Simple hillslope erosion narrated by complex methods

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The overarching objective of work presented here is to better understand how the Earth's surface is evolving under the changing influences of climate and human land management. This objective is reached by quantifying erosional processes and rates on upland, soil-mantled and bedrock-dominated landscapes. Upland landscapes across a large part of the Earth's surface are partially to completely covered with soil. Erosion redistributes this transportable material from the uplands into networks of stream channels, and ultimately into sediment sinks. The persistence of soil on the landscape depends in large part on sediment production from the underlying bedrock at a rate that at least equals the erosion rate, which in turn is depends on the dominant geomorphic processes.

While this conceptual framework is certainly not new, improving our understanding of the rates and processes of intuitively simple processes consumes extensive studies across diverse landscapes. By regulating soil presence and local thickness, the balance between production and removal of soil effects directly the temporal and spatial distribution of hillslope hydrologic processes, dominant vegetative cover, soil biologic activity, and sediment discharge to rivers.

Here I present work from a field site in southeastern Australia using three different methodologies that work together to quantitatively test hypotheses fundamental to understanding Earth surface processes and landforms. I couple measurements of in situ produced, cosmogenic ^{10}Be and ^{26}Al for determining soil production and landscape erosion rates with a comprehensive look the mechanical processes of soil removal. This examination of the erosional processes is enabled by combining measurements of single grain Optically Stimulated Luminescence (OSL) with measurements of the short-lived fallout-derived isotopes, ^{7}Be, ^{210}Pb, ^{137}Cs, and ^{241}Am, where the soil production law is defined using cosmogenic nuclides.
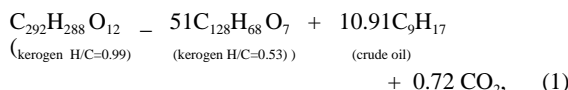
The use of these fallout isotopes presents opportunity to learn a great deal about how sediment is moving off the landscape on relatively short time scales, while the OSL measurements yield results meaningful from hundreds to tens of thousands of years. Short-lived nuclide concentrations, bound to soil grains from different depths, will depend on the transport processes disturbing the soil particles: e.g. soil moving only in a surface layer would receive continuous inputs of ^{7}Be and ^{210}Pb and shows a downslope enrichment of ^{137}Cs and ^{241}Am, while deeper soil that has not been mixed shows little to no nuclide activities. OSL results show mixing of the entire soil column and help lead to determining soil flux rates.

A Chemical and Thermodynamic Model of Oil Generation in the Earth

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Thermodynamic calculations and Gibbs free energy mimimization computer experiments indicate that kerogen maturation and oil generation are inevitable consequences of oxidation/reduction reactions caused by prograde metamorphism of hydrocarbon source rocks with increasing depth of burial. These experiments indicate that O_2 and H_2 are conserved in the process, which consists of incongruent melting of reduced kerogen with relatively high H/C to produce a more mature (oxidized) kerogen with a lower H/C, together with crude oil, and CO_2. For example, incongruent melting at 150 °C and ~5 km depth of a Type II kerogen with a bulk composition represented by $C_{292}H_{288}O_{12}$ to produce a $C_{128}H_{68}O_7$ kerogen, a typical crude oil with an average composition corresponding to C_9H_{17}, and CO_2 can be described by writing.

$$C_{292}H_{288}O_{12} \ \_ \ 51C_{128}H_{68}O_7 \ + \ 10.91C_9H_{17}$$
$$(_{\text{kerogen H/C=0.99}} \qquad (\text{kerogen H/C=0.53})) \qquad (\text{crude oil})$$
$$+ \ 0.72\,CO_2, \quad (1)$$

which represents the sum of a series of oxidation/reduction conservation reactions. If H_2O is stable and present as water in the source rock, it too is conserved in the oxidation/reduction reaction series responsible for the incongruent melting of the reactant kerogen. Hence, the stoichiometry of Reaction (1) is the same with or without the participation of H_2O in the melting process. In the water-absent region of the system CHO, any water in or entering the source rock will be consumed by reaction with mature kerogen to form CO_2 and a new kerogen with a higher H/C, which increases the oil generation potential of the source rock. It can be deduced from Reaction (1) that nearly 11 moles of crude oil are produced from one mole of the reactant kerogen, which increases to 18.56 moles with increasing H/C of the reactant to 1.30 in Type II kerogen corresponding to $C_{292}H_{380}O_{14}$, and to 27.77 moles for Type I kerogen with an H/C of 1.68 represented by $C_{292}H_{491}O_{15}$. The secondary porosities created in source rocks by reaction (1) and others like it are of the order of 80 volume percent of the oil produced, which requires expulsion of the remainder, together with the CO_2 gas produced by the reaction. Mass transfer calculations indicate that this minimal volume of expelled crude oil is comparable to, or exceeds the oil found in major oil fields such as the North Sea, the Paris and Los Angeles Basins, and those in Kuwait and elsewhere in the Middle East. For example, all of the proven oil reserves in Kuwait (96.5×10^9 bbls or 5.4×10^6 bbls km^{-2}) could have been produced at 150 °C and a depth of ~5 km by minimum expulsion of oil generated by Reaction (l) in source rocks with an aggregate thickness of 60 meters. The source rocks would have had to contain an average of only 5 weight % reactant organic carbon in the kerogen represented by $C_{292}H_{288}O_{12}$ to account for all of this oil, as well as the 80 volume % of the oil produced that may remain in the source rocks.