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A Geospatial Investigation into Factors for Rock Weathering in the Contiguous United States

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Rock weathering is a natural process in which exposed rock is broken down. Though it is a natural process, weathering does not occur exclusively in natural environments; artificial rock structures (i.e. buildings, monuments, tombstones etc.) are at the same risk of weathering as any natural rock formation. The question is at what rate do rocks weather when exposed to particular factors? Little comparable research currently exists that attempts to illustrate modern rock-weathering patterns and their factors. Particularly, attempts to map weathering at continental scales are woefully outdated.

This study specifically focuses on a host of naturally occurring factors (precipitation pH, precipitation quantity, plant biomass, bedrock geology, temperature and temperature range), which are believed to either accelerate or decelerate the rate of weathering. Data gathered from the National Atmospheric Deposition Program, Northeast Regional Climate Center, United States Geological Survey, and the United Nations Food and Agriculture Organization were implemented into ArcGIS 9.3.1 for the initial analysis. Climate stations and other data recording sites yielded the information employed in this study. Using GIS techniques, these factors were analyzed in a raster format to find regions of the contiguous United States that are most susceptible to rock weathering.

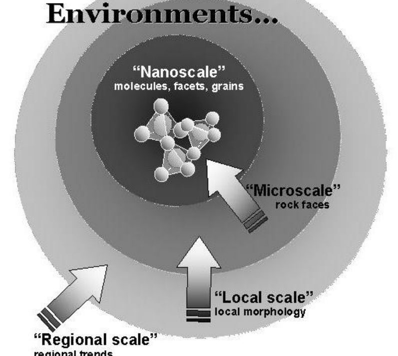
Key words: weathering, GIS, environmental factors

Mechanical Weathering refers to weathering that occurs without the presence of chemical agents. Usually temperature and pressure act on the rock, cause cracks or fractures and reduce the size of the rock.

Chemical Weathering refers to the weathering processes that include chemical reactions. It is a gradual process, usually in the presence of water. Dissolution, oxidation and hydration are important processes.

Relevance to weathering scales
Pope et al. (1994) contend that weathering processes take place at the micro- and nanoscale boundary layer of rocks and minerals. Environmental factors are most relevant at this scale. However, regional conditions filter down-scale (Figure 13). While there can be exceptions, it is likely that regional-scale factors influence the smaller scales, hence it is reasonable to try to predict and map weathering factors at large scales.

Fig. 13



Methods

- Deciding upon key factors in rock weathering
  - Precipitation quantity
  - Precipitation pH
  - Mean temperature
  - Temperature extremes (max temp-min temp)
  - Plant biomass
  - Bedrock geology
  - **See Explanation of Variables table**
- Convert measurements to z-score
  - Z-score allows for factors with different measurements to be compared
  - Z-score creates a standard scale
- Points manually plotted into ArcGIS 9.3.1 via X/Y coordinates
  - Applies to precipitation quantity and pH as well as the temperature data
- Vector data converted to raster layers
  - Plotted data, interpolated using Inverse Distance Weighted (IDW) interpolation
  - Bedrock geology simply converted to raster
  - Biomass converted from unknown format to usable raster format
- Each layer reclassified to 5 sub-categories
  - Each subcategory was assigned a number (1-5) and put on a scale where 1 represents areas least susceptible to weathering and 5 represents areas most susceptible to weathering
  - **See reference maps**
- Maps created for each factor
- Raster Calculator used for a simple overlay process
  - Allows for all factors to be analyzed at once
  - Works as a simple addition problem, each cell has a value of (1-5) and when laid over each other the values are added
  - Weathering index of (1-30) is created when all factors are analyzed
  - Areas with lower values have a tendency to weather more slowly, while the opposite is assumed for higher values

Explanation of Variables

Precipitation- Water is a necessary component for chemical weathering reactions; therefore more water means more efficient weathering. Water is also necessary for making ice in colder temperatures, which is a mechanical weathering process.

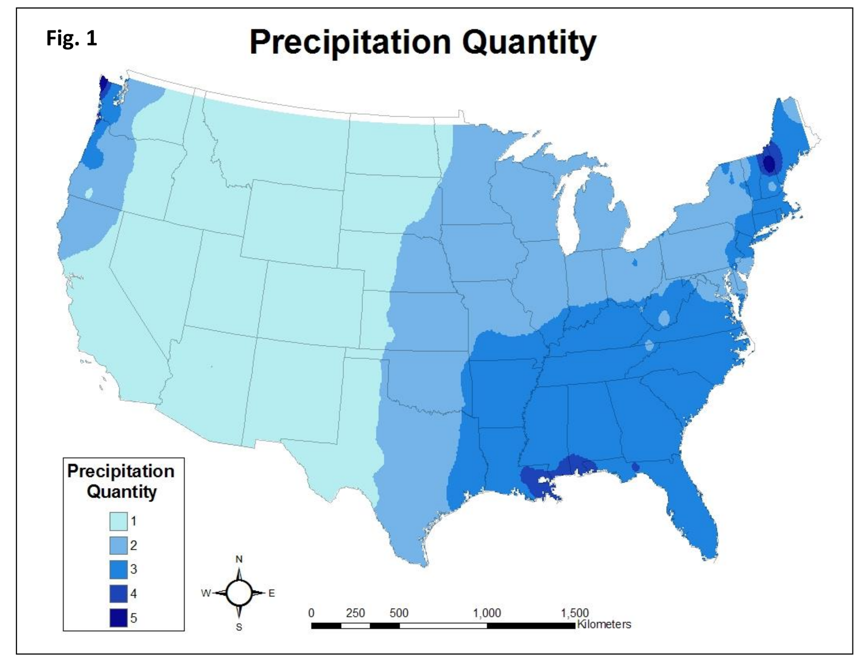
Precipitation pH- Acid is a chemical weathering agent. The more acidic (lower pH) the precipitation is, the quicker the weathering process is.

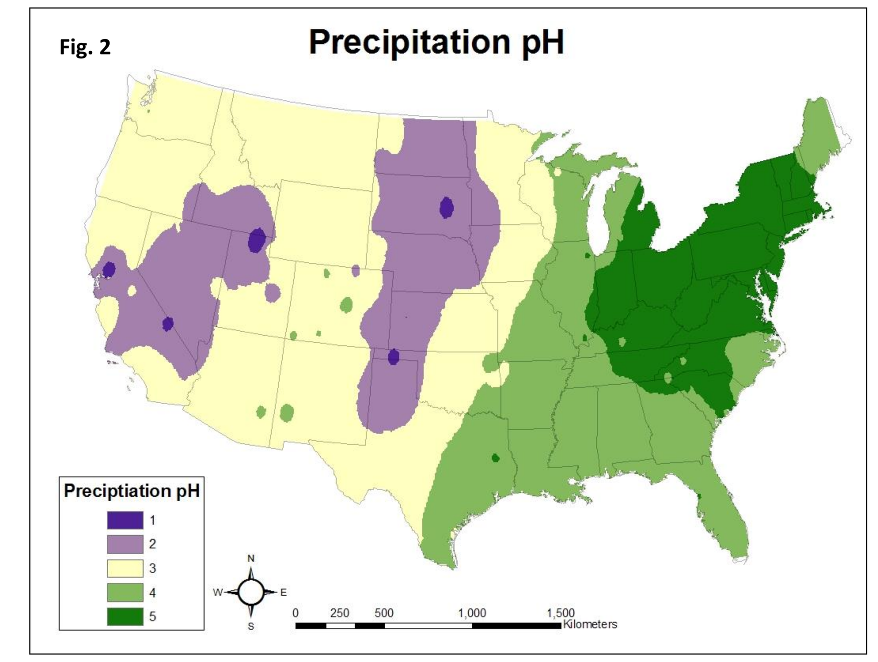
Biomass- Biomass is a proxy for organic chemical weathering agents. Where there is more biomass, there is a greater abundance of organic chemicals, which translates to more weathering.

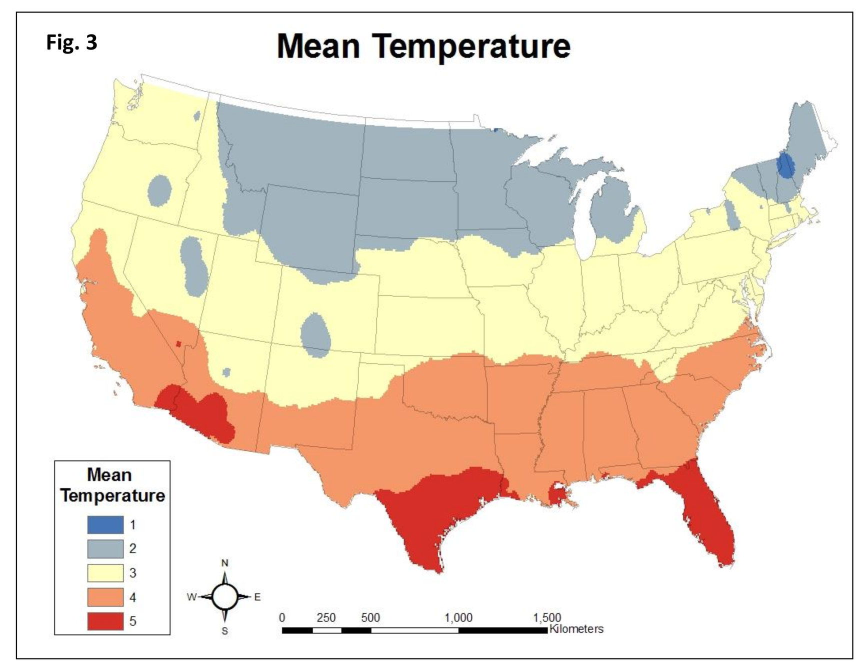
Bedrock Geology- The geology of a particular area refers to rock type. Certain rock types are more susceptible to weathering (chemical and mechanical). Generalizations were made in this case to order the rock types present in terms of weatherability.

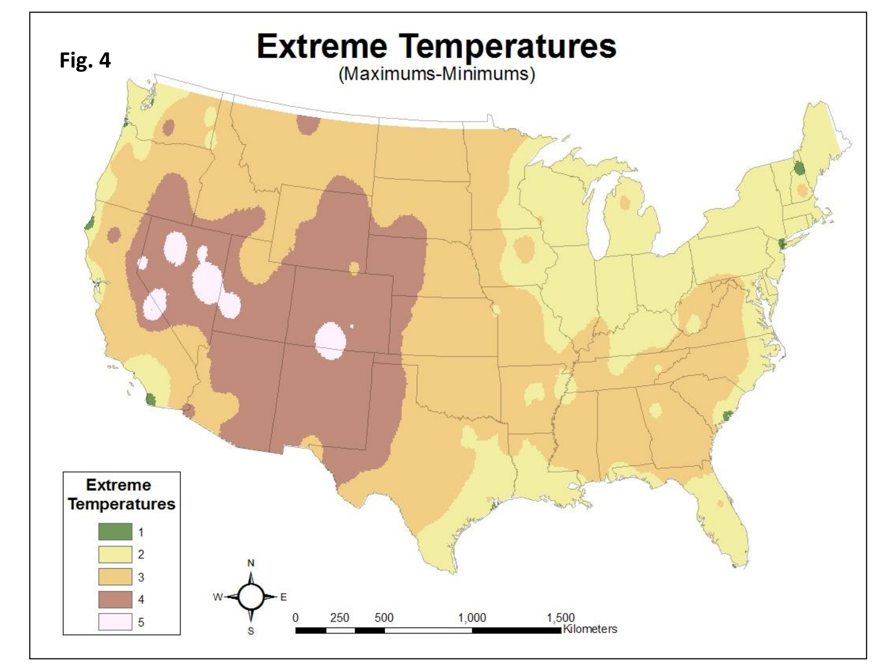
Mean Temperature- Temperature regulates chemical weathering reactions. In this case, higher mean temperature means faster chemical reactions and more weathering.

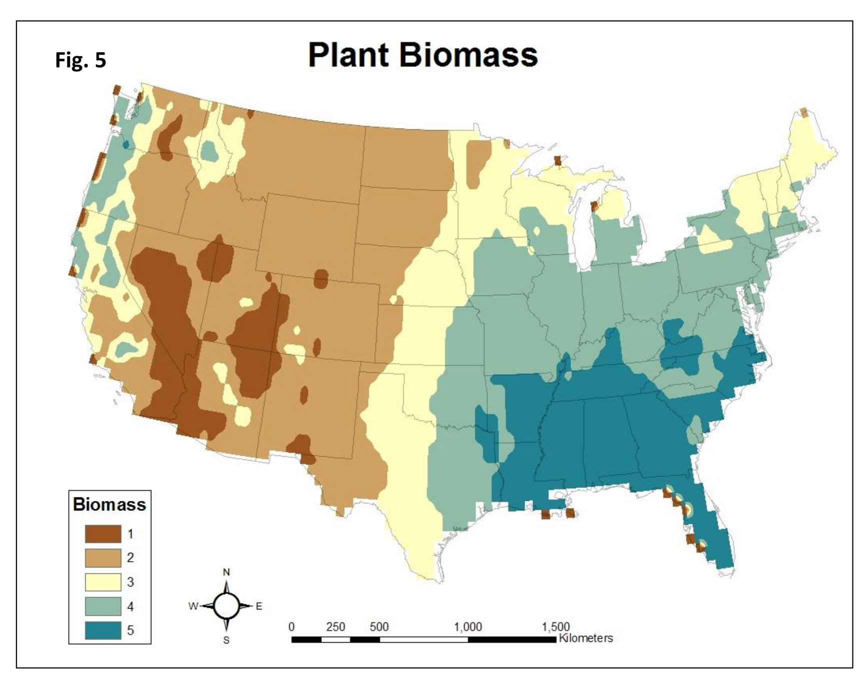
Max-min Temperature- The difference between maximum temperatures and minimum temperatures gives a range of temperatures that areas have experienced throughout the year. The more extreme this difference is, the more stress is placed on the rocks, which results in more mechanical weathering. It also serves as a proxy for freeze-thaw differences.

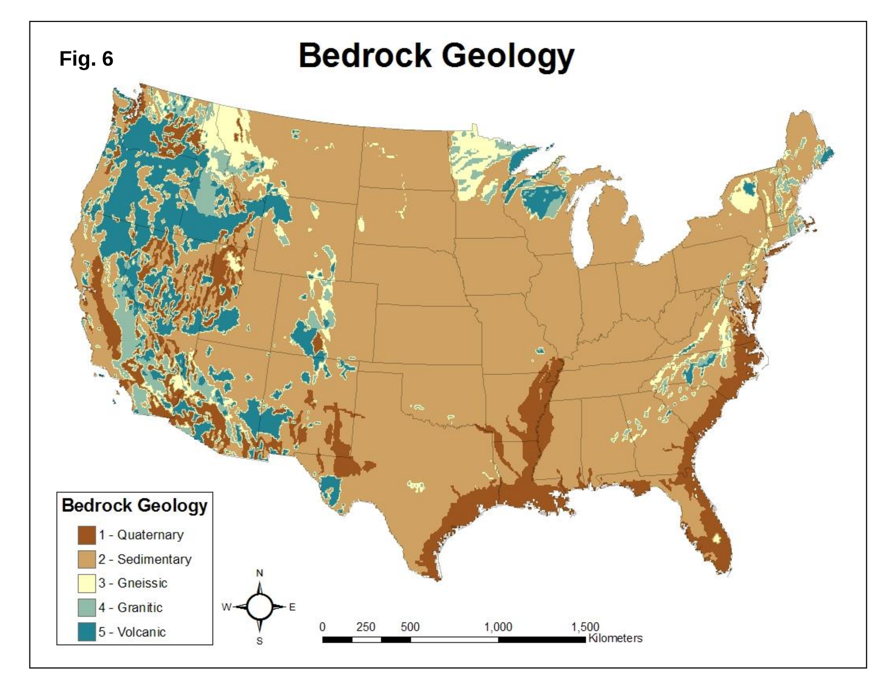








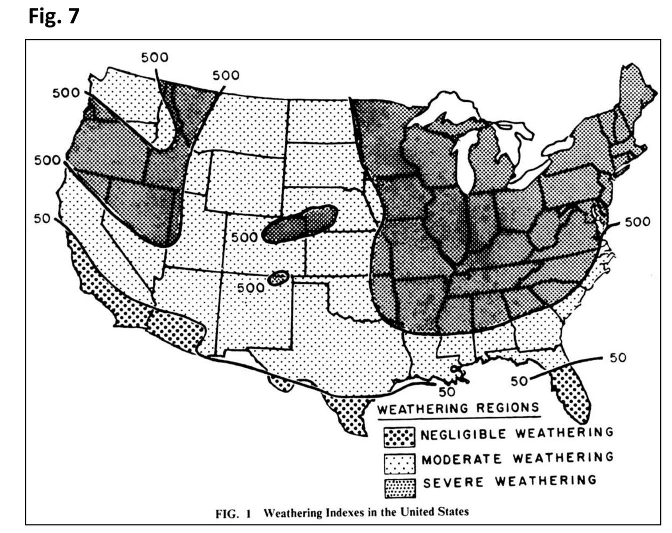




Discussion

- Factor maps were analyzed independently and again after the overlay process
- Precipitation quantity (see Fig. 1)
  - Most precipitation found in SE U.S. and Pacific NW
  - Least precipitation in SW U.S.
- Precipitation pH (See Fig. 2)
  - Most acidic precipitation in the NE U.S.
    - This is likely due to a long tradition of large-scale regional industry.
  - More neutral precipitation in the Western states
    - There is less concentration of industry
- Mean temperature (See Fig. 3)
  - Lower mean temperature in the Northern states
  - Higher mean temperature in the Southern states
  - This is a general, global trend.
- Max-min temperature (See Fig. 4)
  - Broadest range found in the Western states, most notably Nevada, Utah and Colorado
    - Desert areas generally experience extremes year round
- Biomass (See Fig. 5)
  - Tends to follow similar trends as precipitation
    - Highest precipitation would make for the highest biomass.
  - Highest biomass was found in the SE U.S. and Pacific NW
  - Lowest biomass was found in the SW U.S. (deserts)
- Geology (See Fig. 6)
  - Generalizations made about weatherability of rock types
    - "Most weatherable" rock types were found scattered around the country
    - Large sedimentary area, making up majority of the nation's bedrock type
  - Two final maps created, one map with the geology layer included, one map without the geology layer (See Figs. 11 & 12)

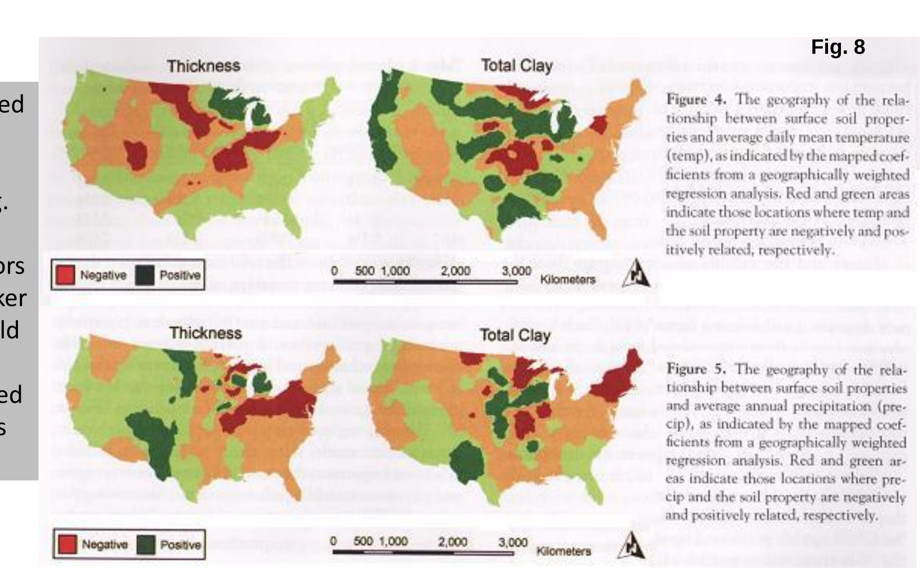
Fig. 7

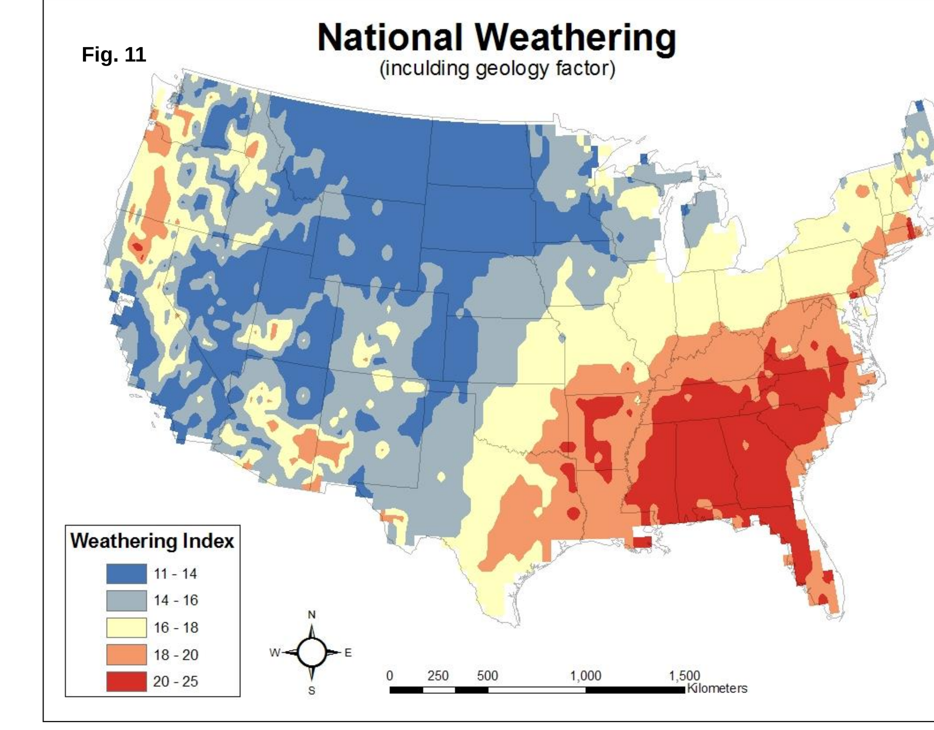


A comparable study was done 1985 that looks into the weatherability of building bricks throughout the U.S. (ASTM 1985) (Fig. 7). This study focused strictly on physical weathering factors (moisture and freezing cycles. It shows a similar, basic trend in weathering to our study map

Another study was done that created GIS maps based on correlations between soil thickness, total clay, temperature and precipitation. (Fig. 8) (Scull 2010). Soil thickness and total clay amount are good indicators for weatherability: areas with thicker soils and higher clay amounts should result from more intense weathering. This study of soil yielded similar results to our study. (Figures courtesy of P. Scull.)

Fig. 8





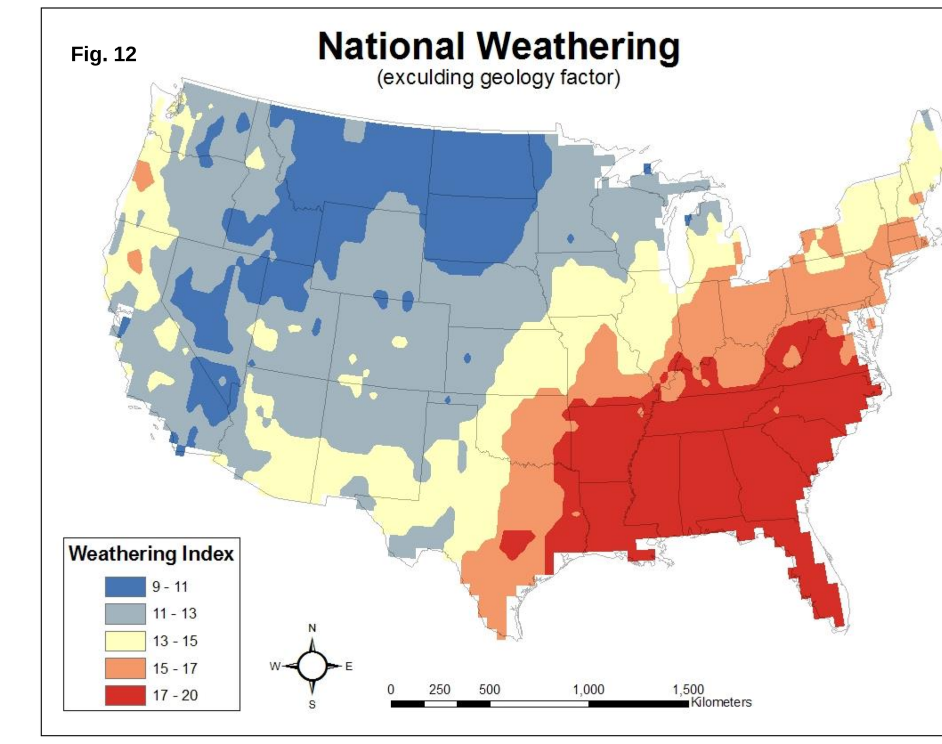
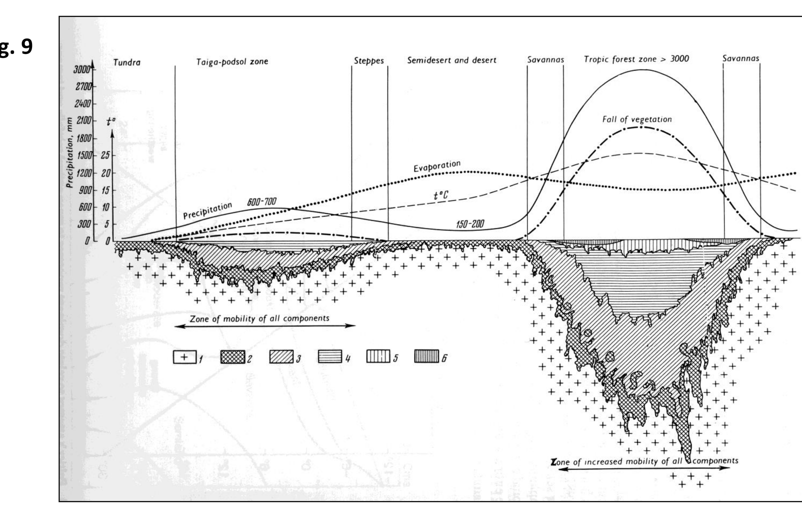
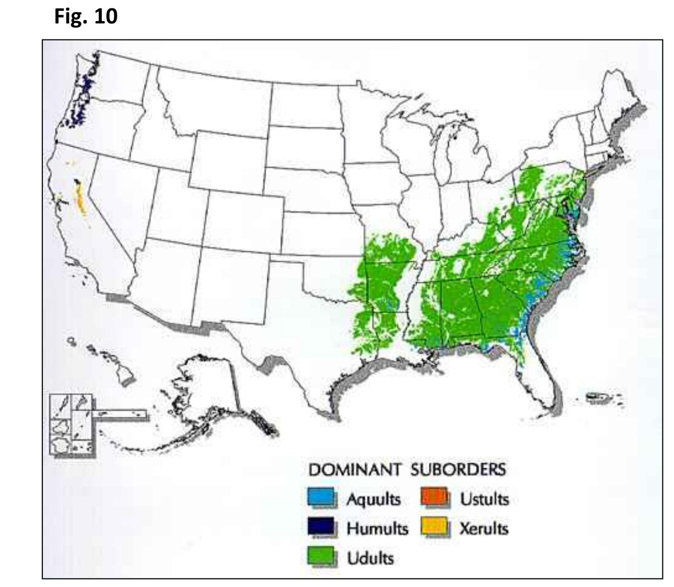


Fig. 9



Strakhov (1967) produced a similar study to Scull 45 years earlier based on soil thickness in different regions of the world (Fig. 9) He predicted that thicker soils are found where there is more biomass and precipitation (Tropics) and thinner soils are found where precipitation and biomass are scarce (polar and hot deserts). Strakhov's finding is similar to our study and supports our weathering regions.

Fig. 10



The location of older soils may also give an idea about how much weathering is going on in an area. (NRCS) (Fig. 10). The map shown focuses on the distribution of ultisols, final stage soils, in the United States. It shows a concentration of ultisols in the SE U.S., the same area that we've determined experiences the heaviest, most intense weathering.

Conclusions

The final maps show the extent of weathering in the U.S. as far as the included variables go. According to the maps, weathering seems to be quickest and most efficient in the SE U.S. and small portions of the Pacific NW. The same basic trends were seen regardless of the inclusion of the geology layer. The results were just more consolidated when the geology layer is omitted. The areas of most weathering were found where rainfall was heaviest and most acidic, where biomass values were highest, and where mean temperatures were highest.

Though the constructed index is rough, it still provides a substantial amount of information about the reality of weathering in the world of today. For future work, it is imperative to tighten current research and certainly to include additional variables. For the highest level of accuracy, it is important to include as many weathering factors as possible to avoid unfairly biasing other variables.

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