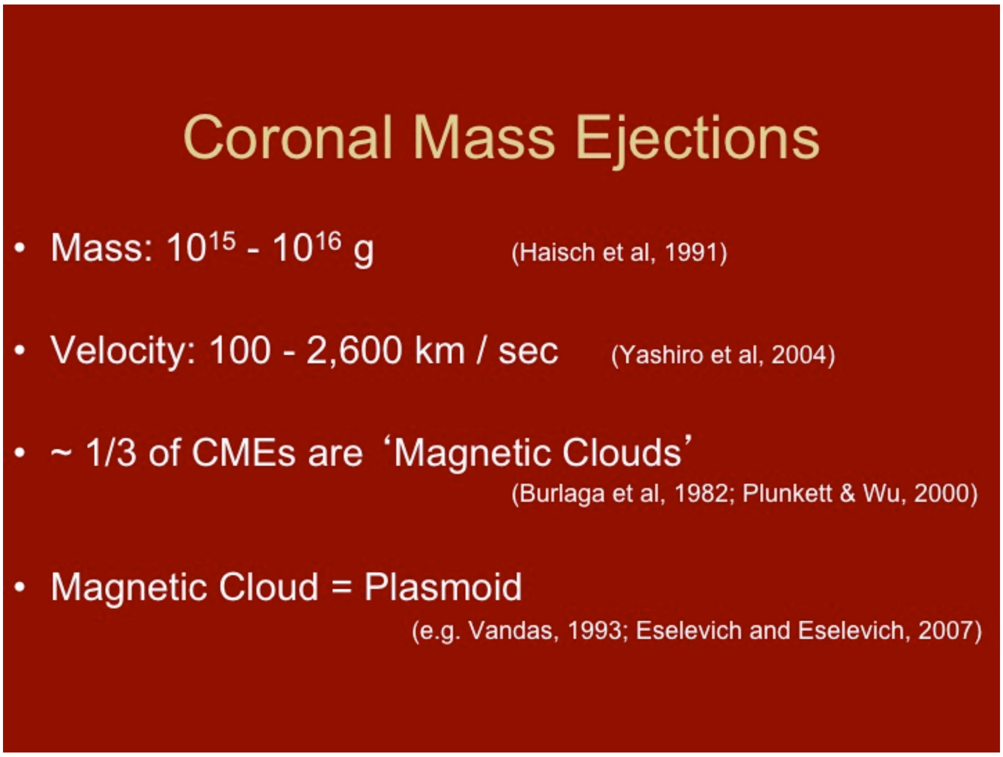
And the extra energy in the solar wind comes from Solar eruptions.



c. Conversion of the Sun's Magnetic Energy into Coronal Mass Ejections

Solar eruptions take a number of different forms, including Solar Flares, Eruptive Prominences, Solar Proton Events and Coronal Mass Ejections. All massive solar eruptions involve conversion of part of the Sun's magnetic energy into one or more of these phenomena.

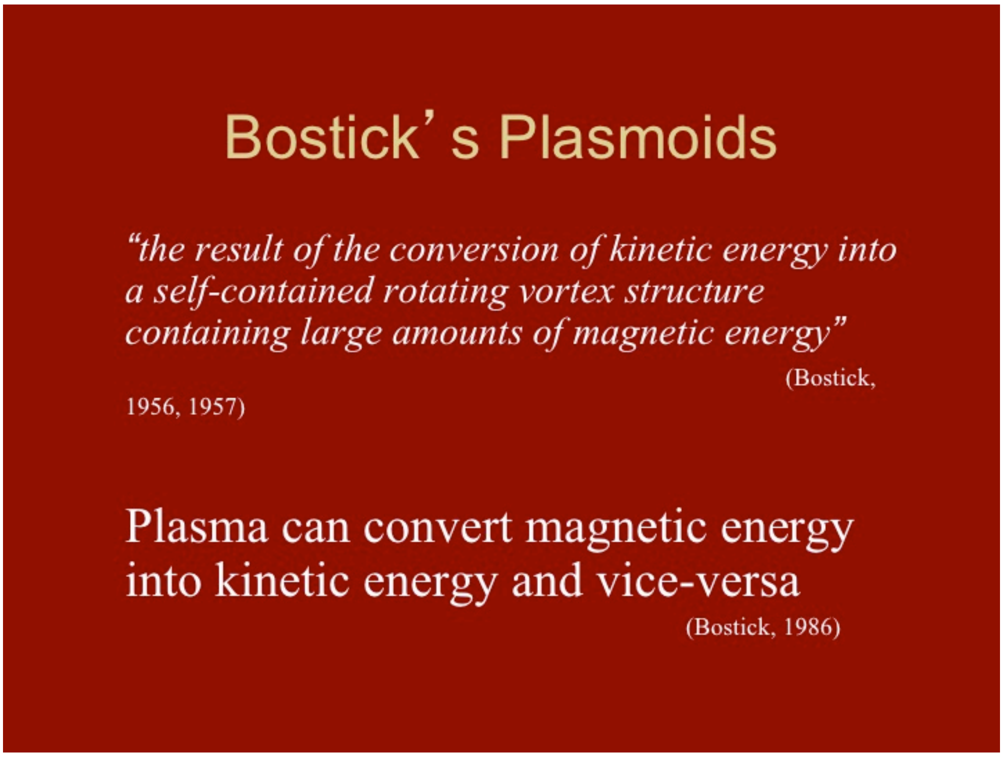
We are mainly interested in Coronal Mass Ejections because "Observations show that … CMEs are the major cause of geomagnetic storms." (Plunkett and Wu, 2000, p. 1807).



A typical CME has a mass of 10^{15} - 10^{16} g (Haisch et al., 1991, p. 288); the velocities of CMEs observed up to 2004 range between 100 km s^{-1} and 2,600 km s^{-1} (Yashiro et al., 2004, p. 6 & fig. 5, p. 7).

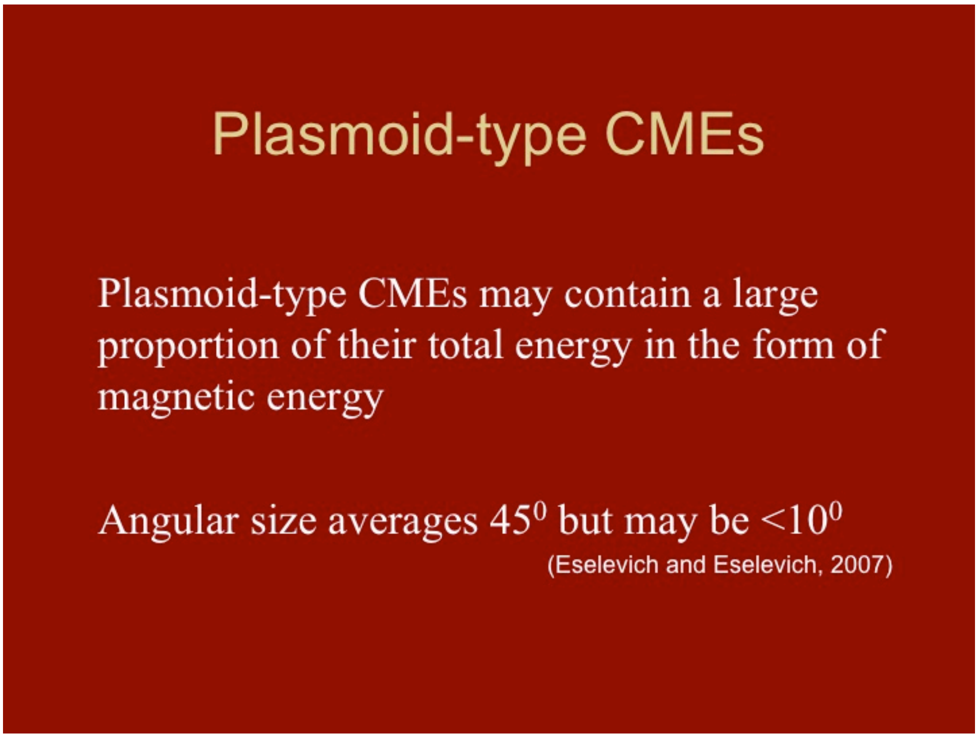
Interestingly, there is a class of CMEs which take the form of a 'Magnetic Cloud' in which the magnetic energy is significantly higher than in CMEs without this feature (Burlaga et al., 1982). Approximately one third of CMEs show the definitive 'flux rope' signature of a Magnetic Cloud (Plunkett and Wu, 2000, p. 1809).

Magnetic Clouds have been identified with 'plasmoids' by some researchers including Vandas (1993a), and Eselevich et al (2007).



Bostick coined the term 'plasmoid' in 1956 to describe "the result of the conversion of kinetic energy into a self-contained rotating vortex structure containing large amounts of magnetic energy" (Bostick, 1956 and 1957); as he later noted, plasma is able to convert one form of energy into the other very easily (Bostick, 1986).

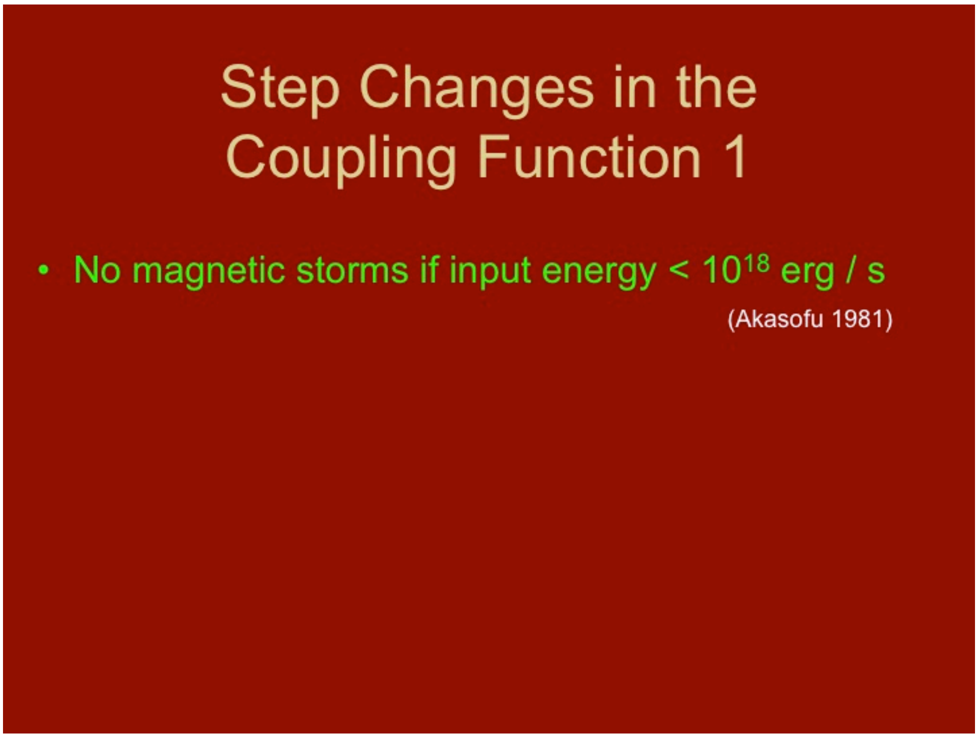
In the Magnetic Cloud or plasmoid-type CME, it appears that part of the Sun's magnetic energy is converted to kinetic energy but a significant proportion is re-converted to magnetic energy *en route*.



The key point is that plasmoid-type CMEs may contain a large proportion of their total energy in the form of magnetic energy.

Unlike flare radiation, CMEs are highly directional. The average angular size of CMEs is about 45^0 (Plunkett and Wu, 2000, p1808), although they may be narrower than 10^0 (Eselevich and Eselevich, 2007). Because they are narrow, CMEs may not impact Earth at all, but when they do, as NASA says, “Part of that energy can be concentrated [into the] .. magnetosphere” (NASA, 1999).

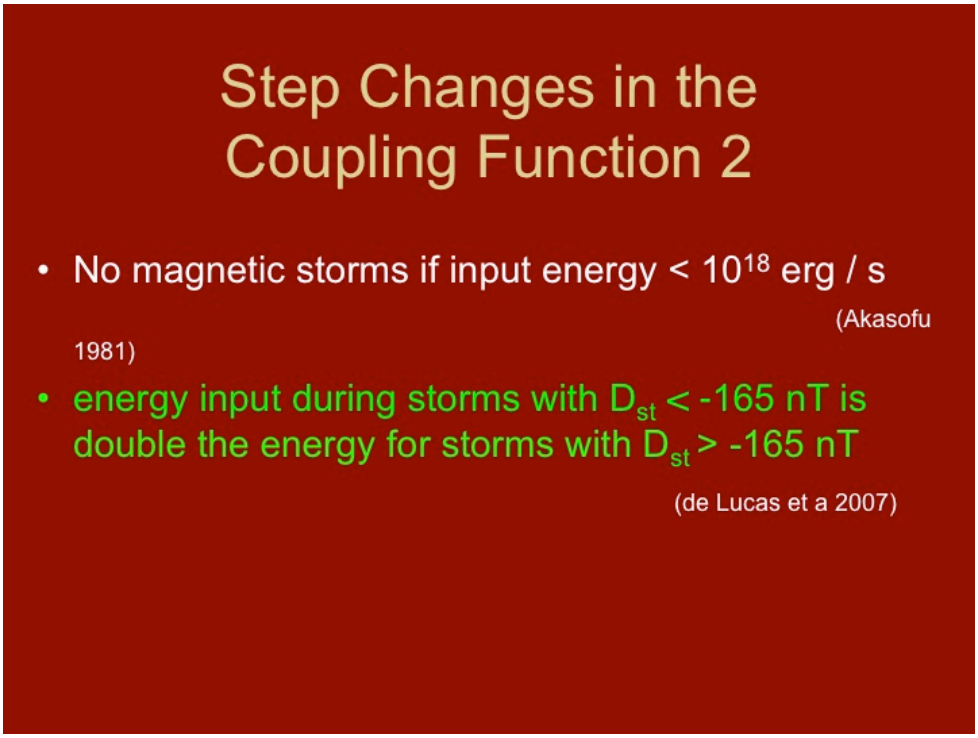
So what is the effect of CMEs on magnetic storms?



d. Step changes in the coupling function

The severity of magnetic storms undergoes step changes at certain energy levels, which are indicative of sudden switches in the coupling mechanism.

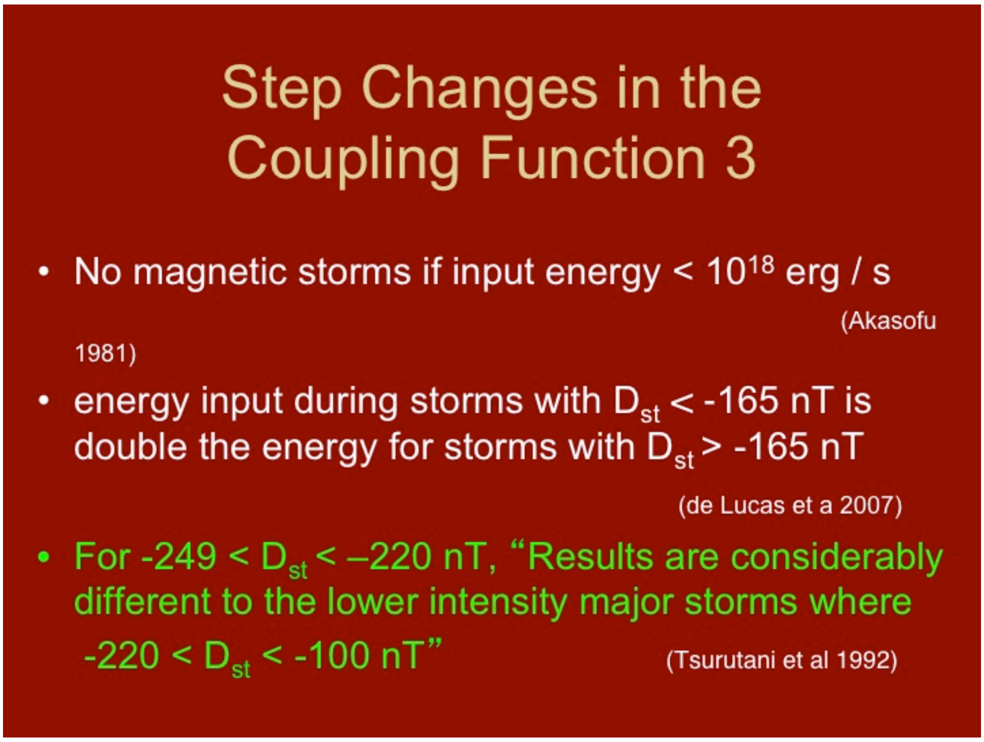
According to Akasofu (1981), no magnetic storms occur below a threshold level of input energy of ~10^{18} erg s^{-1}. Above this power level, a step change occurs in the coupling mechanism and generates storms.



The coupling mechanism also exhibits step changes at other energy levels. For example de Lucas et al. (2007) found that the energy input during storms with D_{st} < -165 nT is double the energy for storms with D_{st} > -165 nT. (ibid., p. 1851),

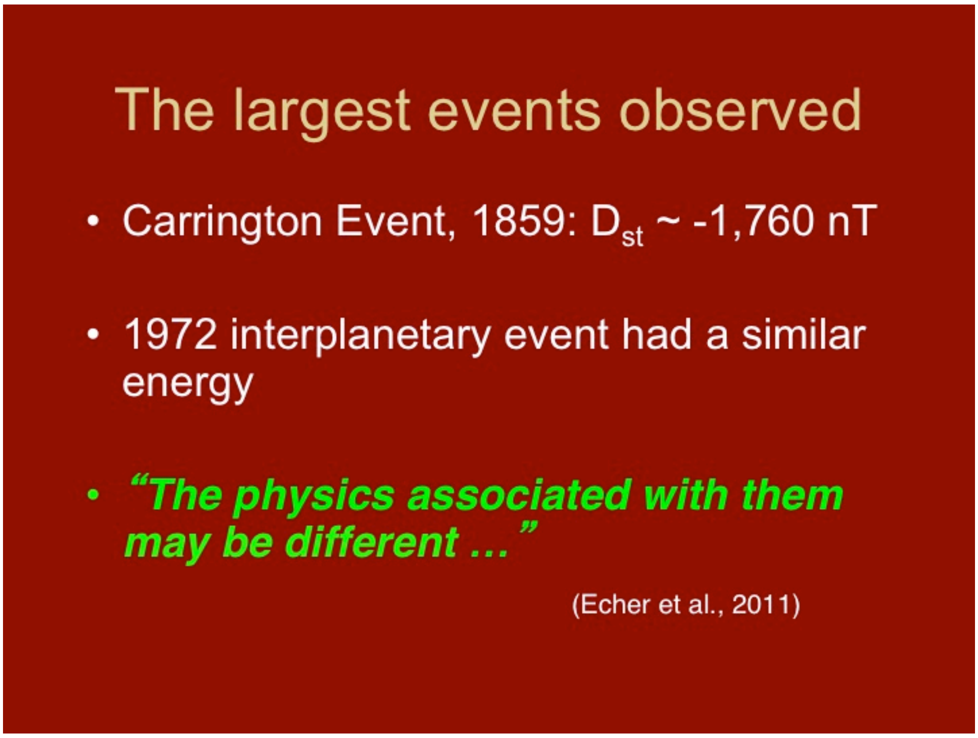
(I should explain, because the index measures a *reduction* in the magnetic field, the D_{st} values are all negative; a larger negative number means a more energetic storm.)

de Lucas went on: ".. the jumps on the energy show that there is a clear separation between the two groups of storms." (ibid., p. 1861).



Similarly, studying the five largest storms between1971 and 1986 with peak D_{st} between -249 and –220 nT, Tsurutani et al (1992) report that "Results are considerably different to the lower intensity major storms where D_{st} is between -220 and -100 nT (ibid., p. 75 and fig. 2)

The fact that step changes are observed in the output of lower-energy events suggests that similar step changes in the mechanism are likely to occur at higher energy levels as well.



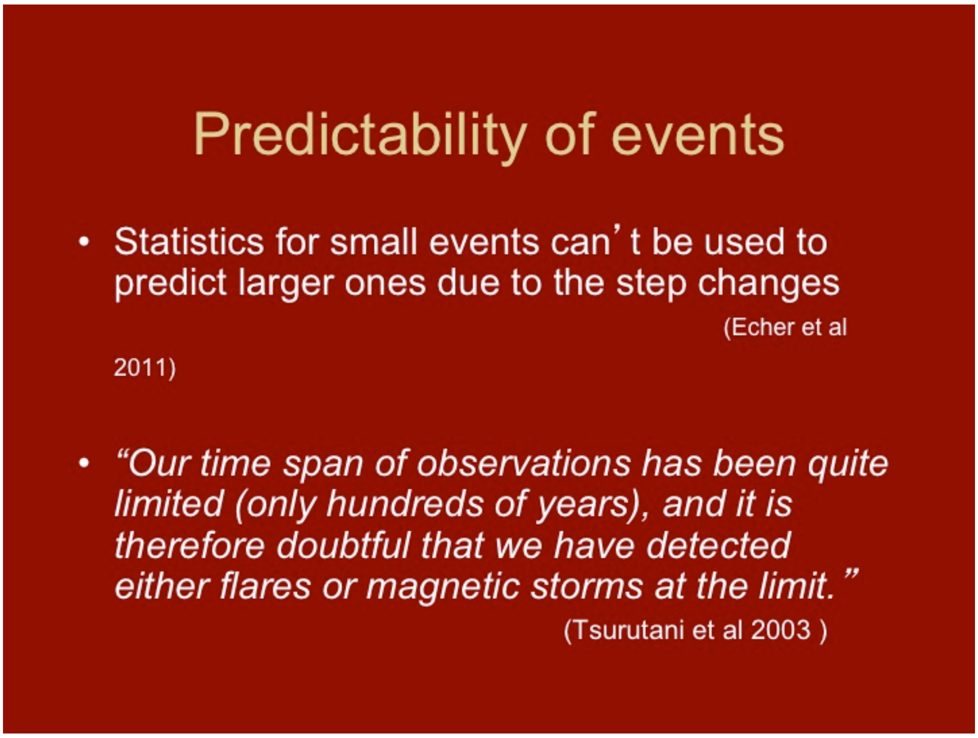
The largest solar eruption recorded in the scientific era is the Carrington Event of 1859 (Odenwald et al., 2005) which is estimated to have had a D_{st} of -1,760 nT. This storm and the 1972 interplanetary event had very different statistics to smaller events. As Echer et al. (2011) stated: "**The physics associated with them may be different...**" (Echer et al., 2011, p. 1458).

Thus, the largest events so far observed are apparently subject to another step change in the mechanism involved.

The Magnitude of Solar Eruptive Events

a. Present-day events

The question of whether another Carrington event is likely to be repeated or exceeded has become significant in today's technological society, especially after the power grid failures in Quebec caused by the March 1989 storm. "This storm caused the Hydro-Quebec power grid to go down for [over] nine hours" and caused a loss of around half a *billion* dollars. (Tsurutani, 2003, p. 5)



Echer et al. (2011) developed an equation for the probability of an event of a given magnitude occurring, based on the statistics for small events. They asked: "An obvious question is ''can one use these distributions to predict the occurrence frequency of extreme events, such as the Carrington event?"

Unfortunately not, they continued, because "It was shown that by using the statistics presented here, the Carrington event would have been extremely rare." (ibid., p. 1458)

It appears that the step changes in the coupling function preclude statistics from one data set being applied to another data set for events of a higher energy.

The problem is, as Tsurutani et al. (2003) noted, "Our time span of observations has been quite limited, only hundreds of years, and it is therefore doubtful that we have detected either flares or magnetic storms at the limit." (ibid., p. 7).

So just how energetic are the solar eruptions we've observed so far?

Magnitude of Solar Eruptions

Energy, ergs

	Frequent	Max. Observed	Max. Possible ?
CMEs	10^{30} - 10^{32}	~7 x 10^{33}	
Solar Flares	10^{29}	~ 5 x 10^{32}	

b. Evidence for massive solar eruptions in the past

Solar flares and CMEs often occur together so we will look at both.

CMEs of 10^{30} – 10^{32} erg occur at a rate of ~1 per day. The CME associated with the flare of 4 November 2003 may have had an effective energy of ~7 x 10^{33} erg, similar to the Carrington event.

A typical solar flare emits ~10^{29} erg in radiant energy in the visible spectrum. More energetic ones generate X-rays. There were 11 X-ray flares between 18 October & 5 November 2003, some of which emitted up to ~ 5 × 10^{32} erg. This clustering of events is not uncommon.

The ratio of flare and CME energies varies between events. Ponomarenko *et al* (2007) suggested that the total energy of medium-size solar eruptions is shared equally between CMEs and flares. Examples occurred on both 21 April & 23 July 2002, when 10^{32} erg CMEs were ejected with flares of the same magnitude.

But Emslie *et al,* (2005) showed that the energy of CMEs often exceeds that of the associated flares; and Lingenfelter & Hudson (1980) argue that more energetic eruptions may convert a larger proportion of their energy into a CME.

So a CME is likely to be at least as energetic as a flare associated with it.

Magnitude of Solar Eruptions

Energy, ergs

	Frequent	Max. Observed	Max. Possible ?
CMEs	10^{30} - 10^{32}	~7 x 10^{33}	
Solar Flares	10^{29}	~ 5 x 10^{32}	10^{38}
Stellar Flares		10^{33} - 10^{38}	

Looking at other stars, Hawley & Pettersen (1991) suggested that flares from stars similar to our Sun may simply be scaled-up versions of their solar counterparts. Schaefer et al (2000) identified “nine cases of superflares with energy of 10^{33} - 10^{38} ergs on normal solar-type stars”.

Referring to this finding and the known solar data, Smith & Scalo (2007) concluded: “… we believe it reasonable to infer that much more energetic **solar** flares have occurred in the past” (*ibid.* p6). They estimated that a 10^{38} erg flare may have been emitted by the Sun about once every 200,000 years.

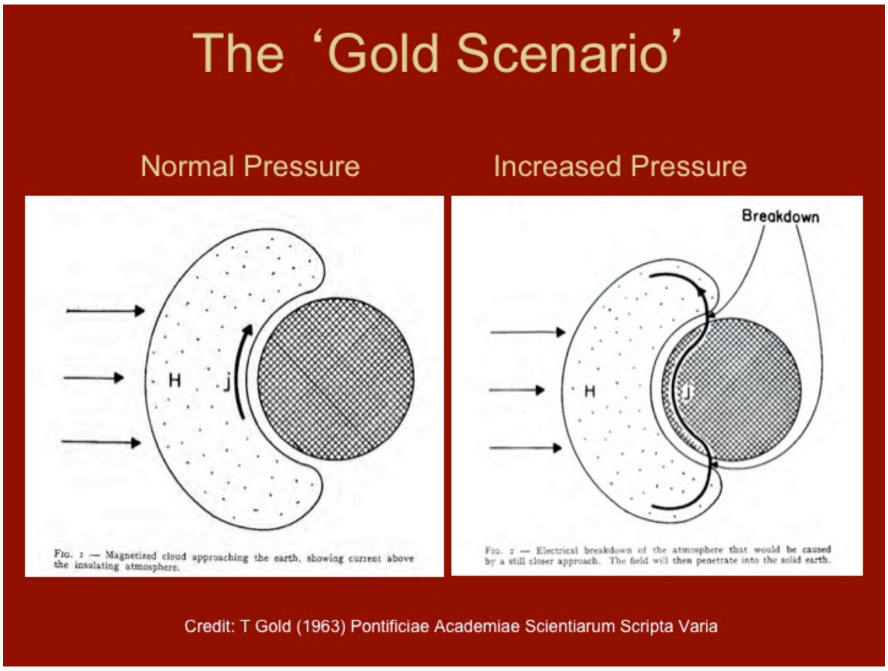
Magnitude of Solar Eruptions

Energy, ergs

	Frequent	Max. Observed	Max. Possible ?
CMEs	10^{30} - 10^{32}	~7 x 10^{33}	> 10^{38}
Solar Flares	10^{29}	~ 5 x 10^{32}	10^{38}
Stellar Flares		10^{33} - 10^{38}	

Because more massive eruptions convert a larger proportion of their energy into CMEs, we should expect a CME of at least 10^{38} erg with such an energetic flare.

So what effects might be expected from a CME up to 10,000 times more energetic than the largest events observed in the present era?



c. The 'Gold scenario'

Back in 1962, the astronomer Thomas Gold considered what effect a more massive solar eruption would have on the Earth's immediate environment. In the scenario outlined by Gold, the increased solar wind pressure would drive the inner edge of the Earth's [outer] magnetosphere down into the upper atmosphere.

Because the atmosphere is a good insulator, the electric currents which are generated in this region then encounter great resistance.

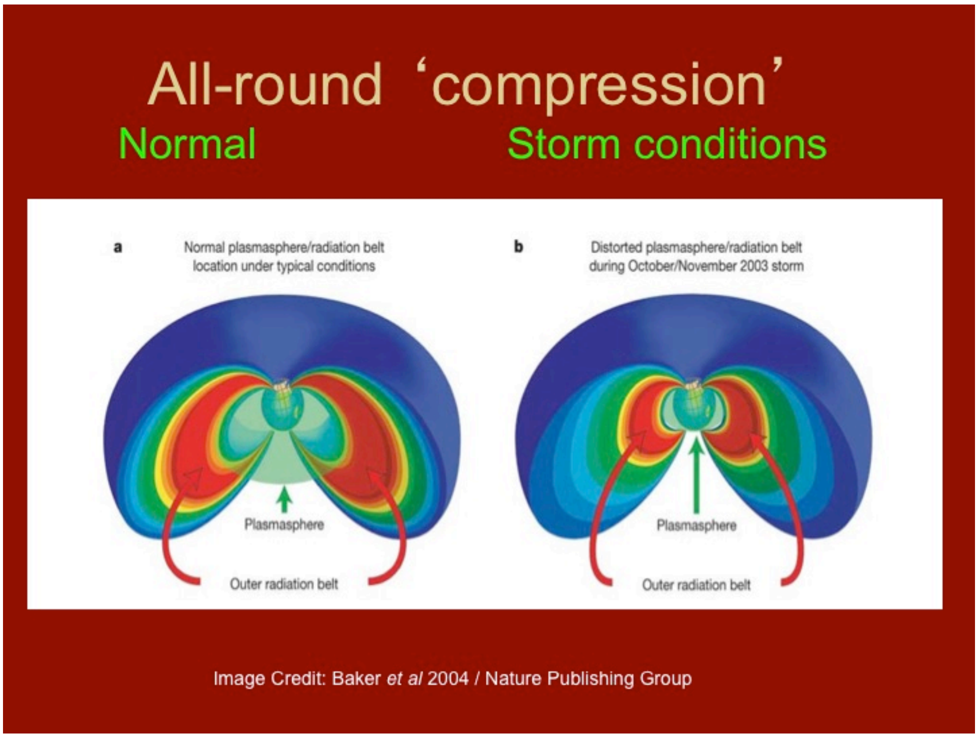
In this circumstance, the path of least resistance is to short down in a massive and continuous 'lightning strike' or discharge through the atmosphere, run through the more conducting surface of the Earth, and short back up to the magnetosphere in a second discharge to close the circuit, as shown in these figures from his paper.

Tony Peratt's 2003 paper on the similarities between petroglyphs and structures in plasma z-pinches was based on Gold's work. However, in contrast to Peratt's interpretation of a Birkeland Current above the south pole, I suggest that under the Gold scenario, currents of "hundreds of millions of Amps" would run in the surface of the Earth between the points of discharge.

The basic principles of Gold's mechanism have been confirmed by more recent investigations. Alfvén (1981) detailed the mechanism underlying the resulting current flows in a conducting plate when a drifting plasma impacts the plate (ibid., Ch.3, p46, Fig. III.1(c)); the plate is equivalent to the Earth's surface in the Gold scenario.

It has also now been confirmed that compression of the magnetosphere is a direct result of enhanced solar wind pressure. For example, Odenwald and Green (2008) showed that the pressure of the Carrington Event probably forced the magnetopause down from its normal distance of ~60,000 km above the surface to ~7,000 km or perhaps lower.

Gold considered that the ram pressure of the solar wind would only compress the magnetosphere on the Sunward side, and so discharges would occur only on that side.



However since Gold's paper in 1962, space missions have established that the mechanism of compression involves plasma draining from the whole of the inner magnetosphere, resulting in shrinkage or compression around the entire globe (Baker et al., 2004). Under these conditions, the discharges to Earth would no longer be confined to the dayside and could occur at any longitude, that is, at any time of day or night.

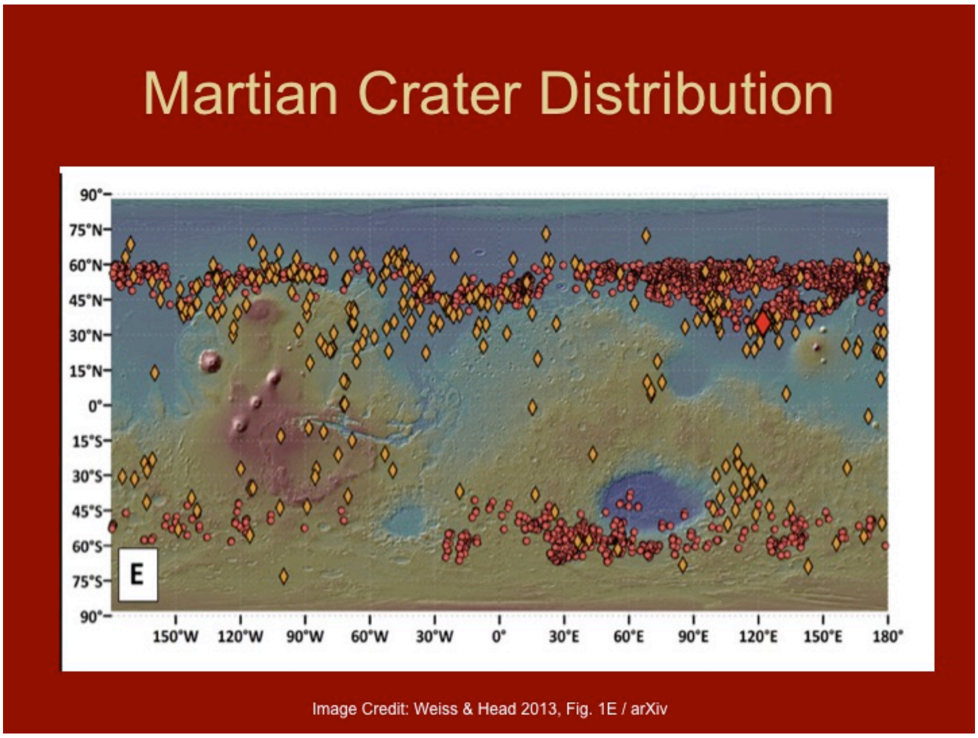
This 'extended Gold scenario' involves a very significant step change in the physics of the coupling mechanism. A further step change is also possible.

Gold considered that the atmosphere would retain its insulating properties during a compressive event and the discharge would have to 'short' through it to reach the conductive surface.

But, as Akasofu (1981b) stated: "The ionosphere .. can be considered as the transition region from a fully ionised magnetospheric plasma regime to the neutral atmosphere regime." (ibid., p1135). Extreme compression of the magnetosphere into the atmosphere would intermix the two regions, introduce charged particles into the atmosphere, and render it conductive.

Under these circumstances, discharges directly to the surface become even more likely, and massive currents would flow unhindered through the Earth's surface, exactly as in Alfvén's conducting plate.

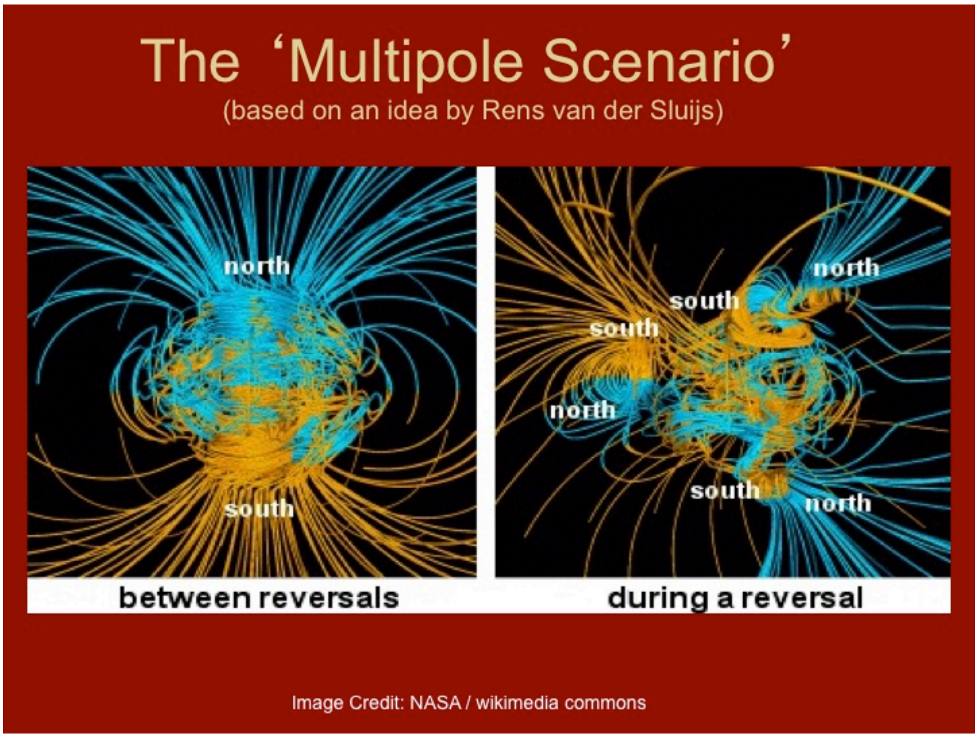
Because currents follow the magnetic field lines in plasma, the discharges to the surface would still tend to occur preferentially at higher latitudes if the Earth's dipole field was unaffected.



Interestingly, the distribution of craters on Mars is heavily concentrated between latitudes 40 and 65 degrees in both the Northern and Southern hemispheres (Weiss and Head, 2013 Fig. 1E), perhaps indicative of a similar process there in the period when Mars still had a magnetic field (Lillis et al., 2007; NASA, 2001).

Back on Earth, one effect of a CME is to enhance the equatorial Ring Current, which generates a magnetic field opposite to the Earth's dipole field and reduces it; this is what is measured by the D_{st} index (Sandel et al., 2003; Wolf, 1997).

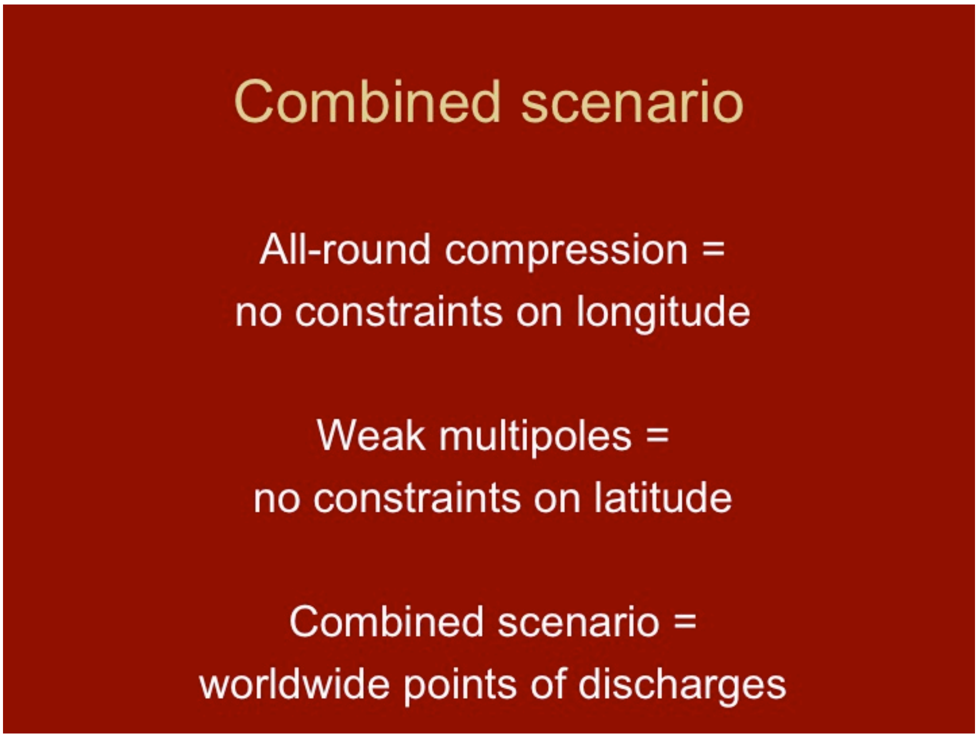
This effect would allow Rens van der Sluijs' 'multipole scenario' to operate.



d. The 'multipole scenario'

The dipole field is only one component of the Earth's total magnetic field. The spherical harmonic equations describing the complete magnetic field pattern have additional components known as the quadrupole (4-pole) and octupole (8-pole) fields. Normally, these 'multipole' components are dominated by the dipole component but if the dipole component was largely or completely neutralised by an enhanced ring current then the multipole components would define the remaining field. This is what happens during a magnetic reversal.

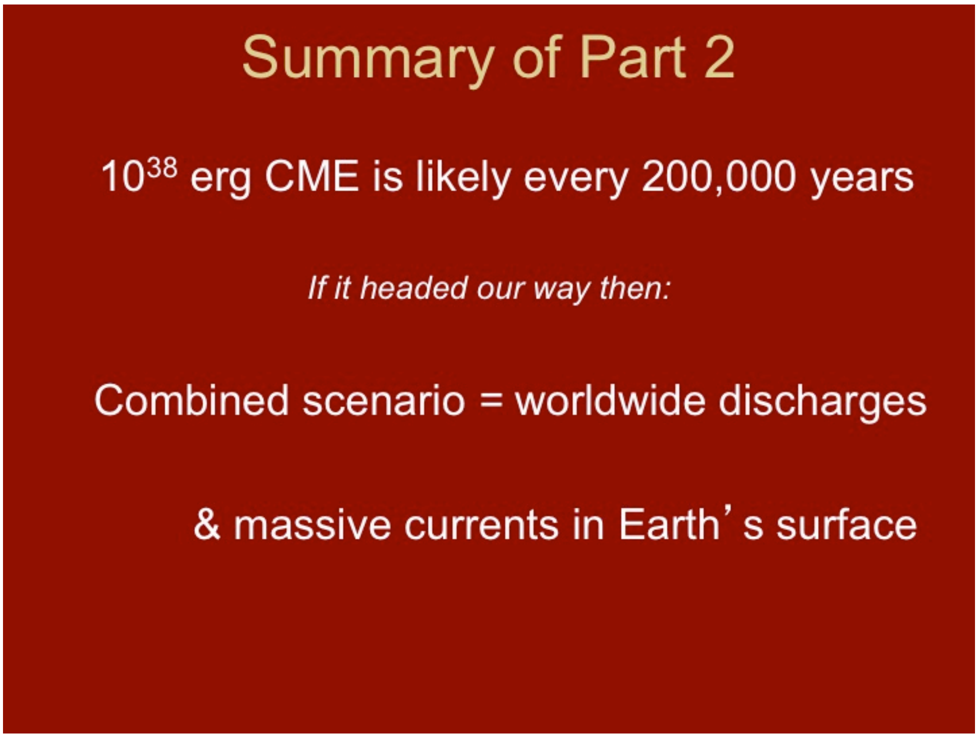
Under the multipole condition, discharge currents would no longer be constrained to higher latitudes by the dipole field and could occur between any two multipole locations at any latitude, as Rens & I outlined in a paper published last year. Combined with the worldwide compression of the magnetosphere, this implies that the discharge currents to the surface may strike at any geographic locations, depending only on the multipole locations at the time.



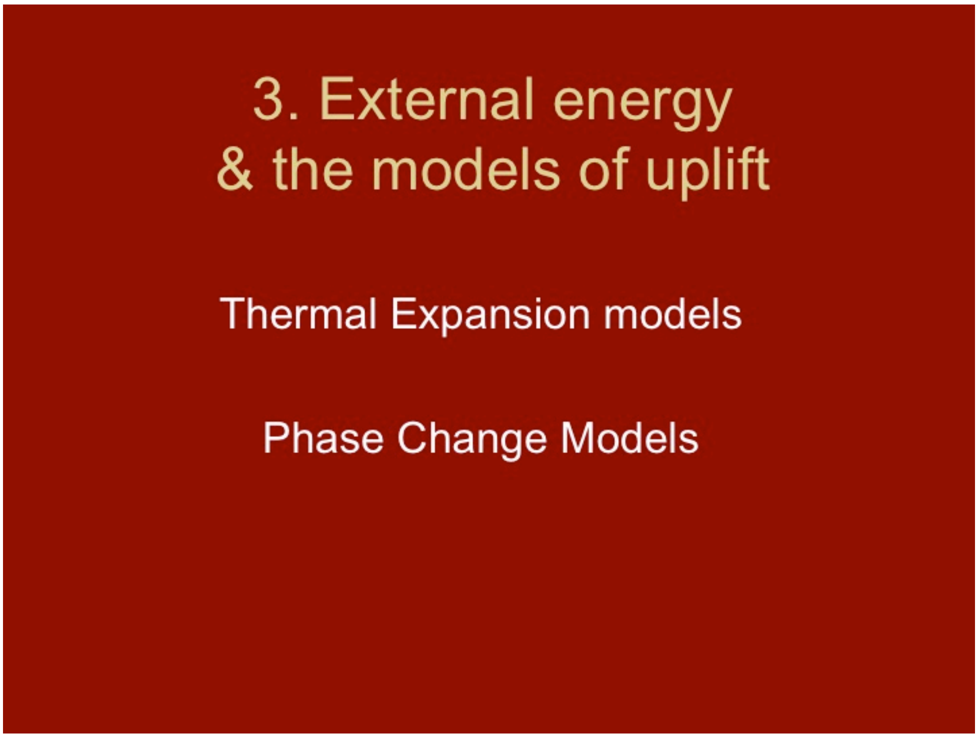
But if the multipole components were too weak to influence the path of the current, then there would be no constraints at all on the discharge locations. A combination of the ‘all-round compression Gold scenario’ and the ‘weak multipole scenario’ could allow discharge currents to occur at any latitude or longitude, day or night.

The energy delivered by these currents running through the Earth’s surface would have been many orders of magnitude greater than the energy in the weak induced Telluric Currents observed today.

No data is available for the geoefficiency under the combined scenario. But it’s clear that if only a small proportion of the CME input energy is coupled to the Earth’s surface, then a 10^{38} erg CME would result in large amounts of energy reaching the ground in the form of discharge currents.



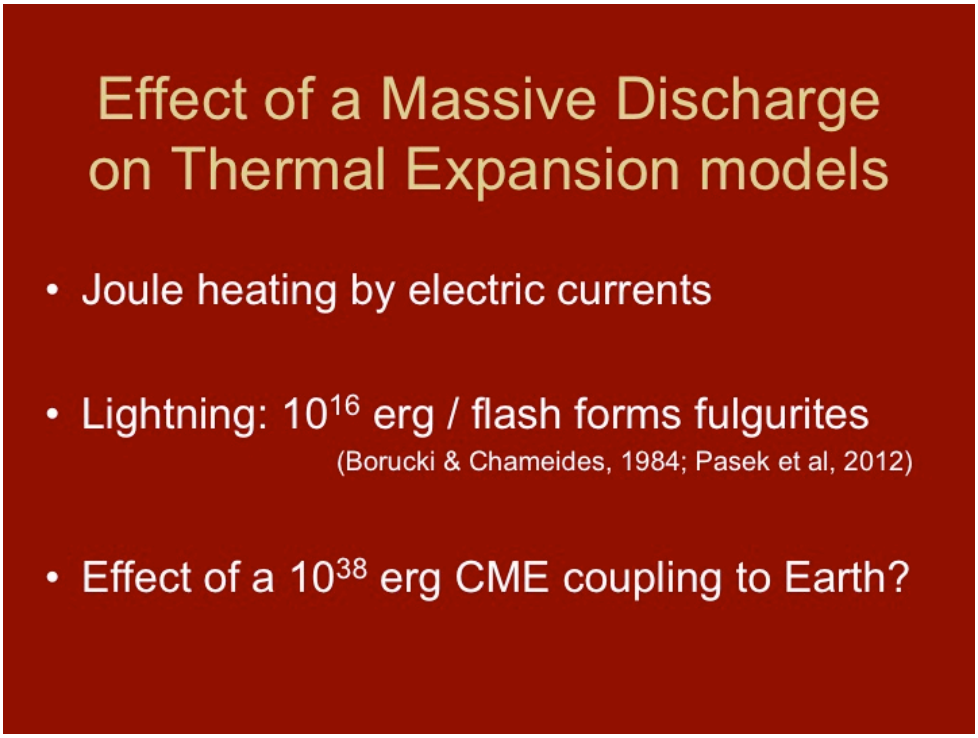
So to summarise Part 2: a 10^{38} erg CME is likely to have occurred once every 200,000 years; if it headed our way, a combination of all-round compression in the Gold scenario with the weak multipole scenario could have resulted in direct discharges anywhere on Earth. These discharges would be linked by massive currents in the Earth's surface.



That brings us to Part 3 of this talk: how does the external energy relate to models of uplift?

The effect of a massive discharge current in relation to the models of uplift

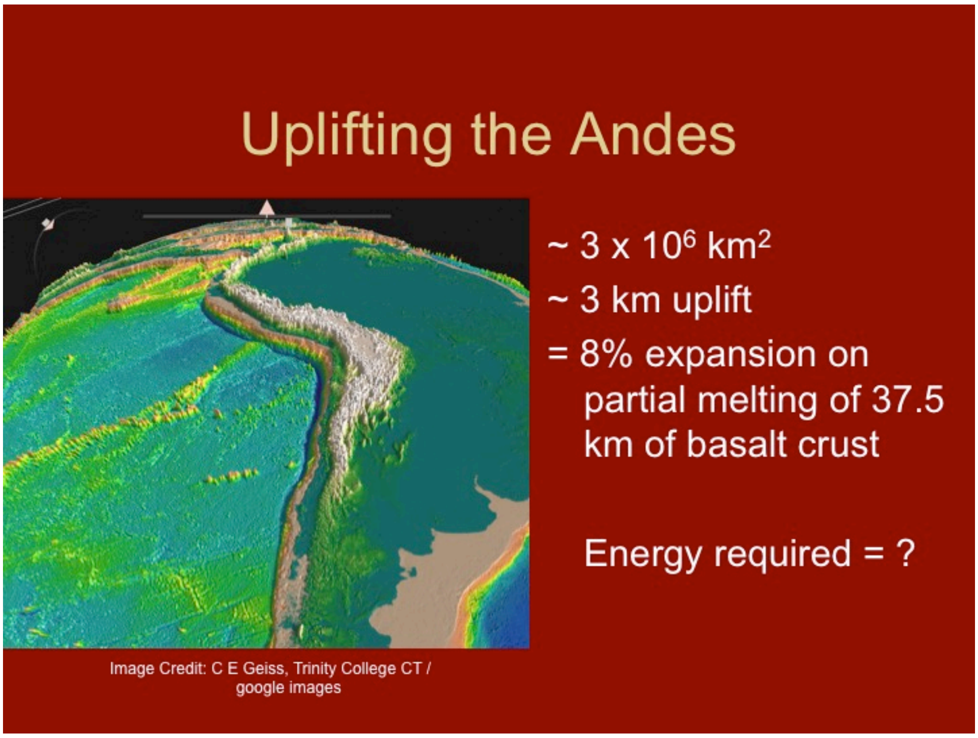
We'll start with the Thermal Expansion models.



a. Thermal expansion models

Any electric current encountering resistance dissipates energy in the form of Joule heating of the conductor. Lightning dissipates up to 10^{16} erg per strike (Borucki and Chameides 1984). As these small discharges can form partially-fused fulgurites (Pasek, Block & Pasek, 2012), we must ask what effect could be expected from a discharge current due to a 10^{38} erg CME.

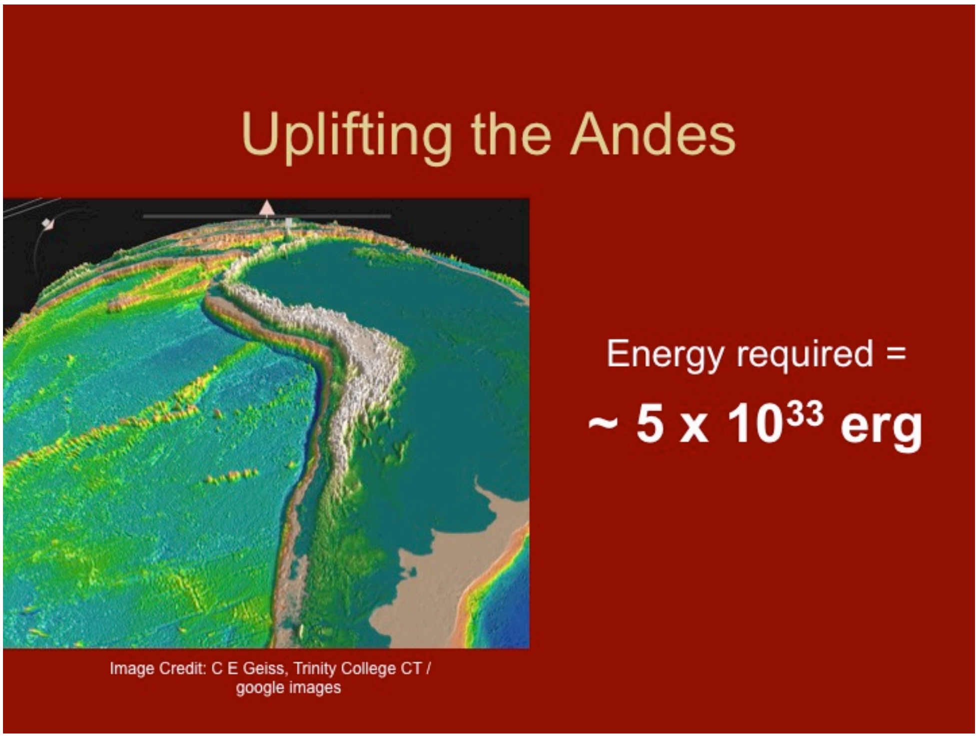
The central hypothesis of this talk is that energies of this magnitude could contribute to tectonic uplift. So let's estimate the energy required to uplift the Andes by a typical thermal expansion model.



The Andes cover an area of ~ 3 million square km; they have been uplifted by about 3 km on average (Ollier & Pain, 2000 pp112-116). The uplift has occurred in a block bounded by vertical faults, so we only need to consider the crust directly under the uplifted area.

One thermal expansion model assumes that uplift could be due to the 8% expansion of basalt on partial melting (Ollier & Pain, 2000, Table 12.2). To generate an uplift of 3 km would require 37.5 km depth of basaltic crust to be partially melted.

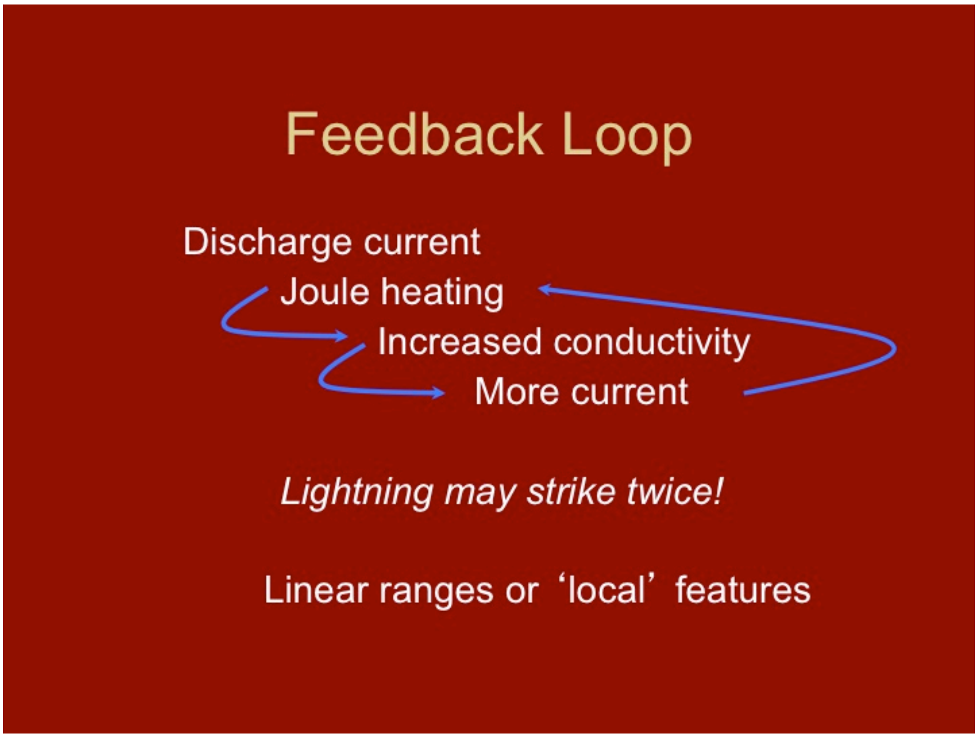
Assuming typical values for the relevant parameters, the energy needed to *fully* melt the basalt under the entire Andes is …



~5 x 10^{33} erg !

Compare this figure to the 10^{38} erg energy in a massive CME: you can see that only a very small part of the CME energy needs to couple to the Earth's surface to cause uplift by thermal expansion.

And the discharge current will probably form long, narrow mountain ranges.



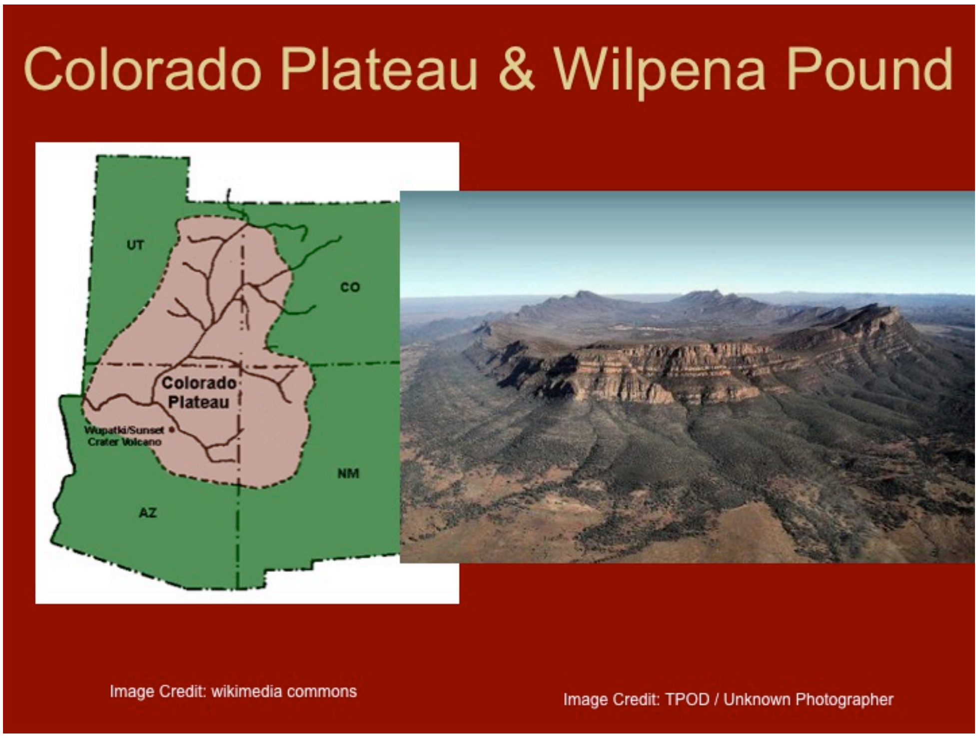
The reason for this lies in the well-known relationship between temperature and electric conductivity of rocks. For example, "partial melting of 1% can produce increases of up to two orders of magnitude in electric conductivity" (Towle, 1980 p628).

That means there will be a feedback loop; the heating from the start of the discharge increases the conductivity and attracts more current, especially whenever the rise in temperature is sufficient to cause partial melting.

The residual heating and increased conductivity from one discharge will attract subsequent discharges to the same paths. Perhaps lightning does strike twice after all!

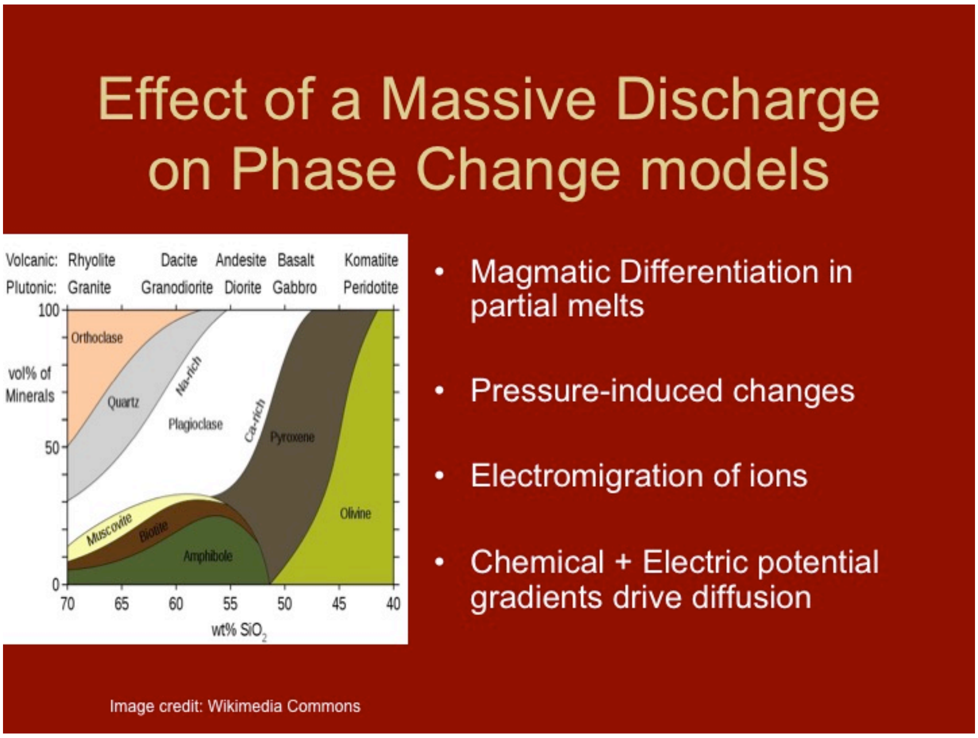
The feedback loop will automatically concentrate the electric currents into narrow channels and mountain ranges will often be the result.

In other cases, the discharge may be dissipated in the surface rather than forming a complete current path back to the magnetosphere. In these cases, the surface feature will be localised around the point of discharge.



The energies involved could have been sufficient to have contributed to the enigmatic 2 km uplift of the Colorado Plateau; the shape of the plateau is very similar to Wilpena Pound shown in the picture on the right, in which you can clearly see the saucer shape with the edges raised even higher than the centre. The same forces seem to have been at work in both cases.

If discharges can contribute to thermal expansion models, can they also contribute to phase change models?



b. Chemical phase change models

Bowen & Tuttle worked out the chemistry of phase changes in partially-melted rocks. This is called the 'chemistry of magmatic differentiation' and it happens automatically whenever rocks are partially melted. Both the melt and the remaining solid fractions can be altered.

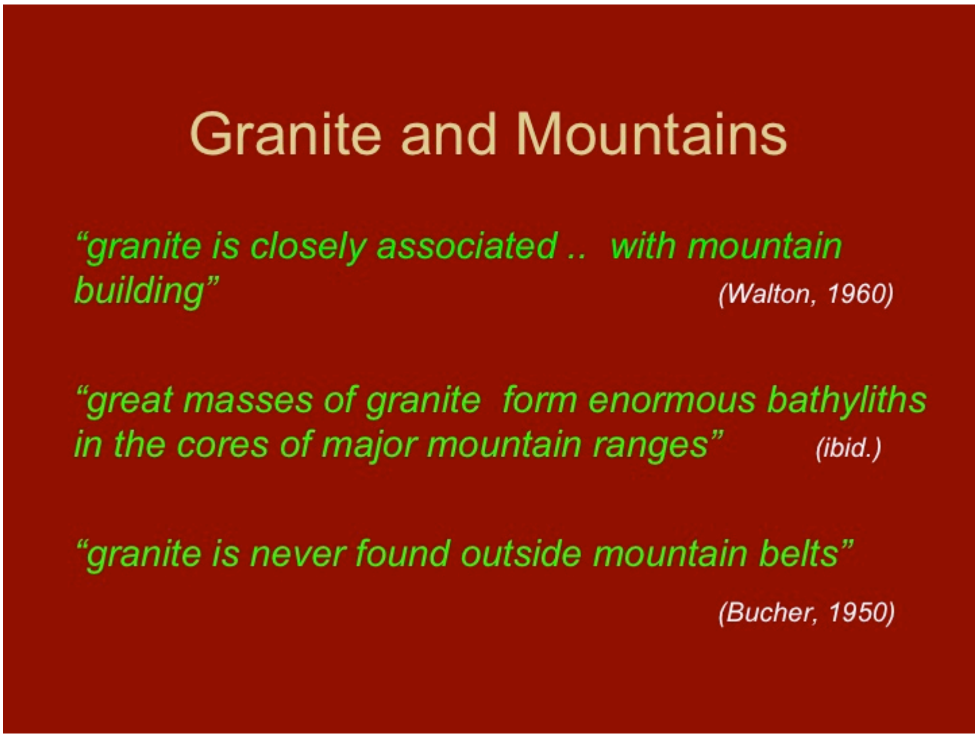
Also, phase changes can arise from extremely high pressures. In the present hypothesis, high pressures will arise due to vaporization of minerals and any water present along the electric current channel.

Electromigration theory shows that the strong electric fields associated with a discharge would drive rapid ion diffusion within the partially melted rock. There is plenty of evidence that ions are present in rocks, and especially in silicates which form the bulk of the crust.

The fact that silicates are semi-conductors is all we really need to know!

What the present hypothesis adds is an occasional source of strong electric fields to mobilize these ions. Diffusion of ionised elements will then be driven by both the chemical concentration gradient and the electric potential gradient.

So phase changes will almost certainly accompany electric discharges, as we see on a tiny scale in fulgurites formed by lightning strikes. What's more, the formation of granite may be a result of the same process.

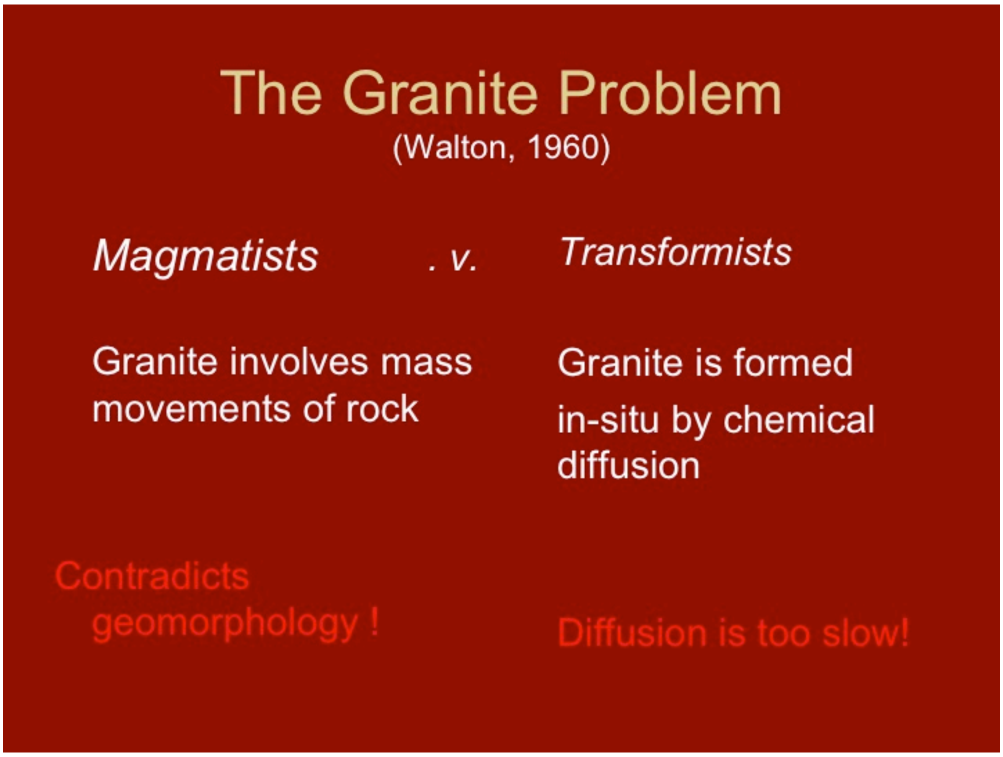


c. The formation of granite

Granite and mountains always occur together. Walton (1960) said:

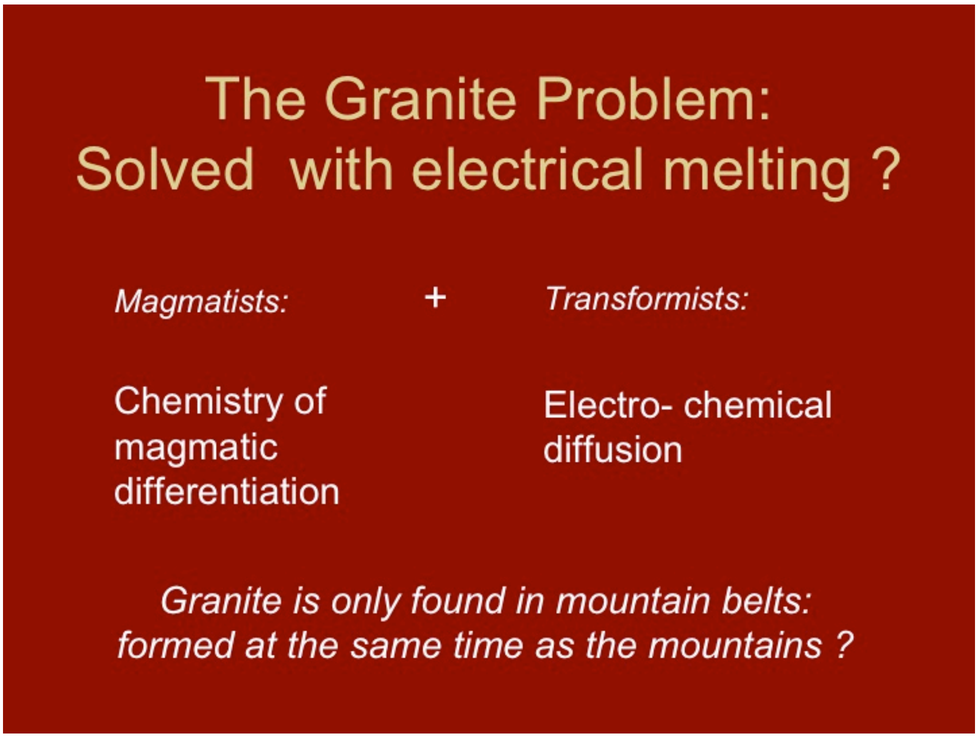
"With trivial exceptions, granite is closely associated .. with mountain building " .. and ".. great masses of granite … form enormous bathyliths in the cores of major mountain ranges." (ibid. p635-6).

In contrast, Bucher stated that granite is never found outside mountain belts (ibid, 1950 p37). The formation of granite is one of the most contentious occurrences of phase changes in geology.



According to Walton (1960), the debate about the granite problem eventually polarised around two opposing positions; magmatists knew their chemistry and argued that mass movements of rock were necessary to deliver the heat to partially melt the strata so that magmatic differentiation could occur. OTOH, transformists knew their geology and argued that the geomorphic evidence often precluded such movements; they argued instead that granite must have been formed in-situ by chemical diffusion.

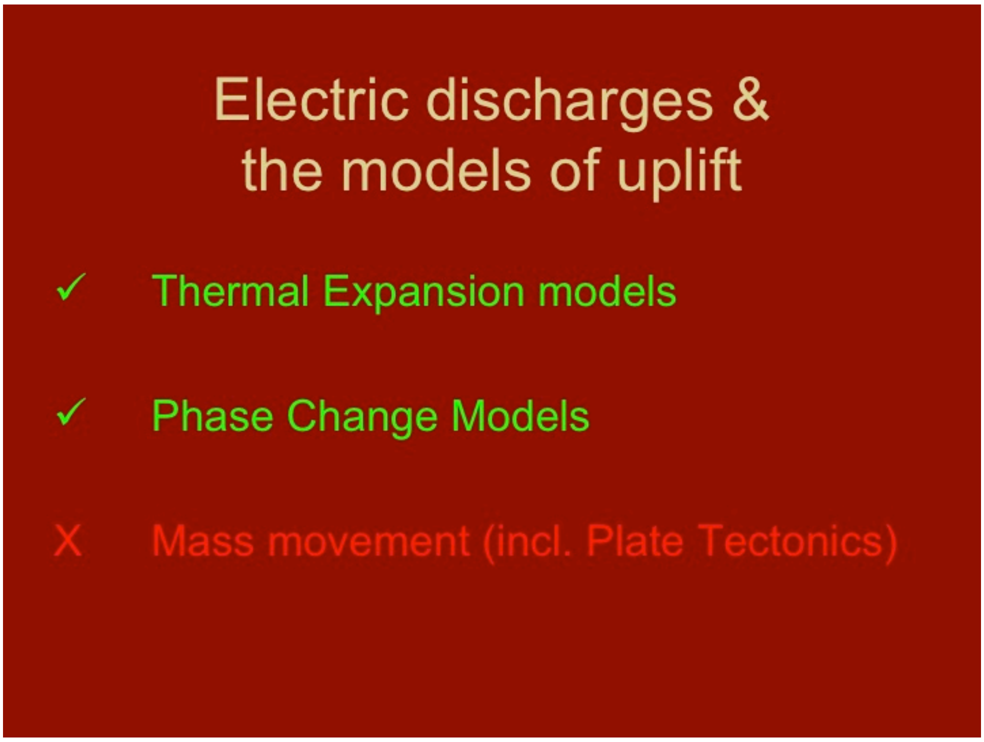
But transformism suffered from the lack of evidence that the necessary diffusion could occur in rock. The real problem was that all the evidence suggested that chemically-driven diffusion rates were far too slow to achieve granitization, even in geological timescales. So the situation reached an impasse.



In the present scenario, massive discharge currents through existing strata would partially melt the rocks and cause very rapid electrically-driven diffusion. That means that the magmatists' chemistry and the transformists' geology could both be satisfied, and granite could be formed in situ along the line of the discharge currents.

This model would also help to explain the association of granite with mountain belts. They were probably both formed by the same discharge.

The fact that "granite is almost unknown in the great ocean basins" (Walton, 1960 p636) could also be evidence in support of the present theory. It is likely that there are fewer electric currents in undersea strata because discharge currents will flow preferentially in the conductive seawater.



It appears that massive electric discharge currents could contribute to uplift by two of the three groups of conventional models, that is thermal expansion and chemical phase change models. But does uplift due to heating by electric discharge currents from CMEs fit the geological evidence of mountain building?

Constraints on Possible Models

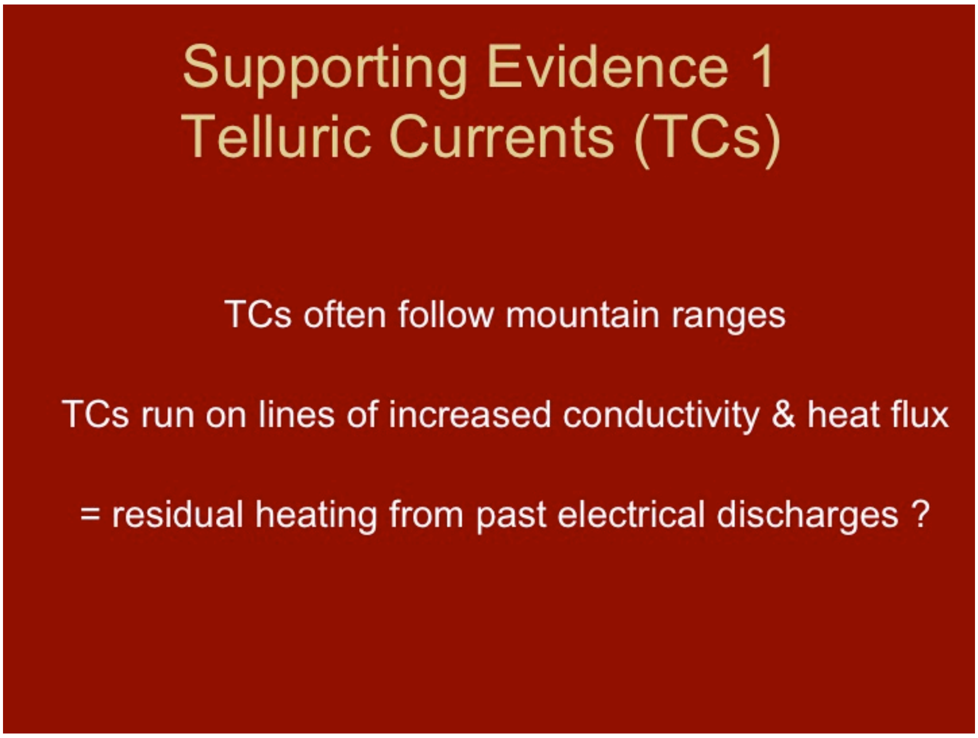
Ollier & Pain (2000) show that there is geomorphic evidence for a major worldwide phase of uplift within the last 5 million years. Models of uplift must be able to explain this.

Ollier & Pain list three constraints on the models:

- "Synchronism of mountain building .. over a large area of the world";
- "Uplift occurred over a relatively short and distinct time"; and
- "Some Earth process switched on and created mountains after a period with little or no significant uplift" (*ibid.*, p303).

This is exactly what we would be expected from massive discharge currents arising from one or more solar eruptions in the past. Nearly simultaneous discharges would be distributed worldwide; the uplift would occur over a short period; and the rarity of the most massive solar eruptions implies long quiet periods between events.

So the present hypothesis meets all three constraints. From our perspective, Ollier & Pain's use of the term "switched on" in their third constraint seems curiously prescient.



Evidence in support of the electric discharge hypothesis

To finish off, I want to look at some other evidence in support of the present hypothesis.

a. The route of present-day Telluric Currents

Anomalous Telluric Currents arise during magnetic storms. For example, Porath & Gough (1971) identified "concentrations of electric current flowing north-south under the Southern Rockies and the Wasatch Mountains" during geomagnetic storms in 1967 (*ibid.* p272).

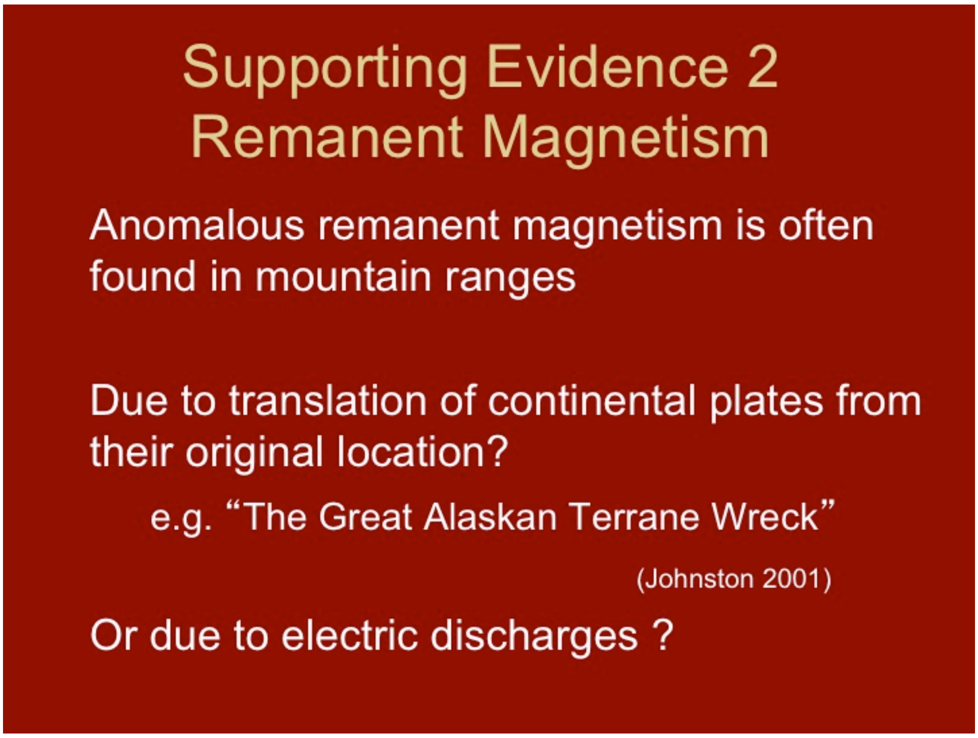
This concentration of Telluric Currents along the line of mountains is not unusual. Other examples in the North American continent include the Canadian Rockies (Bingham, Gough & Ingham, 1985), the Sierra Nevada (Park *et al,* 1996) and the Oregon High Cascades (Stanley, Mooney & Fuis, 1990); elsewhere, examples include the Great Escarpment in Southern Africa (de Beer, van Zijl & Gough, 1982); and the Flinders Range (Gough, Lilley & McElhinney, 1972) and Otway Range (Lilley, 1975) in Australia.

TCs follow the zones of increased conductivity (Porath, 1971). The relationship between increased conductivity and unusually high heat flow is well established; the source of anomalous heat flux is once again assumed to be the mantle.

However, if the present hypothesis is valid then the route of TCs may be indicative of residual heating associated with the past discharge events.

Of course, not all TCs follow mountain ranges. But the number of alignments of increased conductivity with mountain ranges and escarpments does appear to be significant.

The issues are even more clear-cut in the case of remanent magnetism.



b. Remanent magnetism

As is well known, rocks cooled below their Curie point retain an imprint of the magnetic field present at that time. Anomalous remanent magnetism is often found in mountain ranges, for example in the Canadian Cordillera (Enkin *et al,* 2000); the Elkhorn Mountains (Diehl, 1991); and the Rockies themselves (Irving et al, 1986).

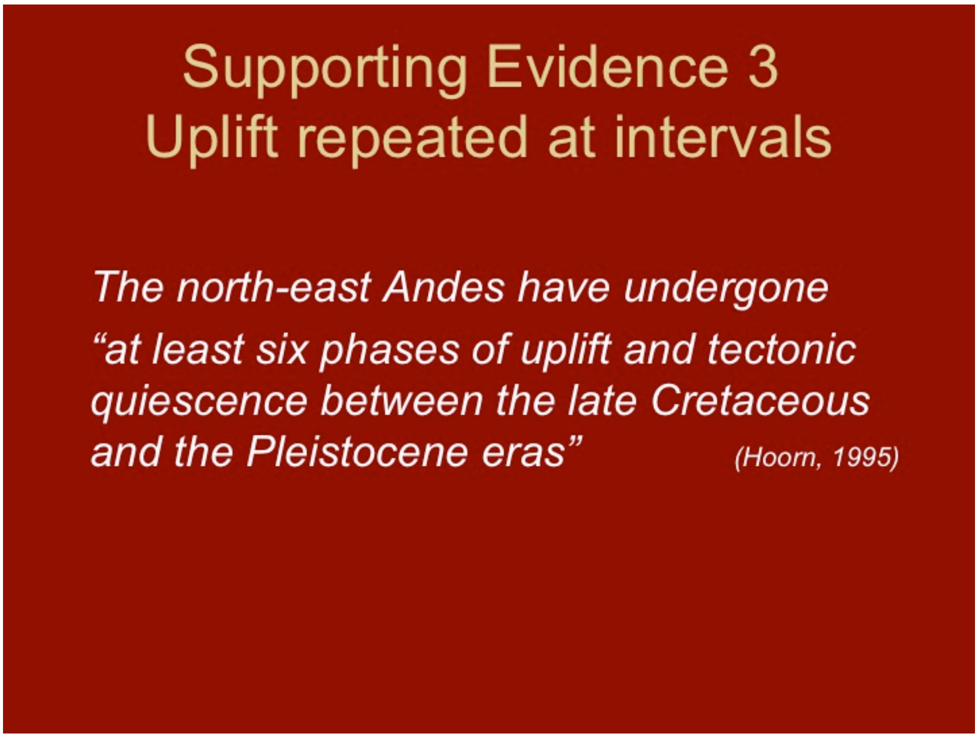
Under present geological models, this anomalous magnetism can only have arisen from the Earth's natural dipole field and must indicate tectonic movements from the location where the magnetic field had the appropriate value. The tectonic explanations involve immense movements, often in different directions.

For example, in the case of the Andes, Roperch et al, (2000) conclude that "there is a consistent pattern showing counter-clockwise rotations to the north and clockwise to the south" of around 30° (ibid. p795).

In the case of the Alaskan ranges, the situation is so confused that Johnston (2001) referred punningly to "The Great Alaskan Terrane Wreck" !

The solution may be that at least some of the remanent magnetism could be due to massive electric discharge currents which caused temporary partial melting.

The implications for the study of palaeomagnetism would be significant.

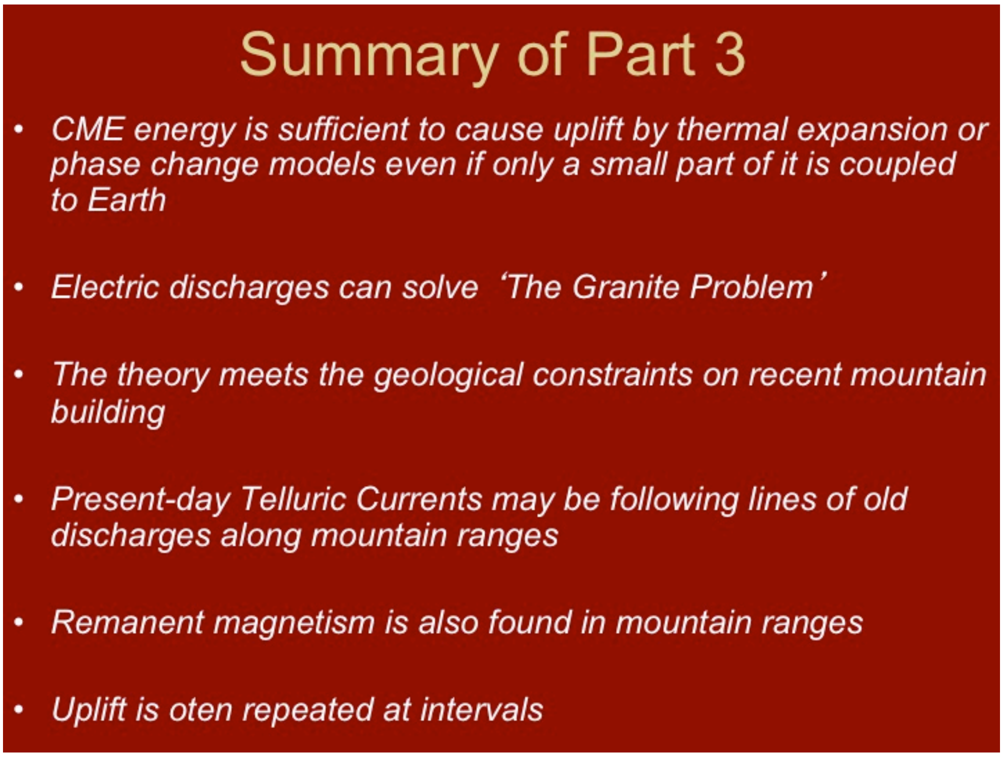


c. Uplift occurring in stages

Thirdly, uplift is often repeated at intervals. For example, the north-east Andes have undergone “at least six phases of uplift and tectonic quiescence between the late Cretaceous and the Pleistocene” eras (Hoorn, 1995, quoted in Ollier and Pain, 2000, p. 114).

Occasional solar eruptions can easily explain uplift repeated at intervals. Uplift of the same regions will occur in subsequent discharges because the currents will tend to follow the same paths due to residual heating and increased conductivity from previous events.

So the evidence supports the hypothesis.



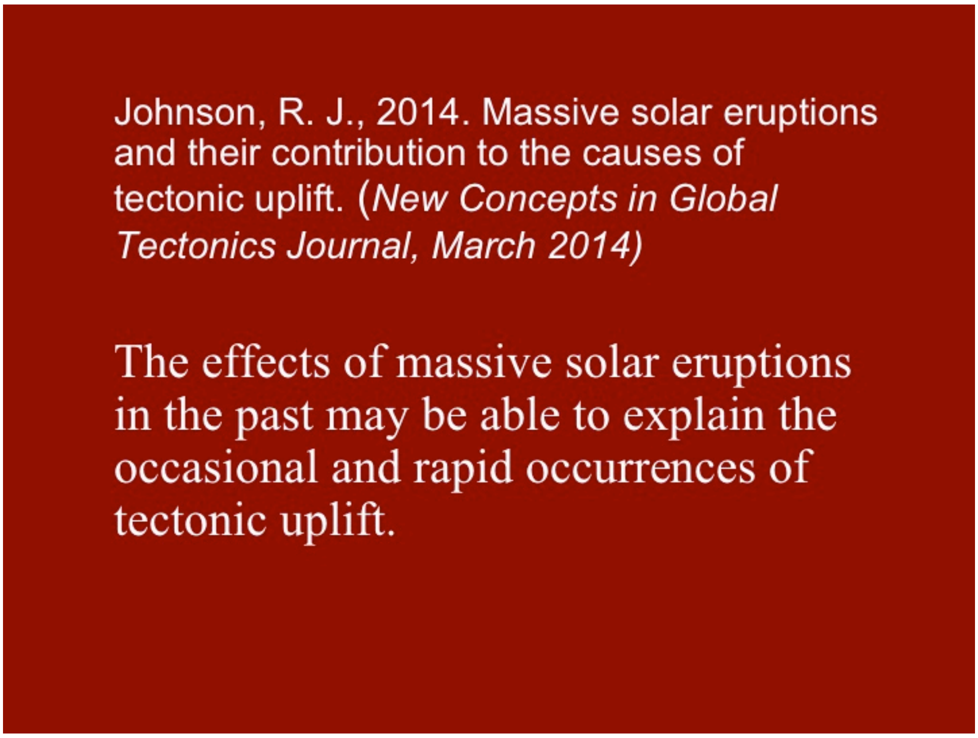
To summarise Part 3:

The coupled energy from a CME is sufficient to cause uplift by thermal expansion or phase change models even if only a small part of it is delivered to the Earth's surface

Electric discharges can solve 'The Granite Problem' by reconciling the chemistry and the geology

The theory meets Ollier & Pain's geological constraints on recent mountain building

Other evidence in support of the theory includes present-day Telluric Currents, which may be following lines of old discharges along mountain ranges; remanent magnetism, which is also found in mountain ranges but is difficult to explain by movements of continental plates; and uplift repeated at intervals.



Conclusions

We've covered a lot of ground very quickly in the last hour or so. More details can be found in my 2014 paper published in 'New Concepts in Global Tectonics' Journal for anyone who would like to know more.

The take-home message for today is that the effects of massive solar eruptions in the past may be able to explain the occasional and rapid occurrences of tectonic uplift.

As Derek Ager said, "geological history is like the life of a soldier: long periods of boredom and short periods of terror" (Ager, 1973).

Could this be the explanation?

Thank you for listening.

****

Acknowledgements: The 'multipole scenario' discussed in this talk is based on an original idea by M. A. van der Sluijs contained in a forthcoming work which the present author has been privileged to have had advance sight of.

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Appendix I. Consideration of the possible effects on the Earth's orbit

A reviewer of an earlier draft of [the published] paper questioned whether a CME of 10^{38} erg energy would change the Earth's orbital parameters either because of the kinetic energies involved, or because magnetic forces are potentially much stronger than gravitational forces. These questions are addressed below.

The impact of the normal solar wind on the magnetosphere does not cause a change to the Earth's orbit because the forces are extremely small. Dryer & Faye-Petersen (1966) calculated that the total drag from the solar wind amounted to ~ 4 x 10^{11} dynes, or ~ 4 x 10^{6} N; this amounts to ~1 part in 10^{16} of the gravitational force on the Earth from the Sun which is given approximately by GMm/R^2 = ~ 3.5 x 10^{22} N (NASA, 2102).

The normal solar wind contains numerous CMEs of between 10^{31} - 10^{32} erg energy emitted on an almost daily basis (see above) which do not affect the orbit. Similarly, the ~ 10^{2} times as large CME of November 4, 2003 with energy estimated at ~ 7 x 10^{33} erg (Ponomarenko *et al,* 2007) had no measurable orbital effect. Even an event 10^{6} as large as a typical daily CME would only generate a force of ~1 part in 10^{10} of the gravitational attraction and so would not be expected to significantly alter the Earth's orbit, even if all the energy was in the form of kinetic energy.

As a very worst case scenario, suppose that the entire energy of a massive 10^{38} erg CME was in the form of kinetic energy and further suppose that this energy was transmitted with 100% efficiency to the Earth's orbital parameters rather than being largely dissipated in Joule heating by electric currents as normal. Under these worst case limiting assumptions, the Earth's orbital energy, given by -GMm/2R = -2.67 x 10^{40} erg (NASA, 2102), might change by ~1 part in 250; under the limiting case assumptions above, and if this energy was converted to an orbital change rather than to a change in the planet's rotation rate, a equivalent ~1 part in 250 change in the radius of the Earth's orbit could have occurred. Thus, under these worst case limiting assumptions, a 0.4% change in the Earth's orbit is theoretically possible due to a 10^{38} erg CME impacting the Earth. Realistically, any effect would have been much smaller because firstly, the coupling efficiency is unlikely to have been 100%; and secondly, most of the energy would have been dissipated in Joule heating, not a change to the orbital energy.

Turning to the second point, a magnetic force between the Earth's magnetosphere and an incoming CME carrying a magnetic field would cause an equal and opposite reaction force on the CME; the kinematic effect on the body of the Earth depends on the relative inertial masses of the Earth and the CME. The mass of a present-day CME is of the order of 10^{16} g (see above) i.e. 10^{13} kg; the mass of the Earth is ~ 6 x 10^{24} kg (NASA, 2102), i.e. a factor of 6 x 10^{11} higher. In essence, this is why the normal solar wind is diverted around the Earth without affecting its orbit.

A typical present-day CME has an energy of 10^{32} erg (see above). In order to estimate the maximum possible mass of an incoming CME, suppose that the 10^{6} order-of-magnitude increase in a 10^{38} erg CME was due entirely to additional kinetic energy, given by $mv^2/2$; and further suppose that both the mass and the velocity had increased by a factor of 100. (This is a conservative assumption for the present estimate because the velocity of CMEs is known to vary over a greater range than their mass – see above.) Under these limiting assumptions, the mass of a 10^{38} erg CME might reach ~10^{15} kg; this is still insignificant compared to that of the Earth. Therefore the kinematic effects due to magnetic forces of a CME 10^{4} times as energetic as the largest measured to date (~7 x 10^{33} erg) will be confined to the CME and kinetic effects on the magnetosphere, and will not measurably change the Earth's orbital parameters.

In summary, the principal effect of an incoming CME is to generate electric currents in the magnetosphere and, under the scenarios discussed in this paper, the body of the Earth itself. The majority of this energy will be dissipated as heat in the surface of the Earth and in the atmosphere and magnetosphere above it and would not be expected to cause significant orbital changes. The effects on the body of the Earth would be limited to the crustal layers in which the currents ran.