Element mobility in transported overburden — are we looking in the wrong direction?

I enjoyed the review of possible mechanisms of metal transfer through transported overburden by Aspandiar, Anand, Gray and Cucuzza (2004) in Explore 125, and have also been impressed by the outstanding work carried out by the Deep-Penetrating Geochemistry group in recent years in both North and South America (e.g. Cameron, Hamilton, Leybourne, Hall and McClenaghan, 2004). It is clear that we now have several elegant and plausible models for element transport through transported overburden. But before we rest on our laurels and accept that all has been explained, can I suggest that we have so far ignored at least two other potential sources of energy which could be capable of driving ions through the regolith to the surface, even though the driving forces come not from within the regolith but above it? These are electrically charged storm cells and tidal pull.

Electrically charged storm cells are common features over almost all landmasses. Around the world lightning strikes the Earth 50 to 100 times each second and at any given moment there are 1800 to 2000 thunderstorms in progress, almost all over land (Anon, 1986). Here in Australia we get between 0.5 and 2 lightning strikes to ground per square kilometre per annum over much of the continent (Australian Bureau of Meteorology, 2004). Such a strike density is not unusual elsewhere. Indeed, over large areas of India, Africa, South and North America it is higher still (NASA, 2001). While fully developed thunderstorms represent the most intense electrical cells there must be many more cases where extremely powerful electrical gradients are generated within developing storm cells even though these do not get to the point of initiating lightning discharge. Consequently, over the course of no more than a few decades this should mean that the whole land surface of most continents will have been repeatedly exposed to the effects of these transient, but immensely powerful, phenomena. Evidence that this has at least some effect on the regolith comes from palaeomagnetic studies, where surface measurements may be unreliable due to the magnetic overprint induced by lightning strikes. Fulgurites, formed by fusion of soil by lightning strikes, have been traced up to 20 metres down into the regolith (Bouska, 1993), and there is even a report of tourists being injured by electrical discharges in a cave that was overlain by 300-400 metres of rock, with no artificial electrically conducting connections, when lightning struck the surface above them (Diendorfer and Schulz, 1997).

Storm clouds act like huge capacitors and the steep electrical gradients associated with them have been measured above ground over thousands of metres, so it would not seem to be unreasonable to argue that these forces could also penetrate a few tens or even hundreds of metres into the regolith below. They could therefore constitute a significant mechanism for mobilisation of elements. Figure 1 summarises some of these features. Typically a strong negative charge develops at the cloud base and this field

continued on Page 4

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Element mobility in transported overburden — *continued from page 3*

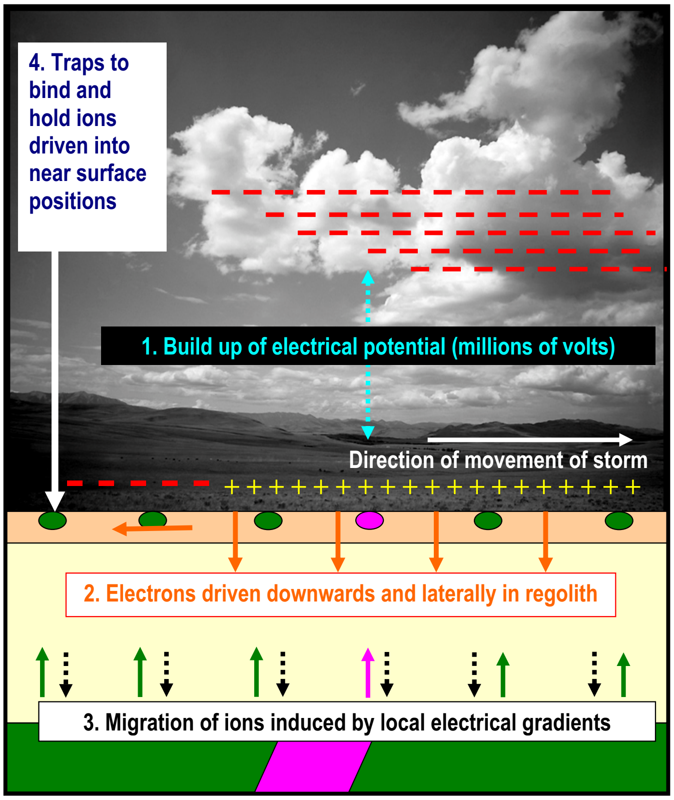

Figure 1. *Suggested mechanism of ion migration within regolith, driven from above by powerful atmospheric electrical gradients associated with storm cells.*

becomes so intense that it interacts with the ground, often several thousand metres below it, driving electrons in the surface regolith away from it, both downwards and laterally. This results in the acquisition of a strong positive charge in the surface regolith immediately below the storm cloud. Under a mature storm the electrostatic field can achieve levels of between 10000 and 30000 volts per metre of elevation above the earth's surface (Carpenter and Tu, 2000).

The rate of movement of charged species in an electrochemical field can far exceed that of chemical diffusion, provided the voltage gradient is high enough. Hamilton (2000) has estimated that voltage differences as low as 10 - 60 millivolts would be sufficient to move ions through a 30 metre thick electrolyte in 8000 years. This assumes the groundwater behaves as a perfect electrolyte, whereas in the real world many geochemical processes may affect the migration rate. Nevertheless, it does suggest that ions at least have the potential to move quite quickly through transported overburden if conditions are right, even with very small voltage gradients. A modest increase in voltage difference will speed up this process considerably, as demonstrated by recent research on electrokinetic remediation of metal contaminated soils. For example Reddy and Shirani, (1997) quote a study where electrodes were implanted in a clay-rich soil containing up to 500 ppm As, and potential gradients of between 20 and 40 volts per metre were applied. After three months 75% of the site had been reduced to the target of 30 ppm As. If gradients of a few volts per metre can achieve this kind of ion mobility in months how long would it take to move ions through significant thicknesses of regolith if they were exposed to local storm cells where – at least for short periods of time – electrical gradients are orders of magnitude greater?

What might happen in the regolith as a storm cell moved over it, assuming there was sufficient moisture in the vadose zone to allow movement of ions in solution? In the area immediately under the cell, where the regolith surface carries a strong positive charge, a reduced cation such as Fe^{2+} could be expected to be driven up towards the surface where it would lose an electron to become Fe^{3+}. It might then be available to scavenge other cations which could migrate to the surface under the influence of the negatively charged trailing edge of the storm footprint as it moved across the earth's surface. Such suitable near-surface chemical traps, which could immobilise ions once they had been driven up in the weathering profile, would probably be an equally important part of this model – otherwise ions could be just as easily driven down in the regolith as driven upwards.

Storm cells are complex things and many factors could come into play. If there was a lightning discharge this would result in a sudden local rush of surface charge to the lightning stroke channel (Carpenter, 2000) and this could in turn act as an engine to mobilise ions in the regolith, perhaps inducing different dispersion patterns from those generated by the storm cell itself. No doubt such factors as moisture content, resistivity and mineralogy of the regolith would also influence behaviour of ions. In an appreciable minority of cases the charge is reversed with a positive charge developing at the cloud base while a negative charge develops at the surface of the regolith. This could generate very different dispersion patterns from those generated under 'normal' storm cell conditions. It would be interesting to measure vertical voltage gradients in the regolith as a storm cell approaches, passes overhead (or nearby) and then moves on. How long can an effect be measured; how intense is it and how does it change as the cell moves on?

The above is pure speculation. I simply make the point that these electrically charged juggernauts rumbling across the landscape could prove to be an enormously powerful driving force, capable of inducing perhaps extremely rapid migration of ions through the regolith. Why invoke millivolts to move ions when we have millions of volts at our disposal?

continued on page 5

Element mobility in transported overburden —

continued from page 4

As a footnote it is worth noting that the effects of these storm cells linger long after the cells themselves have dissipated. A portion of their electrical activity feeds into telluric currents which flow at or near the earth's surface. These currents can be modified, and at times intensified, by interactions between the solar wind and the ionosphere. Perhaps they too play a role in element dispersion in the regolith.

Tidal pull. Ocean tides are obvious. So obvious that we tend to forget that the same gravitational forces that cause the oceans to rise and fall are also operating on the air and solid landmasses. Although the movement is much less in the land than in the sea it can amount to a metre of vertical shift (UK National Maritime Museum), although it is normally probably of the order of 15 – 30 cm. If such a movement is happening twice a day across a land surface, is it too fanciful to speculate that this rising and lowering of the land surface may act as a driving force for movement of ions, either in gaseous form or in solution, rather like the action of a giant pump or set of bellows? Perhaps every geochemist should be issued with a set of tide tables.

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