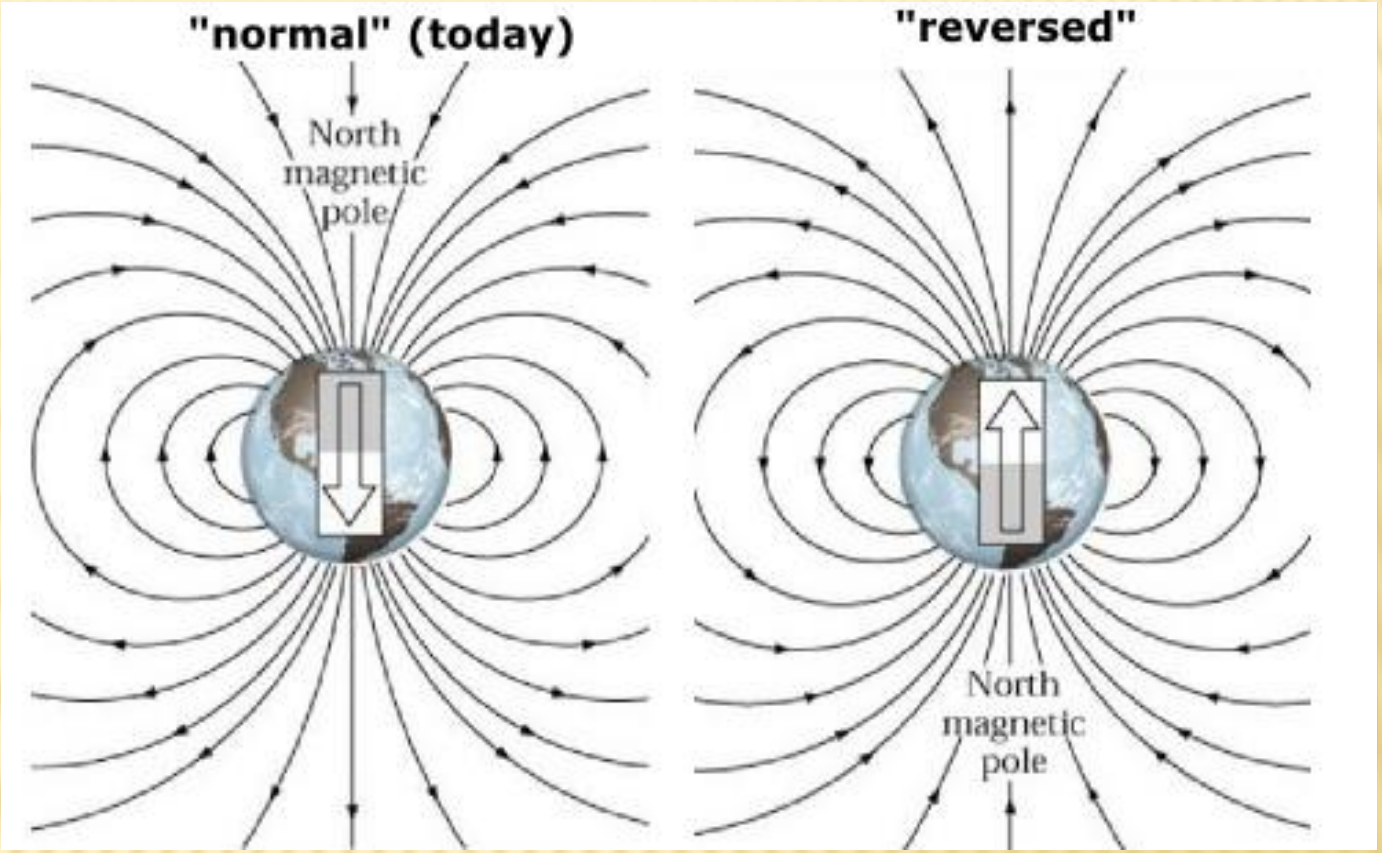


MAGNETIC FIELDS REVERSAL

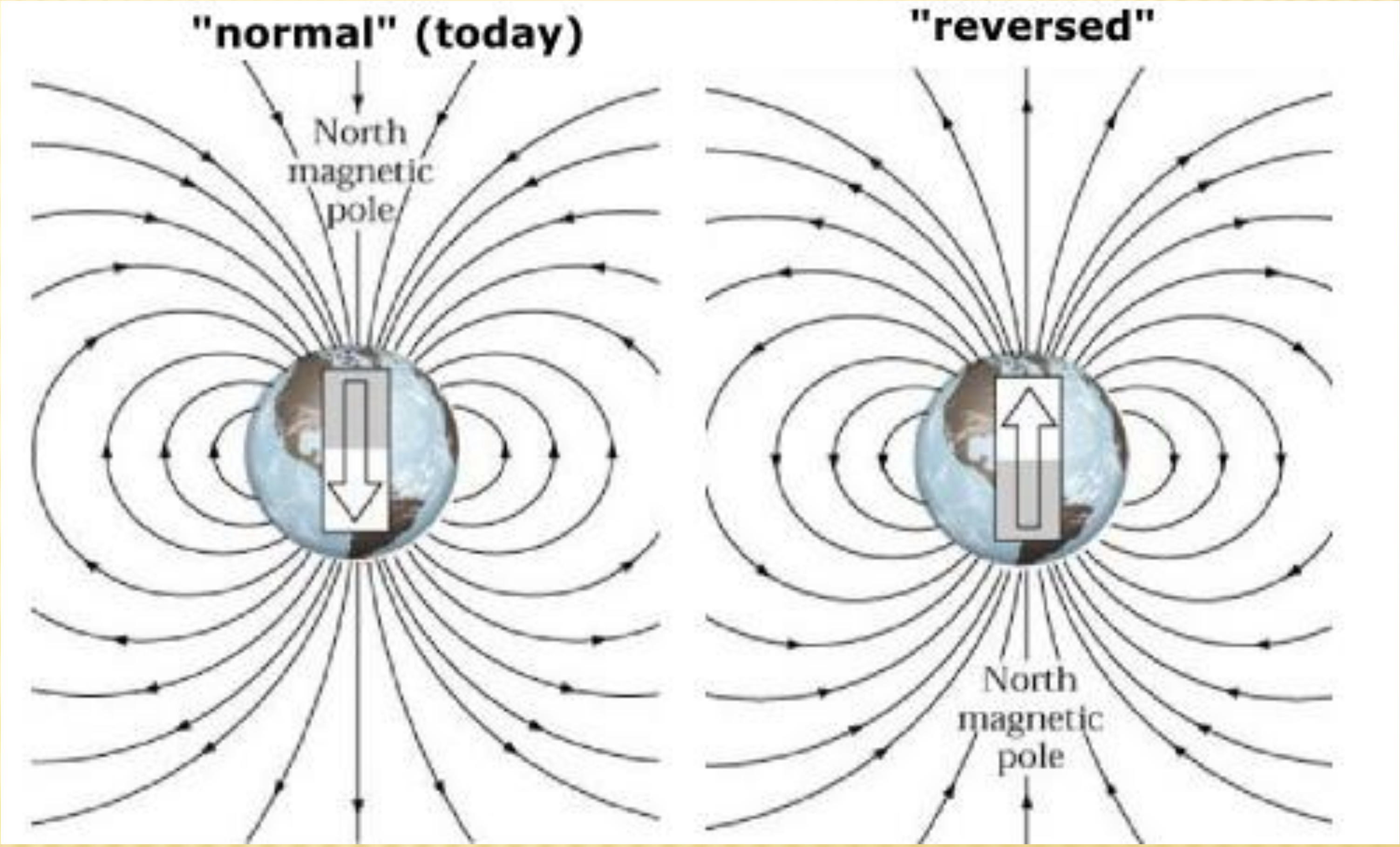
Reno, NV

June 25, 2009

MAGNETIC FIELDS REVERSAL

- It's fairly common knowledge that the Earth's magnetic field periodically reverses its polarity. At the moment, magnetic field lines run from the south pole to the north pole, and point up in the southern hemisphere and down in the northern hemisphere, as in the figure on the left below. But at many points in the past, the field lines (and compasses, if they'd been invented) pointed south, and, as the figure on the right below shows, were directed *upwards* in the northern hemisphere and *downwards* in the southern hemisphere.

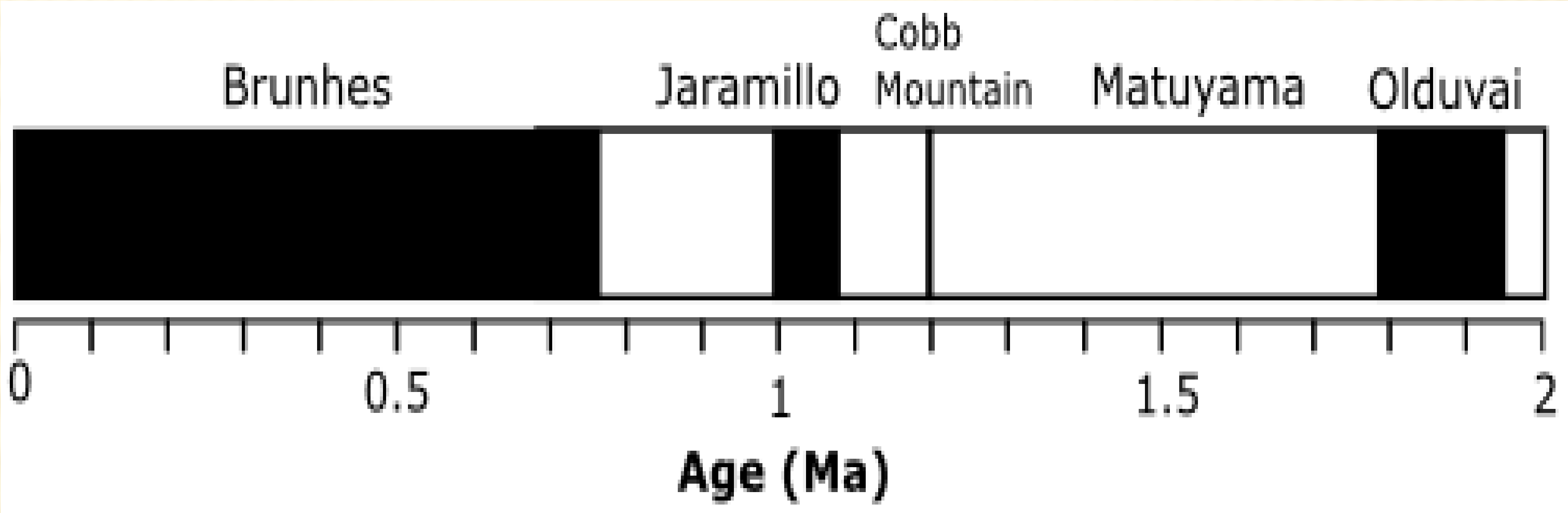
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- Rocks record the direction of the ambient magnetic field as they form, allowing us to reconstruct the history of these reversals. In the next figure, periods when the field is "normal" (the same as the present day) are in black, and periods when it is in the opposite, "reversed" polarity are in white. The field last flipped over about 780,000 years ago (0.78 million years); previous reversals occurred about 0.99, 1.07, 1.19, 1.2, 1.77 and 1.95 million years ago.

MAGNETIC FIELDS REVERSAL

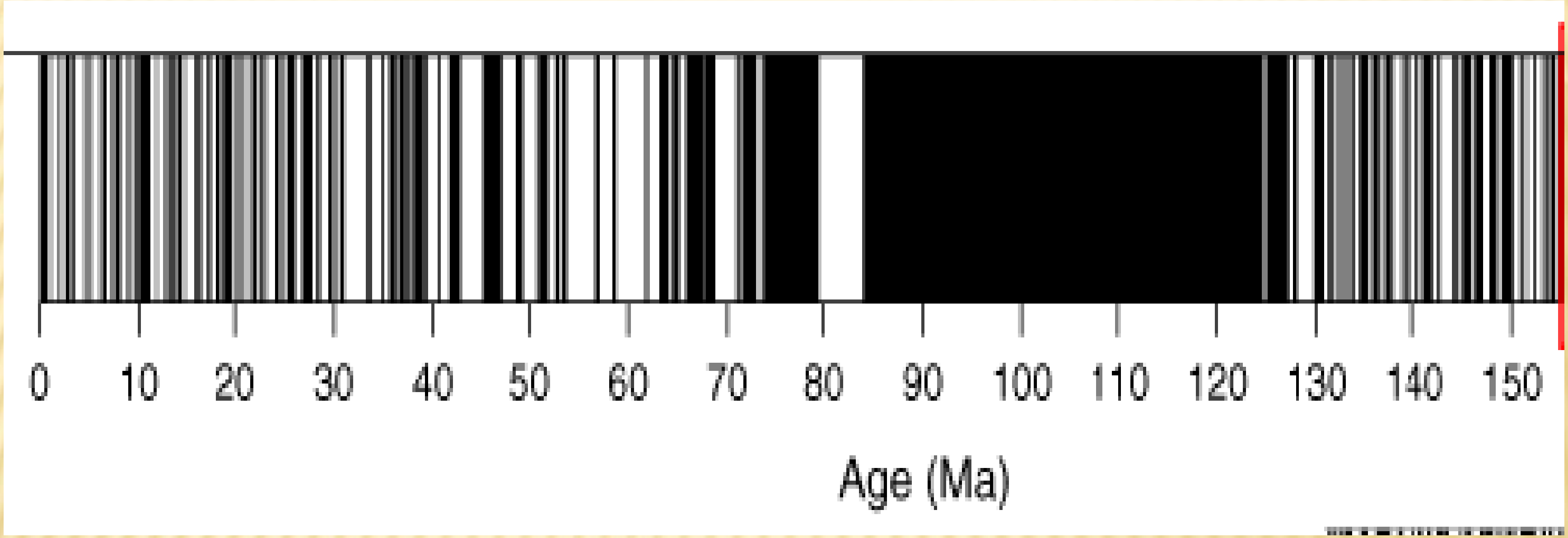


The last couple of million years worth' of reversals.

MAGNETIC FIELDS REVERSAL

- You can't help but notice that the typical period between the reversals in the last couple of million years is a lot less than 780,000 years, which is why you might hear talk about us being 'overdue' a reversal. Is this true? When can we next expect the field to reverse? And should we care if it does?
- The question of whether we should be *expecting* a reversal is most easily addressed by taking a longer view. The symmetric pattern of magnetic anomalies either side of mid-ocean ridges, give us a continuous record of magnetic reversals stretching back almost 200 million years. This shows that the time between reversals is not constant, varying from a few hundred thousand years to many millions of years, as it did in the Late Cretaceous normal "superchron" (the big black block between about 85 and 125 million years ago) where the field retained the same polarity for around 40 million years.

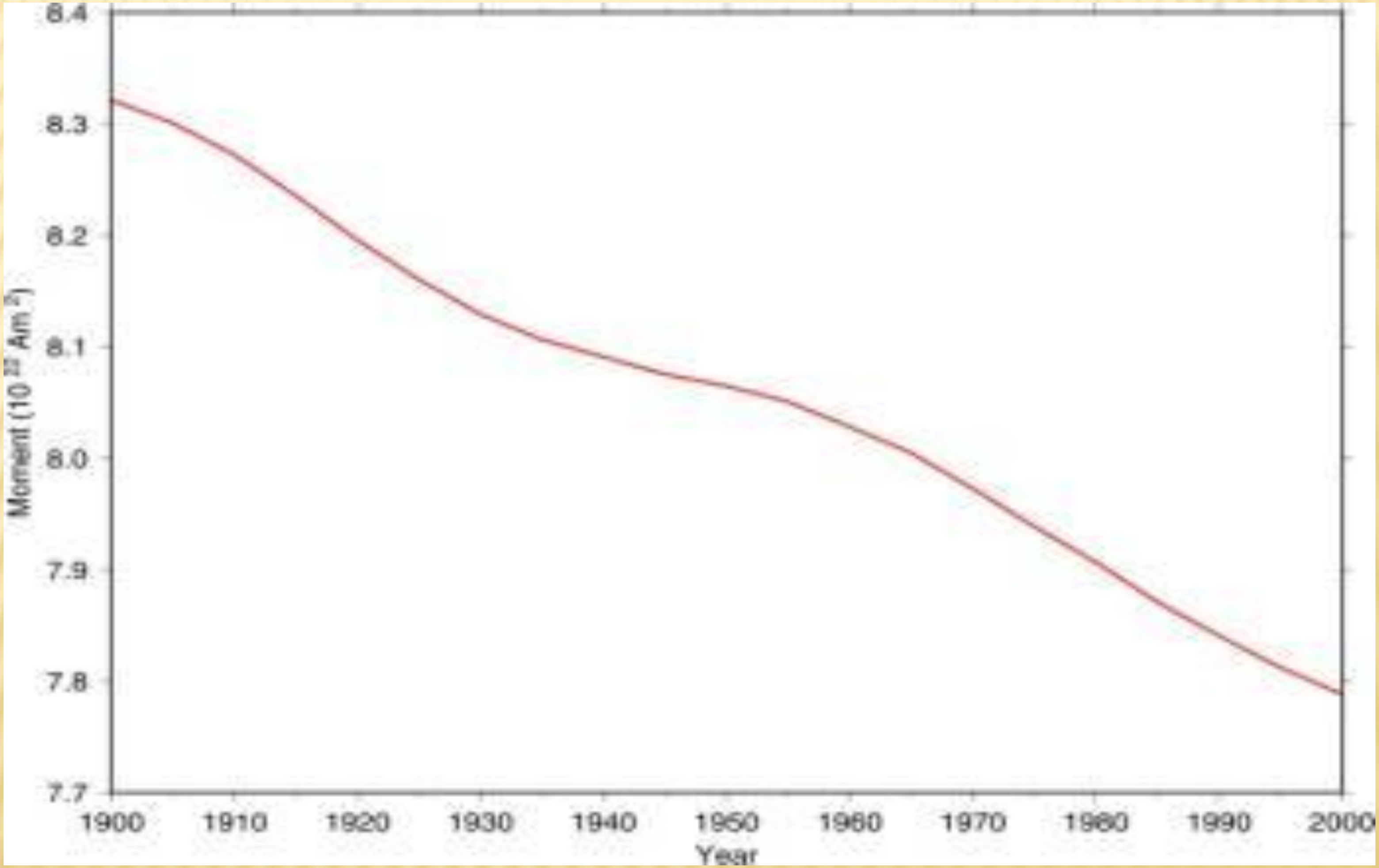
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- This longer view suggests that trying to predict the geomagnetic future from the 'periodicity' of past reversals is a risky enterprise, to say the least. But that's not the end of the story; by looking at the recorded behavior of the magnetic field prior to previous flips, it might be possible to identify precursors that may herald the next one. Researchers are particularly interested in how the *strength* of the Earth's magnetic field varies during reversals, because geo-dynamo theory suggests that reversals are probably more likely to happen when fluctuations in outer core convection weaken and destabilize the dipole. This prediction is particularly relevant in light of the fact that the strength of the Earth's magnetic field has been steadily decreasing, at a rate of about 5% a century, since we first started directly measuring it in the mid 1800s. Is this a prelude to a reversal? Without a better idea of how the geo-dynamo behaves over geological time, there's no way of knowing.

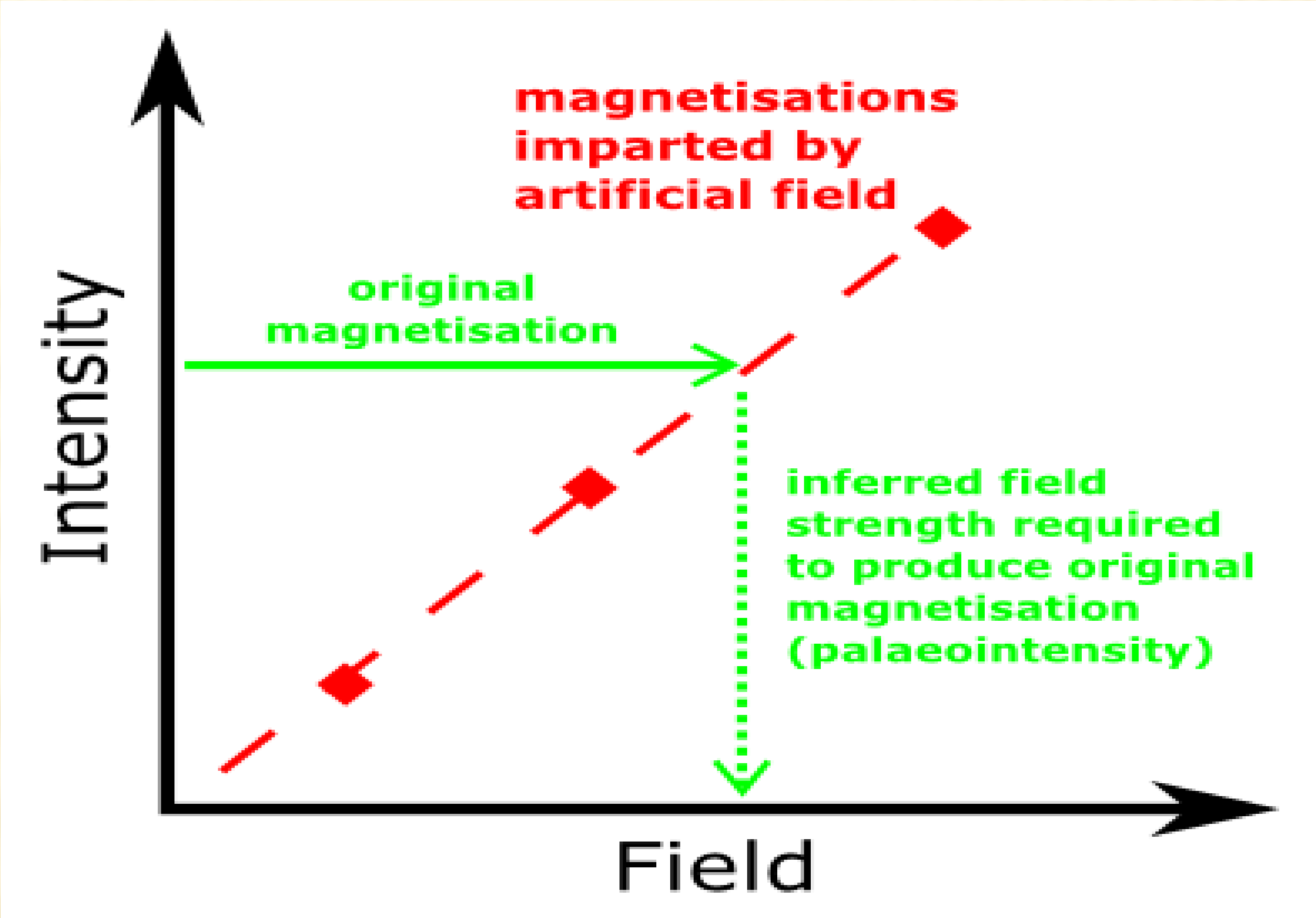
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- Fortunately, rocks can preserve information about the paleo-intensity (literally, ancient intensity) of the Earth's magnetic field. Effectively, the stronger the magnetizing field, the stronger the rock's magnetization will be. If you measure the magnetization acquired by your rock samples in artificial magnetic fields of known value, you can use this experimentally determined relationship to infer the strength of the geomagnetic field required to impart the original remnant magnetization.

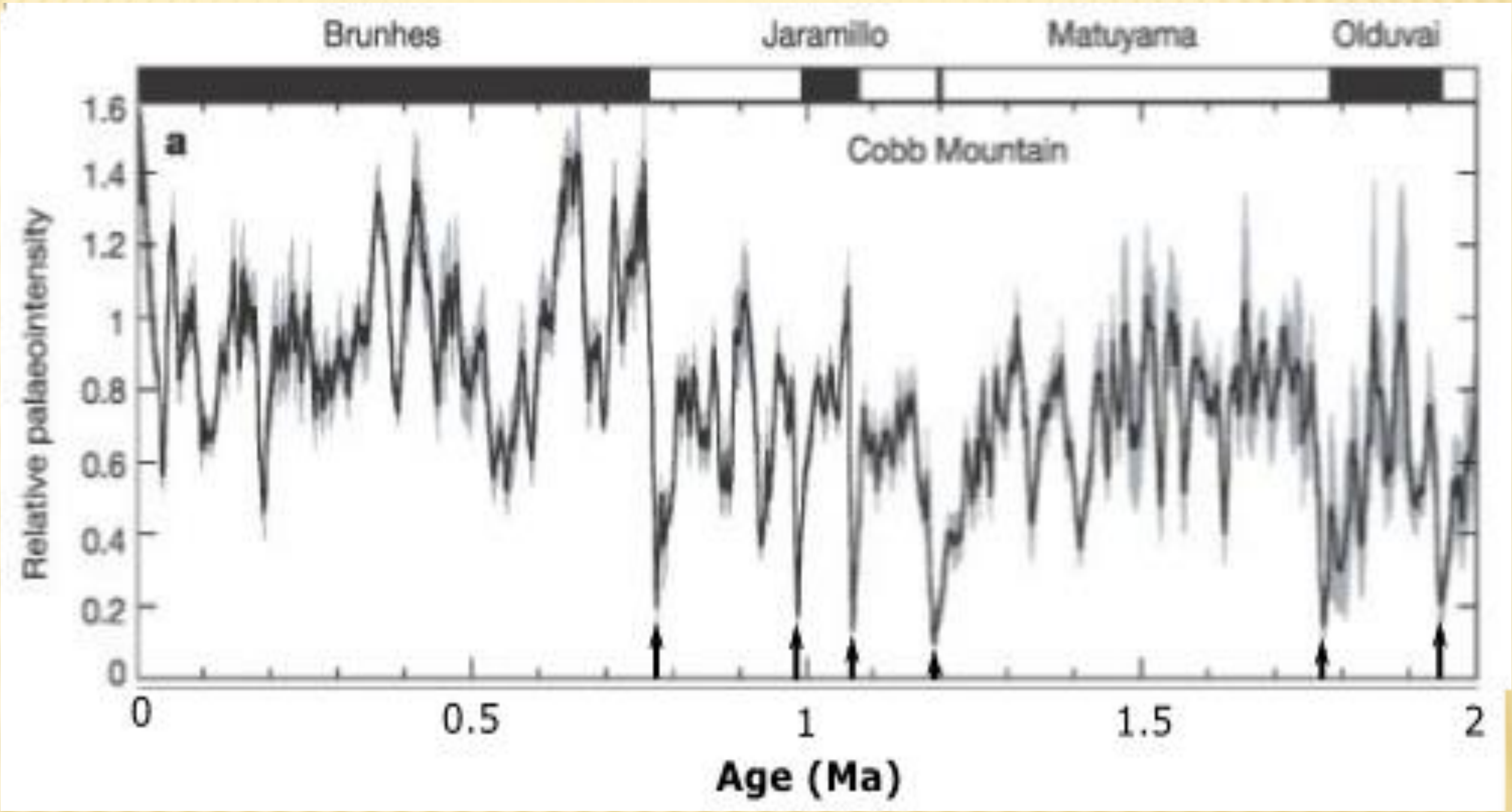
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- In practice, reliable measurements of absolute paleo-intensity can be quite tricky. However, although absolute values would be nice, we're actually most interested in relative changes in the strength of the field over time - and if you can find some nice continuous sedimentary sections with constant mineralogy, you can be reasonably sure that changes in the intensity of the magnetization as you move up- or down-section are mainly due to changes in magnetic field strength at the time of deposition (in other words, if the characteristics of the recording medium stay constant, then variations in the record must be due to changes in the input signal). Increasing numbers of relative paleo-intensity records, mainly from measurements of marine sediment cores, have been published in recent years. If you're clever, like Jean-Pierre Valet *et al.* were in their 2005 *Nature* paper, you can stitch and stack the most reliable of these records together, to produce a composite curve of the last 2 million years of relative variations in geomagnetic field strength.

MAGNETIC FIELDS REVERSAL



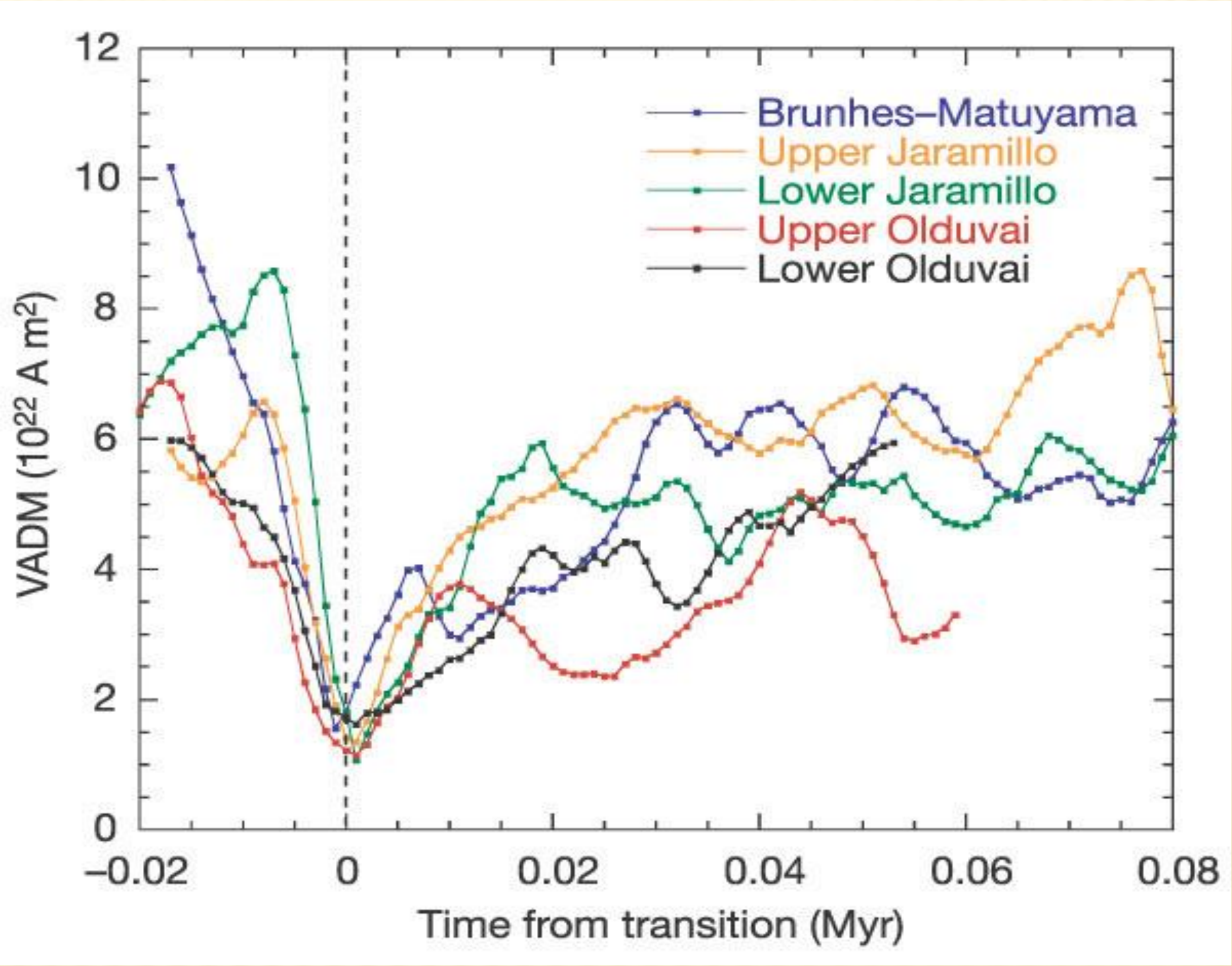
MAGNETIC FIELDS REVERSAL

- There's no other word for it - these data are beautiful. Every switch in polarity occurs when the field is at its weakest - the paleo-intensities are lower during reversals than at any other point in this record. Rather intriguingly, slightly less extreme dips in the field intensity appear to be associated with what are called excursions - periods where changes in the direction of the recorded magnetization show that the magnetic poles have wandered quite a long way from the geographic poles, but without the field reversing. So, just as geo-dynamo theory predicts, a weakening of the magnetic field seems to be associated with less dipole-like behavior, and reversals. It's interesting to note that the field seems to have been stronger, on average, since the last reversal, which might explain why this current polarity interval has lasted longer than the preceding ones.

MAGNETIC FIELDS REVERSAL

- The other interesting thing about this record is that the field has behaved in quite a consistent way during every reversal. In the figure below, Valet *et al.* plot the changes in field intensity across each individual change in polarity atop one another, with time decreasing from right to left. In each case, the reversal is preceded by at least 20,000-40,000 years of fairly continuous decay in field strength to about the same (very low) value, with a much more rapid recovery in field strength following the transition. In this context, a couple of centuries' worth of field decay is not particularly significant, especially since the present field strength (about 8 on the scale in this figure) is still a lot higher than the value reached during all of these reversals .

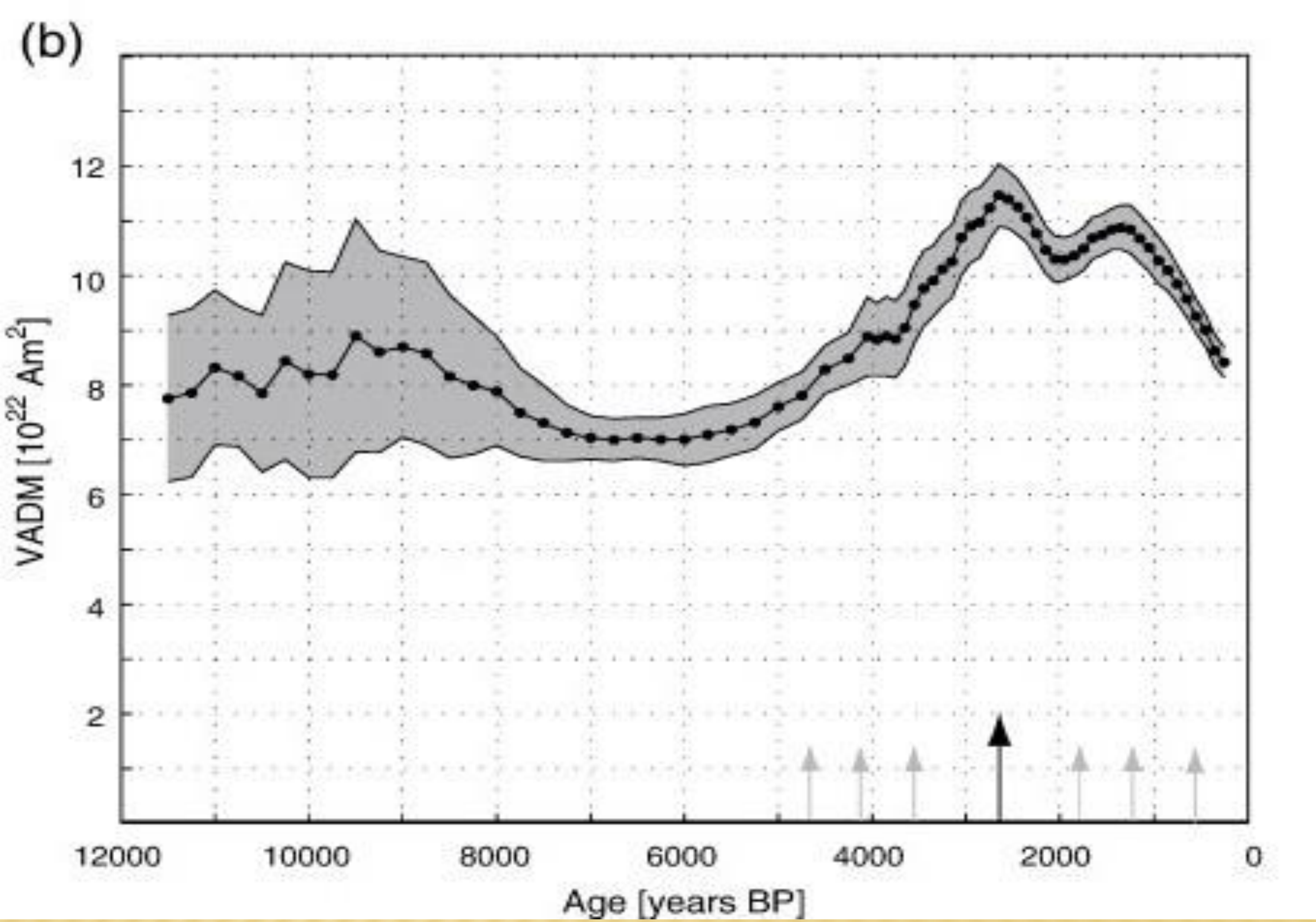
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- To really place recent field behavior in context, we really need a better idea of what was going on geo-magnetically prior to the instrumental record. As it turns out, archaeological sites are a very good source of absolute paleo-intensity data: - human artifacts like hearths, forges, and kiln-baked pottery are pretty good magnetic recorders, with easy to understand behavior. In a recent paper, Knudsen *et al.* use the wealth of paleo-intensity measurements from the last 12,000 years or so to produce a best-fit model of dipole strength for the Holocene (the grey shaded region is the estimated error - and note that the time axis here runs the other way to all the other figures...).

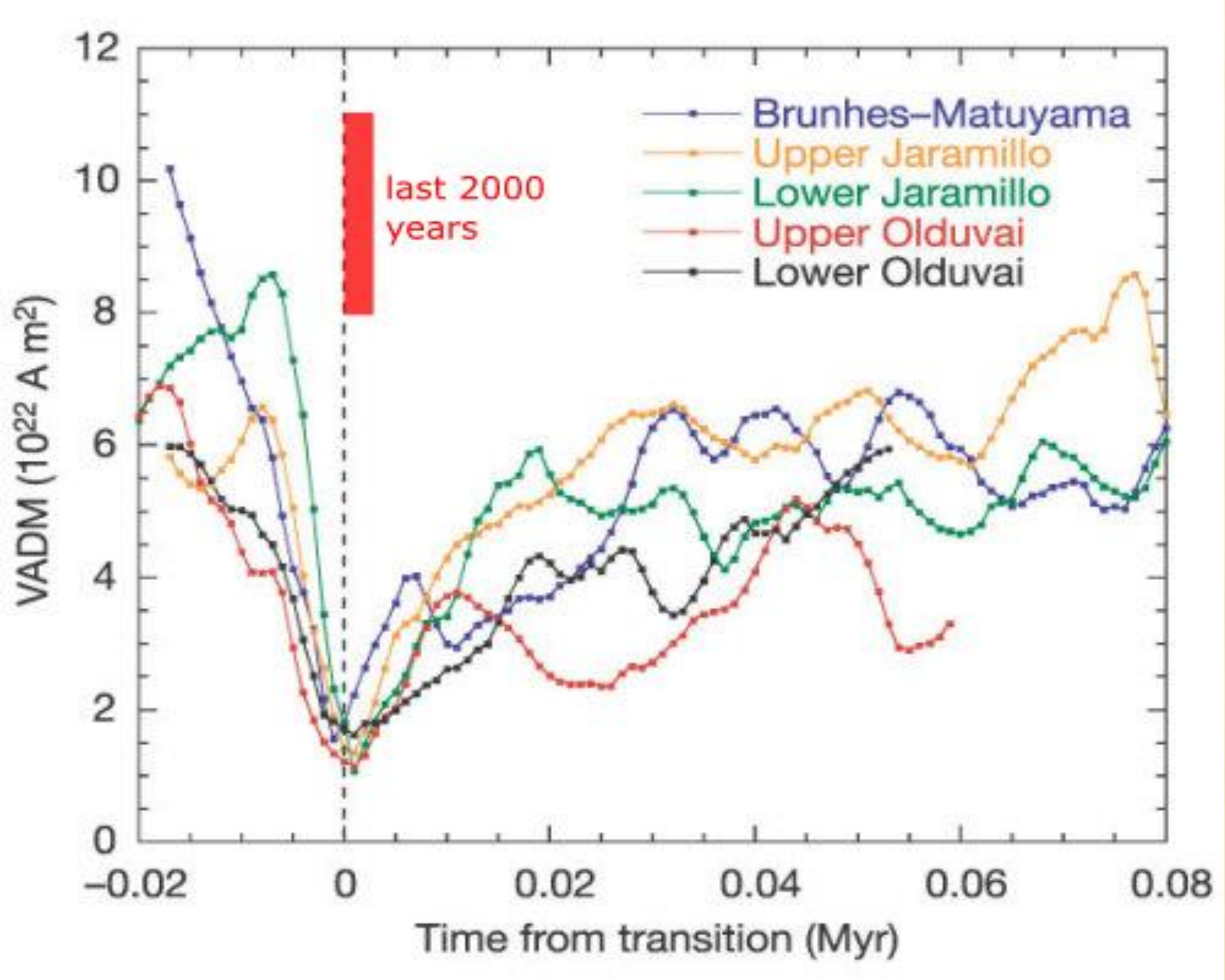
MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- This shows that for most of the last 12,000 years, the field strength was actually lower than it is today; it increased between about 4,500 and 2,500 years ago, and after this peak- which is high even when you look over the last 2 million years - it has been decreasing again for most of the last 2,000 years. If you compare the duration and magnitude of the recent decrease (the red box in the figure below) to the field behavior for past reversals, it doesn't look like we have to worry about the field reversing for a while - it looks like it needs to continue weakening for a few thousand more years, and reach a much lower strength, before a reversal is going to happen.

MAGNETIC FIELDS REVERSAL



MAGNETIC FIELDS REVERSAL

- Of course, another thing you should get from the Valet et al. paper is that a full reversal sequence is not an instantaneous event; our compasses will not point north today and south tomorrow. Instead, the geomagnetic field will weaken, and the magnetic poles will start to wander to lower latitudes, and possibly multiply, over a period of hundreds and thousands of years. It looks dramatic from the perspective of Deep Time, but during a reversal the changes over a human lifetime will probably be little different from the secular variation we see today. No extinction event has ever been linked to a magnetic field reversal, and I think that we might just cope with the next one too - whenever it might occur.

MAGNETIC FIELDS REVERSAL

- Scientists have been observing changes in the direction of earth's magnetic field which took place recently as well as in the distant past. NASA's website features a map showing the gradual northward migration of the north magnetic pole in the past century and a half. Since more than double the time interval has elapsed since the last reversal, compared to the time lapse between the previous two pole reversals, some believe we may be overdue for the next north-south flip. However, though the interval between reversals of the Earth's magnetic field can be as short as 5,000 years, it can also be as long as 50 million years. There does not seem to be any logic or rule governing the planet's behavior.
- It is not only the direction but also the strength of this magnetic field that is a concern. In the time of dinosaurs, at an estimated 2.5 gauss, it was eighty percent stronger than it is now. This may have been one of the reasons such gigantic life forms thrived. It is now accepted that a catastrophic event ended the reign of giant reptiles. However, they did not re-evolve to equivalent dimensions. And the disappearance of mammalian "mega-fauna" in more recent times is still considered to be a mystery. The mastodons and mammoths would have towered over modern elephants. Why are there so few large terrestrial animals today?

MAGNETIC FIELDS REVERSAL

- The smaller average size of modern animals may be due to the gradual decline of Earth's "steady state" (as opposed to “pulsed”) magnetism. Thousands of years ago the Chinese, with their astute discovery of bio-electrical energy flows known as “meridians”, learned that magnetism promotes vigor in biological life. They used magnetic rocks in medical treatment. In the past century there has been a further decline of earth's magnetic field by another five percent down to only 0.5 gauss. This has led Dr. Dean Bonlie to identify a "magnetic deficiency syndrome" resulting from the biological stress caused by the weakening of this "energy base" for life.
- The weakening of earth’s magnetism is one of the factors believed to be predictive of a pole reversal. That magnetic field reversals have occurred in the past is confirmed in the geological record. What is unclear is how precisely the transition occurs, and what happens to life forms extant at the time of this pole flip.

MAGNETIC FIELDS REVERSAL

- Does the magnetic field drop to zero gauss? Dire predictions follow upon the heels of this theory. Electronic devices would all be at risk: there may be damage to, or complete loss of, all near-earth-orbiting satellites and possibly the space station itself. Effects on life forms could range from migrating birds losing their sense of direction to immune system decline and even widespread die-off from radiation-induced cancers.
- Losing its protective magnetic envelope, the atmosphere would expand and become thinner, possibly leading to altitude sickness near sea level. No longer filtered out, deadly cosmic rays would kill most if, not all, living creatures on the surface. Only those living in deep caves would be safe. This scenario has prompted some to build underground bunkers in hopes of surviving.
- Countering this frightening vision, NASA predicts that, rather than declining to zero gauss, the magnetic field would become disordered. Thus we might for short time have more than one north and south pole on the planet. This official scientific stance says that the magnetosphere which shields us from cosmic radiation would not entirely disappear either.

MAGNETIC FIELDS REVERSAL

- Thus, while communications would be erratic and perhaps at times completely inactivated, humans would find ways to survive. However, there are dissenters in the ranks, pointing to the vast South Atlantic magnetic anomaly and radiation damage to satellites over that region attributed to weakening of the protective magnetosphere.
- The disorderly-flip theory is supported by evidence from geology that in past reversals the decline was not total. Lava flows that solidified at Steen's Mountain during a lengthy reversal process show that the magnetic poles wandered across the equator three times. Though strength of the field was reduced to about 20% of maximum, there is no record that it fell to zero gauss during that transitional period.
- The theory that activity in the turbulent molten outer iron core of the planet generates its magnetic field currently dominates scientific thinking. Stormy activity deep in the earth's outer core, believed to be filled with roiling convection flows of molten iron, is understood to generate the planet’s magnetic field. Such violent seething could affect the mantle as well, possibly disturbing the earth's crust and causing the quakes.

MAGNETIC FIELDS REVERSAL

- However, there is an alternate theory of how the magnetic field is generated. In his article, "Origin of the Earth's Magnetic Field", Ernest McFarlane outlines gaps in the molten-iron convection theory. He proposes a system of electronic cells in a crystalline metal core with hot spots of heavy metals releasing alpha and beta particles. Due to the high heat the alpha particles are unable to combine with the free electrons. "Consequently an electron current flow is produced and conditions are set up for the generation of current loops throughout the inner and outer core. ... magnetic fields are produced as a consequence, in accordance with the right hand rule of electromagnetic theory.“
- Which theory is right? We may find out from experience sooner than we can come to amicable agreement, given the conflicting theories and computer models. The actual dynamics may include aspects of both, or new insights not yet fully developed.
- The sun reverses its magnetic field like clockwork every eleven years at the peak of the sunspot cycle. The next solar flip is due in 2012.

MAGNETIC FIELDS REVERSAL

- South-pointing magnetic flux moves from sunspots, which are intense magnetic loops near the equator of the sun, along “meridional flows” to the north magnetic pole, and vice versa. As the oppositely-directed charge accumulates at the poles the field declines, until eventually the reverse charge predominates.
- Scientists point out that the heliosphere does not wink out of existence during this reversal. The sunspots are intense magnetic knots, much stronger than the star’s main field, which continue to spiral outward even when the main dipole field vanishes briefly. Though the solar magnetic reversal is not completely understood, the Ulysses space probe has sent back detailed data which has supplied answers to many questions.

MAGNETIC FIELDS REVERSAL

- The mechanism that controls earth's field reversals may not be based on similar principles. For one thing, a planet does not seem to have any equivalent to the powerful sunspots. McFarlane refers to there being more than one north-south pole system and about 10% of the total field being involved in smaller extra fields. If these subordinate minor magnetic fields take up more of the magnetic activity during the main field’s decline, they might become active enough to sustain a minimal protective layer shielding the biosphere, even if the main dipole field declines to zero gauss. This could be important for our survival, as the Steen’s mountain lava flows indicate that the reversal took 4,500 years to be completed!