Mega-Geomorphology and Reconciliation of Regional Weathering Assumptions

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Abstract

Deeply weathered regolith is a hallmark of tropical regions, but is not limited to tropical regions; examples of deep weathering are common in other climatic zones. One long-standing perception is that deep weathering in extratropical regions is also the product of tropical conditions of high temperature and abundant precipitation. While some evidence accounts for tropical weathering, by way of climate change and continental paleogeography, other factors such as stability and time are also relevant. Given enough time and lack of erosion or tectonic deformation, deep weathering can occur in any climate, and there is evidence for this as well.

A re-examination of regional maps at the mega-geomorphic scale reveals biases based on time and tectonic stability. Landform types, encompassing age and relief, were classified on a cellular global grid based on regional maps. Using this gridded classification, areal coverage and location quotients (regional/global representation of landform classes) were calculated. Stable continental shield areas, with surfaces dating to Tertiary to Mesozoic in age, are much over-represented in the Tropics (LQ>>1), and under-represented in the Middle Latitudes (LQ<<1). By comparison, sediment-covered lowland are slightly underrepresented in the tropics (LQ<1), and over-represented in the middle latitudes (LQ>1). Both the Tropics/Subtropics and Middle Latitudes have comparable, nonbiased coverage of active orogenic zones (LQ≈1). While there are some instances of deep weathering in active orogenic zones (including the tropics), the prevalence of stable, old terrains partially predicts the occurrence of deep weathering without the need to invoke tropical factors.

Background

Climate and geomorphology have been linked for as long as the sciences have existed. Weathering geomorphology is not different. It is well established that bioclimatic variables have an important role in the rate and extent of rock weathering. The environment is the source of weathering agents: atmospheric precipitation, soil and ground water, biotic chemicals, extremes in temperature and pressure. The environment also modifies the weathering process: temperature influencing the rates of both physical and chemical processes, environmental change over weathering time spans that alter the near surface parameters of climate and vegetation. For these many reasons it has long been assumed that the environmental conditions of the tropics bring about ideal conditions for aggressive weathering: abundant precipitation and organic weathering agents, high temperatures, rapid rates of chemical process, and long-term persistence of these characteristics. In terms of the depth and extent of weathering profiles, Strakhov's (1967) conceptual diagram (Figure 1) illustrates the expectations of weathering regolith (depth and secondary mineralogy) with respect to latitudinal variations in temperature, precipitation, and biomass; and Tricart and Cailleux's (1968) map (Figure 2) of morphoclimatic provinces illustrate the expected coverage of different bioclimatic regimes.

However, extensive and deep weathering is not limited to the tropics. The wide assumption is that these presently extratropical locations were under the influence of tropical conditions, either by climate change or by tectonic drift over the long time spans of weathering. It is true that some deep weathering regoliths, for instance those seen in Colorado, California, and Spain (Figure 3) did exist in at least subtropical conditions in pre-Quaternary periods.

All this ignores another prime weathering factor, one that is equally relevant to the establishment of transport-limited environment assumed in the tropics stability, quiescence, and lack of erosion. Is it coincidental, or meaningful, that the preponderance of "tropical" weathering also occurs over terrains of unusual stability and quiescence? The purpose of this research is to demonstrate this association.

The idea is not new. Thomas (1994:80-81) outlines conditions necessary for deep weathering which include both bioclimatic and tectonic advantages, and reviews the prevalence of tropical weathering over the Gondwana Shield (see also Fairbridge and Finkl 1980), including inheritance of morphologies of the geologic past.

Megageomorphology characterization is not a topic of significant recent interest. Utilizing new remote sensing technology in obtaining digital terrain as well as near-surface regolith profiles, applied to a global scale, could reveal new information and update concepts now decades old. The present research relies on the landform mapping of Murphy and Thrower (1968), a map supplement originally published in the *AAG Annals*, and widely reproduced in subject textbooks and atlases up to the very present. Like the climatic classifications of Trewartha and Köppen, little can be found to supplant it. This map is reproduced here (Figure 5). No global scale assessment of weathering regolith exists at present.

Methods

Using existing maps and studies, geomorphic regions were classified by type of terrain, geological or structural system, and relative age. This classification is compared to presumed (theoretical) and actual weathering regolith thickness.

I. Murphy and Thrower's (1968) map, "Landforms of the World", classifies global land terrain by means of three categories.

- topography (mountains, widely spaced mountains, high tablelands, hills and low tablelands, depressions or basins, and plains)
- regional structure (Alpine system, Caledonian/Hyrcenian/Appalachian remnants, Gondwana Shields, Laurentian Shields, sedimentary covers of shield areas, rifted shield areas, and isolated volcanic areas)
- erosional and depositional regions (humid landform areas, dry landform areas, and glaciated areas)

II. Subsequent studies and maps, evolved from Murphy and Thrower (1968), add additional information.

- *Atlas of Physical Features* by Snead (1972) provides generalized world maps of weathering, rock types, and morphotectonic regions, compiled from contemporary studies.
- The *Perthes World Atlas* (Herb, et al., 2006) provides a reprint of Murphy and Tower's map, with additional information on the generalized age of erosion surfaces.

III. Dividing the world into 5°x5° latitude/longitude cells, each land cell is classified as to topography, regional structure, and age, generalized to the dominant characteristic if containing more than one type. Small islands that do not cover the majority of a 5°x5° cell were omitted. Each grid layer has 2,370 cells, extending fully east to west, and from 60°S to 75°N latitude.

IV. A location quotient is calculated for representation of landform classification (based on the three-tiered assignment above) with respect to broad latitudinal zones (e.g., the Tropics or Middle Latitudes):

$$LQ = \frac{R_L / R_T}{G_L / G_T}$$

Where R_L is the regional area represented by a specific landform type, R_T is the total area of land of all landform types in that region, G_L is the global area represented by a specific landform type, and G_T is the total area of land of all types. $LQ > 1.0$ indicates an overrepresentation of a specific landform type in the region, compared to the global average, $1.0 < LQ > 0$ indicate underrepresentation of a specific landform in the region.

V. A predictive model of global distribution of landscapes conducive to deep weathering uses the gridded cell classification above. This model ignores environmental variable such as temperature, moisture, biota, and rock type. It includes only variables relevant to topography, stability, and time. Conditions that contribute to deep weathering, in other words, transport limited landscapes, include flat terrain, long term tectonic stability, and long exposure age. Ranked values for landform characteristics were assigned as follows, the higher values representing conditions most conducive to deep weathering:

- Topography (assuming more and steeper slopes result in faster erosion, weathering limited condition) – mountains (1), widely spaced mountains (2), high tablelands (3), hills (4), and plains (5).
- Tectonic stability – Alpine orogenic system (1), Caledonian/Hercynian/Appalachian orogenic system (2), stable cartons covered by Paleozoic and later sediments (3), and the Laurasian and Gondwana shields (5).
- Relative age of erosion surface – Recent/Holocene (0) [limited to new sediment deposits], Pleistocene (1) [includes terrain strongly modified by glaciation, eolian deposits, and mountain slopes], pre-Pleistocene (3) [most areas not qualifying for any of the above].

VI. Simple cell addition arrives at a total score, highest values indicating conditions most relevant to the development of deep weathered regolith.

Figure 5, from Murphy and Thrower,

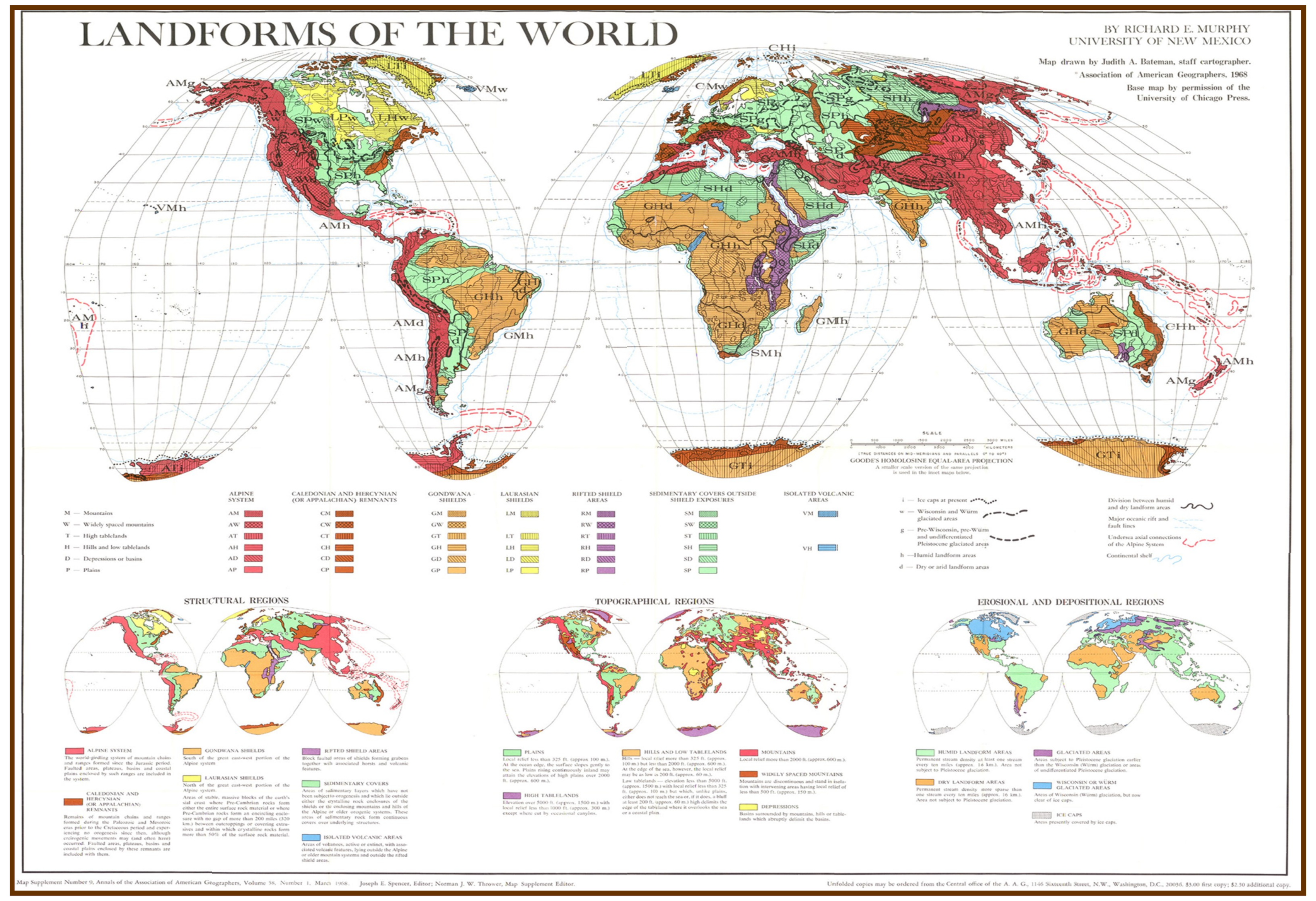


Figure 1. Prediction of soil and weathering profile development as controlled by bioclimatic factors. (Strakhov, 1967)

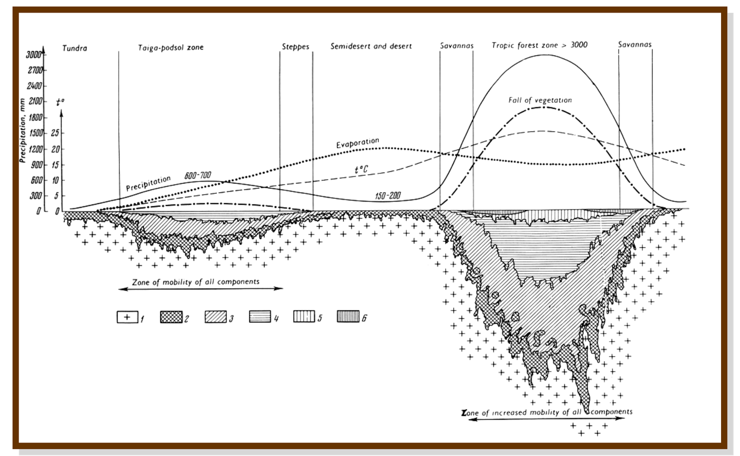


Figure 2. Morphoclimatic, as opposed to morphotectonic, provinces, predicted by Tricart and Cailleux (1965).

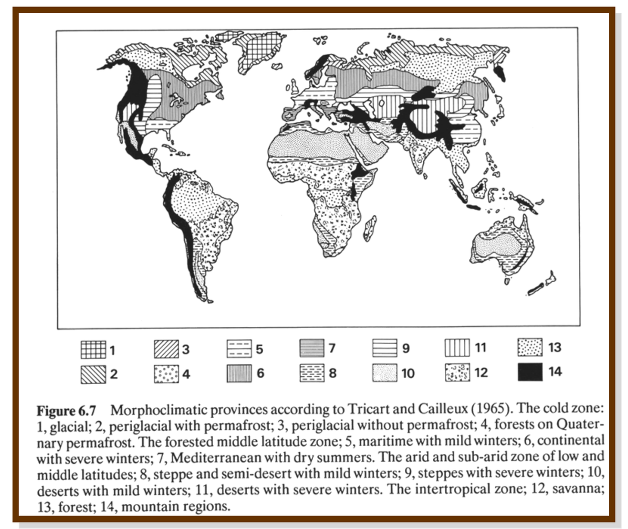
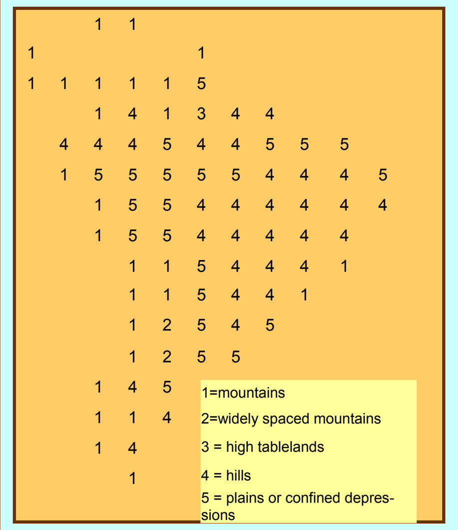
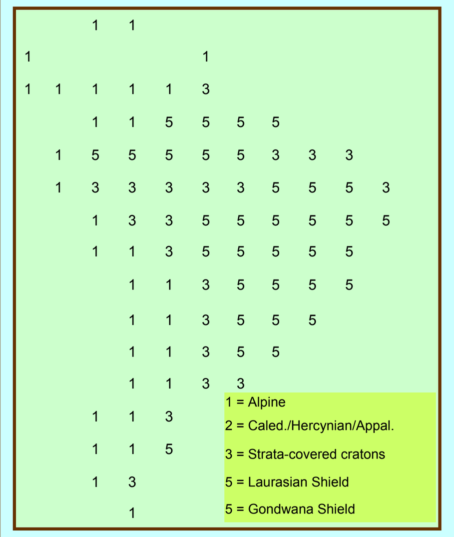


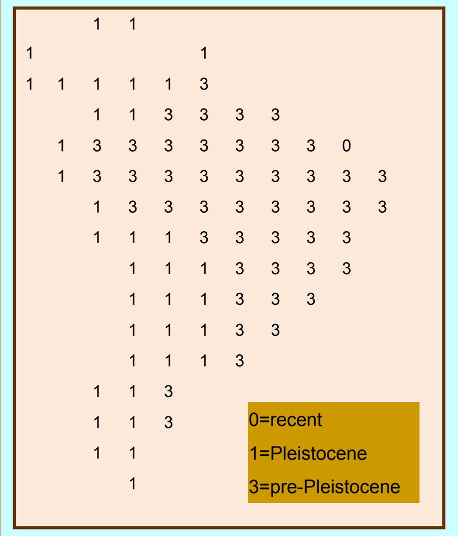
Figure 3. Deep weathering and laterite, Serra do Mar, Brazil. Source: Migon, 1999. (http://www.geomorph.org/sp/arch/rio99ft.html#BRA 3/32)

Figure 4. Deep weathering saprolite in granite, near Pikes Peak, Colorado. Photo by author.

Results



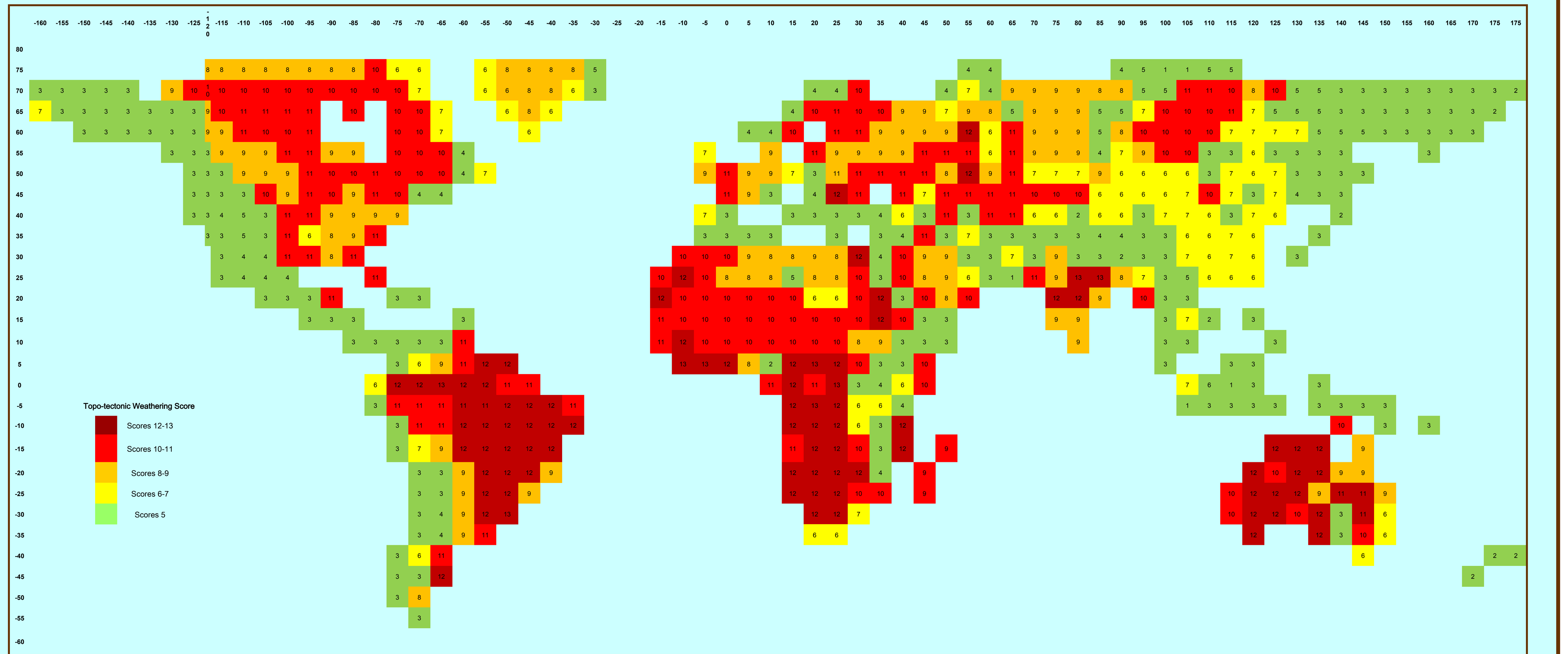




Location quotients	Alpine	C/H/A	Shields	Plains
Tropics	1.023	0.21	1.432	0.83
MidLatitudes	1.038	2.259	0.424	1.328

Location quotients — Between the Tropics and the Midlatitudes, there is no bias in the distribution of Alpine Orogeny mountain systems, compared to the global average. Older mountains of the Caledonide/Hercynian/Appalachian orogenies are more commonly found in all latitudes, but with a bias toward middle latitudes. Ancient shields, with exposed pre-Pleistocene erosion surfaces, are predominant in tropical latitudes. Shield areas covered by sedimentary rocks, the stable cratons, are more common in the middle latitudes.

Topo-tectonic factors — The gridded cell map below summarizes the addition of the three components: topography, structure, and age (examples of the three for South America are shown with insets to the left). Cells shaded red or maroon have a high score, a combination of older exposures, more subtle terrain, and lack of tectonic activity. These tend to be located over shield areas. Almost all of the highest-scored grids (maroon) are found in the tropics, particularly northern South America, Central and South Africa, India, and Australia. . This demonstrates the expectation of extensive weathering profiles coincides with topo-tectonic factors conducive to preserving weathering profiles. Deep weathering profiles are also seen outside of the tropics, for instance the Baltic Shields and portions of the Canadian Shield (Lidmar-Bergstrom, 1995), areas also shown with relatively high values (shaded red). Areas of Central Asia and northeast Siberia are not well researched for deep regolith, though Strakhov's model predicts reasonably deep saprolite in boreal regions. Deep regolith is also found in local areas of the Rocky Mountains, California Sierra Nevada, Spain, and Hong Kong, locations not indicating high values in the grid model. Locally preserved areas may have conditions of stability or protection against erosion, but much below the scale of this analysis.



Conclusions

Stable shield surfaces with long exposure histories do preferentially occur in the Tropics. The combination of abundant weathering agents, tectonic quiescence, and time lead to ideal conditions for the development of deep weathering profiles. Indeed, the cellular grid model of topo-tectonic factors appears to be strongly related to known regions of widespread deep weathering in the tropics. Definitive correlation and substantiation will require a globally complete dataset of weathering regolith, or proxy data by way of dissolved sediment load in major rivers.

These results support, in a circumspect way, the views of recent authors that deep weathering and related features (such as laterite) need not be associated with tropical conditions (cf. Molina Ballesteros and Cantano Martin, 2002). This megageomorphic study demonstrates the importance of non-climatic factors in weathering geomorphology. These factors should be more explicitly addressed in developing models of landscape evolution over long time spans.

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