ON SOIL REMINERALIZATION FOR SUSTAINABLE AGRICULTURE AND CLIMATE STABILIZATION

A CALL FOR ACTION

by Fred B. Wood, IV and Fred B. Wood, III

This is the first of two articles – part one discusses the importance of remineralization in the context of glacial-interglacial cycles and the need for stronger remineralization programs; part two will discuss why remineralization should help stabilize climate under a wide range of climate scenarios.

Soil is part of the immune and nutritional system of vegetation. Healthy plants and trees require good soil – with adequate mineral content, organic matter, and microorganism activity. Currently, soils are being depleted due to a combination of natural forces associated with glacial-interglacial cycles and human activities such as nonsustainable agriculture, fossil fuel consumption, and deforestation.

Soil remineralization – using glacial rock dust and humus – can help restore the health of farms and forests. But for this to happen, as soil remineralization advocates, we must redouble our efforts to get remineralization included in local, national, and international sustainable agriculture, reforestation, and climate stabilization programs. Also, as advocates we must convince governmental and private sector leaders that remineralization deserves the immediate attention of those who wish to help stabilize climate and reduce the risks of global climate change.

The views expressed are those of the authors and not necessarily those of the CSIRI or other organizations with which the authors are affiliated.

Remineralization and Glacial-Interglacial Cycles

The rationale for soil remineralization is straightforward. The earth is presently in the later stage of the current interglacial. During late interglacial stages, soils are substantially depleted of key minerals due to natural processes.

Humans have further compounded this soil depletion through harmful agricultural and forestry practices, and through climate changes resulting from large-scale deforestation and consumption of fossil fuels. Soil remineralization can help offset or counteract the adverse effects of both natural and human processes.

Soil mineral content is closely tied to the glacial-interglacial cycles. Paleoclimatic, paleoecologic, and geologic evidence indicates that, for at least the last 2 million years, the Earth has experienced a series of such cycles. Each cycle consists of a glacial period lasting roughly 70,000–110,000 years followed by an interglacial period of about 10–12,000 years. The exact lengths appear to vary and are difficult to measure precisely, since the accuracy of dating techniques ranges from plus or minus several hundred to several thousand years. [1]

Nonetheless, the best scientific evidence (based on analysis of air trapped in ice, and of pollen trapped in ocean and lake sediments) indicates that the prior interglacial lasted from about 130–125,000 to 120,000–115,000 years ago – a period of 10,000 years. By numerous scientific accounts, the present interglacial started about 10–11,000 years ago.[2] Compared to the prior interglacial period, the Earth would appear to be in the late stage (near the end, in geologic time) of the present interglacial.[3]

The paleoclimatic and geologic records alone cannot tell us precisely how close to the end of the present interglacial we may be. Natural variability in the length of interglacials combined with measurement limitations mean that we could already be at the end of the natural interglacial cycle or we could be decades, centuries, or still even millennia away. Improvements in the accuracy of measurement techniques, including closer sampling of ice and sediment cores at the interglacial-glacial boundaries, should eventually provide more precise estimates.

The 1979 work of Genevieve Woillard in northeast France is one oft-cited effort to do more precise pollen analyses at the prior interglacial-glacial boundary. Sediment core was sampled in 250 micrometer thin sections at one millimeter intervals, with each millimeter equivalent to 6 plus or minus 3 radiocarbon years. The results indicated that changes from temperate – oak-elm-ash-hazel – to boreal (subarctic) – fir-spruce-pine-birch – forest vegetation took place within a 150 year time span, with key transitions perhaps in as little as 20 years about 115,000 years ago. The Woillard work has been interpreted as suggesting that interglacial-glacial transitions can occur in just a few decades, and that the Earth is presently in such a transition. Indeed, Woillard concluded that boreal forests replace temperate forests at the end of all interglacials, and that we "cannot exclude the possibility that we already live at the beginning of the present equivalent of the terminal interglacial pollen zone."[4]

For soil remineralization to be most effective, we need not know precisely where we are in the present interglacial--only that we are in the late interglacial stage that is characterized by mineral deficient soils. The immediate, critical concerns for human civilization are restoring health to the soils and stabilizing global climate. At or near the transitions between climate regimes, from interglacial to glacial, changing weather patterns are likely to adversely affect crop growing seasons in the temperate zones, further stressing agricultu-

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ral areas already hampered by soil deficiencies and water shortages. Without strong action, the result could be massive crop failures and widespread starvation.

The Soil-Vegetation Cycle

The mineral content of soil tends to degrade over time due to the natural recycling of forest and vegetation cover and the effects of local climate. For example, in a typical mid-latitude deciduous forest such as in the Shenandoah National Park in northwestern Virginia, U.S.A., the oak trees may have recycled 50 times over the last 10,000 years (assuming an average lifetime of 200 years). The organic and mineral content of the soil can be partially maintained by decayed plant and tree matter, but even in healthy ecosystems, the total mineral content is slowly depleted through natural cycling. Local rainfall and snowfall also can contribute to soil runoff and erosion--and the loss of key nutrients--although the effect is minimized if the natural vegetation and forest cover are preserved.

The analysis of pollens and soils from ocean and lake sediments and glacial loess indicates that soil quality and mineral content are highest in the early stages of an interglacial period and decline during the interglacial to the point where soil is substantially depleted at the onset of the subsequent glacial period. The vegetational patterns appear to correlate closely with soil quality.[5]

A typical European (western Ireland) successional pattern from a glacial climate through an early, middle, and late interglacial climate involves the following:

The soil shifts from skeletal mineral soils, to unbleached mineral soils, to fertile brown soils, and finally to peats and acid humus; the vegetation shifts from open herb assemblages, to juniper-birch-pine woodland, to pine-oak forest, and to yew-spruce-rhododendron and heather.

For comparison, a pattern in North America (Florida) involves, for soil, a shift from active sand dunes (glacial), to stable sandy soils (early-mid interglacial), to leached soils and peats (late interglacial). The vegetation shifts from open prairie vegetation, to oak scrub-hickory, to pine-oak woodland, to pine woodland with bogs and swamps.[6]

Depleted soils in the Northern Hemisphere mid-latitudes are eventually replenished in large part by glacial movements occurring over thousands of years. During the height of the last glacial period, about 18,000 years ago[7], major ice sheets covered much of what is now Canada, the northern United States, and northern Eurasia.

As these ice sheets grew, they ground up and transported large quantities of rock from mountains and valleys in their path. The slow advance of these ice sheets from about 110,000 to 18,000 years ago, and then their subsequent retreat from about 18,000 to 8,000 years ago, ultimately distributed "glacial rock" over much of the Northern Hemisphere mid- to high-latitudes, both by direct glacial movement of rocks and by water borne transport of glacial till and wind-blown spreading of glacial dust (known as loess) for hundreds and sometimes thousands of miles beyond the southernmost extent of the ice sheets.

This is one of nature's major ways of remineralizing the Earth's soils in the temperate and boreal regions of the Northern Hemisphere. Weathering of mountains and river basins--through seasonal weather events such as freeze-thaw cycles and storms--is another way; volcanic activity is a third way. The remineralizing effects of ice sheets in the Southern Hemisphere are much more limited, because the Antarctic ice sheet is surrounded by ocean and because, overall, the Southern Hemisphere has twice as much ocean area as the Northern Hemisphere. Some remineralizing does take place in areas in or near major alpine glaciers and ice caps (the Andes in South America). Overall, the areas remineralized through the glacial cycles include the bulk of the world's temperate and boreal forests. The other major forested areas lie in tropical zones--the tropical forests of Central and South America, equatorial Africa, and South and Southeast Asia. Tropical forests do not appear to depend as much on the soils for necessary minerals, but on complex multi-story ecosystems reaching from the ground to the tops of the tropical forest canopies. Tropical forest soils typically are thin and deficient in both mineral and organic content. Deforestation of many tropical forests has demonstrated that in these areas the soil denuded of its natural ecosystem cannot support vigorous forest growth.

Remineralization and Climate Stabilization

Over the last two hundred years or so, humans have been accelerating this soil demineralization through high-input, nonsustainable agriculture and through deforestation. In addition, humans have been burning fossil fuels that contribute both to climate changes associated with an enhanced greenhouse effect and to acid precipitation. The best available scientific evidence suggests that climate and pollution stresses, combined with declining soil quality, result in further deterioration of agricultural and forest lands.[8]

Soil can be viewed as part of the immune and nutritional system of vegetation. Healthy plants and trees require good soil--with adequate mineral content, organic matter, and microorganism activity--that provides nutrients to the vegetation and makes growth possible. Without proper nutrition, plants and trees--like people--are weaker, more susceptible to disease, and generally less able to withstand the stresses of life.

Soil remineralization should be an attractive adjunct to sustainable agriculture and forestry and reforestation, thereby contributing to climate stabilization. Soil remineralization is still limited largely to the small-scale organic agriculture community, and is not yet included in the action programs of the major governmental or environmental groups. To date, only very small, alternative environmental and organic agriculture groups are actively promoting soil remineralization, although these groups have powerful--but underutilized--evidence in the research reports from, for example, Austria and Germany.[9] (Interestingly, some mainstream scientific groups recently have supported a form of ocean remineralization.[10])

The absence of remineralization is particularly striking, given that remineralization, at least at the conceptual level, appears noncontroversial and scientifically sound, and that numerous other policy actions have been identified and supported by the major environmental groups. Many policy actions are now the focus of intense governmental and scientific scrutiny. The most commonly discussed types of policy actions include: energy and water conservation, natural resource conservation generally, renewable energy, recycling, sustainable agriculture and forestry, forest preservation, and reforestation.[11] Remineralization is a logical addition to the core list of possible climate stabilization actions.

Europe has a long tradition of remineralization research and, recently, application. The results, however, are not yet being used in European, U.S., or international climate programs.[12]

Need For Remineralization Action

Soil remineralization needs to become part of mainstream climate stabilization programs. Remineralization projects to date have been very small-scale, widely scattered, and lacking a coherent policy framework. The results of these projects, while compelling as a whole, generally have not been sponsored by established university and governmental agriculture and forestry research programs, and typically have not been written up in the referred scientific literature. This needs to change if soil remineralization is to get the attention it deserves.

Remineralization logically fits into the agriculture and forestry research programs of state, national, and international governments. In the United States, for example, remineralization should be included in the U.S. Department of Agriculture's soil conservation and forestry programs (perhaps with lead roles assigned to the U.S. Soil Conservation Service and U.S. Forest Service), and eventually in the Extension Service's many programs for assisting farmers, gardeners, and foresters at the local level.

Expedited pilot projects are needed to test a wide range of mineral additives (using a variety of glacial rock--including gravel and gravel dust from glacial valleys, streambeds, and other natural deposits--with different mineral compositions and particle sizes) under a range of soil, vegetation, geographic, geologic, and climatic conditions. The pilot projects also need to consider different methods for preparing (including grinding), transporting, storing, and applying the glacial rock dust--alone or in combination with organic matter (humus, compost) and/or water (a glacial slurry).

The results should help identify the remineralization strategies that are optimal for both domestic and foreign sustainable agriculture and forestry and reforestation. Undoubtedly, the optimal methods of application will vary widely. For example, on the low end of the scale of difficulty, farmers with a level terrain and preexisting fertilizing equipment should be able to spread or spray glacial rock dust just as they would any other fertilizer. At the high end, foresters dealing with a rugged terrain where fertilizing equipment does not work may need to resort to "volunteer" hand application, supplemented by aerial spreading by helicopter or airplane in priority areas.[13]

As remineralization advocates, we need to redouble our efforts to prove that remineralization works and convince governmental, agricultural, forestry, environmental, and climate change officials at all levels to support remineralization.

As private citizens, we should take to heart the Earth Day 1990 motto "think globally, act locally." Here are some action steps we all can take:

1. Experiment in our own gardens and farms using different combinations of glacial rock dust and humus to remineralize soils for growing vegetables, fruits, flowers, and trees. Use standardized methodologies and keep a record of the experiment and the results, with standardized reporting formats, so that the pilot tests will be scientifically valid and the test results will be publishable.
2. Ask our local, county, or state agricultural department or extension agency to develop the capability to test glacial rock (and dust) for mineral content, just as many now test for soil acidity.
3. Encourage local garden supply, hardware, and farm supply stores to carry glacial rock dust in both convenient bags (e.g., 10, 20 and 50 pound sizes) and in bulk quantities.
4. Seek local, state, or federal financial support for pilot tests of remineralization, for example as part of urban tree planting and rural reforestation programs.
5. Encourage local organic food stores and cooperatives to carry literature on remineralization and related advocacy groups.
6. Ask our local or county agricultural extension agent to carry literature and provide information packets and basic instruction on remineralization. This usually will first require training of the extension staff itself in remineralization theory and practice.
7. Collaborate with local tree planting and organic farming groups so that remineralization becomes part of their overall strategy.
8. Encourage local elementary and secondary schools to include remineralization projects as part of their science, ecology, and nutrition classes.
9. Ask local and state science museums to include remineralization information booths and demonstrations as part of their exhibits.
10. Discuss remineralization in letters to the editor of our local newspapers, and meet with the science editor (or other reporter) to propose a news or science feature story on remineralization.
11. Collaborate with local community college or university faculty in departments of agriculture, ecology, forestry, nutrition, and the like to encourage them to teach remineralization in their classes and write scientific papers on remineralization results for publication in referred journals.
12. Suggest remineralization projects to local 4-H, Brownie, Cub Scout, Girl Scout, Boy Scout, and similar youth organizations with an outdoor orientation.
13. Write up articles on remineralization for publication in newsletters and journals of the mainstream (as well as alternative) scientific and environmental groups.
14. Write letters and meet with officials of the local, national, and international environmental and climate research programs to insist that remineralization be included.

In Conclusion

A wide range of concerned scientists and citizens are advocating action now to reduce the risks and adverse impacts of nonsustainable agriculture, deforestation, and fossil fuel consumption under a range of climate change scenarios (global warming to cooling and anything in between).

Soil remineralization is one of those actions that seems viable and helpful, regardless of what the future may hold. If this analysis is correct, soil remineralization deserves a place in the consensus package of climate stabilization actions being developed by concerned environmental, scientific, governmental, and industrial groups. But as remineralization practitioners and advocates, we are going to have to redouble our efforts, along the lines outlined above, if we wish to see the vision of remineralization become a widespread reality in the near future.

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REMINERALIZE THE EARTH TO REDUCE CARBON DIOXIDE

A CALL FOR ACTION

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*This is the second of two articles – Part One (**Remineralize the Earth,** Winter 1991, pp. 32-35) discussed the importance of remineralization in the context of glacial-interglacial cycles and the need for stronger remineralization programs; part two discusses why remineralization should help stabilize climate by reducing atmospheric carbon dioxide.*

Paleoclimatic (prehistoric climate) data indicate that the Earth is in the late stage of the present interglacial (see *Remineralize the Earth,* Winter 1991, pp. 32-35.[1]) but we are not sure how the natural late interglacial climate process interacts with anthropogenic "manmade" climate forcing due to greenhouse gas emissions and deforestation. We do know that the climate forcing is unprecedented in magnitude and rate of increase; paleoclimate data suggest that the Earth has not faced such a forcing for several million years and perhaps longer. Climate monitoring and modeling are fraught with uncertainties and complexities, leading to a variety of climate change scenarios. Scientific uncertainties may take years to resolve. In the interim, the prudent course of action is to stabilize and then reduce atmospheric concentrations of greenhouse gases as soon as possible. Soil remineralization can play a significant role by helping to increase the global biomass (e.g., forests and vegetation) which through photosynthesis serves as a major sink that absorbs atmospheric carbon dioxide.

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Soil Remineralization and Climate Change

Soil remineralization has not yet been widely accepted in part because it has been caught up in the larger debate over the nature and direction of global climate change. The idea of "fertilizing" or "remineralizing" some forest and agricultural soils with high mineral content glacial or volcanic rock dust has recently attracted attention not only for sustainable ("organic") farming, but as a way to increase vegetation productivity and CO_2 uptake and thereby help stabilize climate.

The scientific rationale for soil remineralization, outlined in part one of this two-part [2] series, is based on paleoclimatic and paleoecological data that indicate: (1) the Earth is presently in the later stage of the current interglacial period; (2) during late interglacial stages, soils are substantially depleted of key minerals due to natural processes; and (3) a primary source of "natural" high mineral content fertilizers is glacial and volcanic rock.

Small-scale organic farmers in the U.S., Europe, and elsewhere have successfully used high mineral content rock dust to improve soil quality and vegetation productivity.[3] It is well established that healthy plants and trees require good soil–with adequate mineral content, organic matter, and microorganism activity–that provides nutrients and makes growth possible. Properly mineralized soil is a necessary but not, of course, by itself a sufficient condition for healthy vegetation. Other factors such as temperature, water, pollution, and urbanization all affect the health of plants and trees.[4]

Scaling soil remineralization up from small farms to large geographic areas should increase vegetation productivity and photosynthesis enough to make a significant contribution to reducing atmospheric CO_2, since the global biomass is a major sink for (i.e., absorbs a large amount of) atmospheric CO_2.[5] Remineralization should be an important adjunct to reforestation and sustainable agriculture which are among the most promising opportunities, along with renewable energy (including bioenergy) as a direct substitute for fossil fuels, to help stabilize and then reduce atmospheric CO_2.[6]

Remineralization should help improve the health of already established temperate and boreal forests, augment tropical reforestation programs, and complement a wide range of other organic farming techniques (such as crop rotation, conservation tillage, integrated pest and weed control, and low input irrigation).[7] Remineralized forests and farms should be more resistant to the ravaging effects of drought, insects, acid precipitation, fire, and weather extremes, all other things being equal.[8] As an added benefit, remineralization should help improve human health through more nutritious food.[9]

Additional research is needed, however, to analyze remineralization from three related perspectives: (1) carbon and other biogeochemical cycles of both vegetation and soil, to ensure that atmospheric CO_2 and other greenhouse gases indeed would be reduced through remineralization, all other things being equal; (2) energy and environmental requirements, to ensure that the greenhouse costs of the energy and environmental impacts of sourcing, grinding, transporting, storing, and applying the rock dust would not offset the greenhouse reductions anticipated from increased photosynthesis of the remineralized vegetation; and (3) engineering and technical requirements, including pilot tests, to ensure that remineralization is feasible under a range of soil, vegetation, geographic, geologic, and climatic conditions.

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Analyses of a conceptually similar proposal to fertilize ocean surface waters with iron (and thereby stimulate growth of phytoplankton) have identified a significant potential to sequester CO_2 but also possible scientific and practical limitations.[10] We believe that the odds are much better for large-scale soil remineralization to work and that the logistical problems, however challenging, are much less onerous on land than at sea.

In sum, remineralization should help significantly increase the size and health of the biomass, which in turn should result in greater photosynthesis and a lower level of atmospheric carbon dioxide (or a reduced rate of CO_2 increase), all other things being equal. But to date, the debate over the nature and direction of global climate change has diffused or diverted attention from using soil remineralization to help stabilize carbon dioxide levels.

Finding answers to the climate change puzzle is not easy, given the immense complexity of the climate system. This system involves the interaction of many variables: the atmosphere, oceans, cryosphere (snow and ice), land masses, and biomass (plants, animals, humans), as well as solar, volcanic, glacial, and probably other geologic, geophysical, and biogeochemical cycles. Systems science is essential to both modeling and monitoring climate complexity.[11]

More comprehensive climate monitoring is urgently needed--monitoring that reflects the complexity of the "real-world" climate system.[12] For example, zonal and regional temperature trends need to be carefully monitored in order to validate and determine where the hemispheric and global trends are actually occurring. We need to better understand how temperature changes vary by tropical, temperate, subarctic, and arctic zones, and by key climatic regions such as the Tibetan high plateau and Canadian tundra. And monitoring of seasonal extremes (e.g., record high and low temperature, rainfall, snowfall, frost/freeze dates, thaw dates) deserves high priority, since the extreme weather events may have as much or more impact on forests and farms than changes in long-term climatic averages.[13]

Need to Stabilize Trace Gas Concentrations

Despite the uncertainties and complexities of climate change, many global climate researchers emphasize the urgency of stabilizing and then reducing the concentration of trace gases in the atmosphere. These researchers cite the exponential increase in carbon dioxide and other radiatively active trace gases that already are at higher levels of atmospheric concentration than at any time in the last 160,000 years and, quite likely, much longer (probably millions of years).[14] The researchers believe that this increase in trace gases is so large and so rapid that the global climate change will occur on a much faster time scale than a naturally-occurring interglacial-glacial or glacial-interglacial transition. Most researchers believe that if left unchecked, the trace gas emissions and subsequent climate change likely will outstrip the ability of natural and human systems to adapt, with severe adverse consequences for the Earth and its inhabitants (plants, animals, and humans). A minority of climate change researchers remain unconvinced that increasing greenhouse gas concentrations pose a serious threat.[15]

Many global climate researchers also agree that trace gas-induced climate change is likely to occur very rapidly--on the scale of years to decades, not centuries to millennia. They cite the growing paleoclimatic, paleoceanographic, and paleoecological evidence that critical shifts in, for example, wind patterns, ocean currents, and vegetation assemblages can occur in just a couple of decades--even though the full transition from interglacial to glacial conditions (and vice versa) takes millennia.[16]

The fact that the atmospheric concentration of carbon dioxide is increasing more than 100 times faster than natural variability indicated in the paleoclimatic record,[17] and at 354 ppm is already well above the peak levels (of 290-300 ppm) recorded during the last two glacial-interglacial cycles, lends credence to this concern.[18] The early part of this recent increase in atmospheric carbon dioxide correlates in time with the widespread clearing of forest lands for agriculture during the 1800s. The latter part of the increase correlates with the rapid increase in fossil fuel consumption and urbanization during the 1900s, augmented by rapid tropical deforestation since the 1950s.

The paleoclimatic record suggests that a significant (50 percent) increase or decrease in atmospheric concentration of CO_2 from pre-industrial levels could destabilize global climate.[19] We have concluded that the interglacial level of atmospheric CO_2 (around 280-290 ppm for the last 10,000 years, until the agricultural/industrial revolutions) is at a critical and quasi-stable threshold.

For much of the last 1 billion years, atmospheric CO_2 and surface temperature were much higher than at present. Over the last 100 million years, CO_2 and temperature declined to the levels that permitted the onset of the Ice Ages over the last 2 million years or so (the "Quaternary"). During the Quaternary, paleoclimatic data suggest many glacial-interglacial cycles, each roughly 100,000 years long with a 90,000 glacial period and 10,000 warm interglacial, on the average. The Earth is presently in the later stages of the present interglacial (the "Holocene") which commenced about 10,000 years ago[20]. During the Quaternary, CO_2 appears to have ranged from a low of about 200 ppm (during the peak of the glacial periods) to a high of about 300 ppm (during the peak of the interglacial periods).

In sum, it appears that the Earth's climate has somehow arrested the long-term decline in CO_2 and temperature to achieve a quasi-stable state that oscillates between glacial and interglacial levels. The Earth's climate has been stable or quasi-stable during the Quaternary apparently because somehow the negative feedbacks in the system dominate and are self-correcting, keeping the climate from getting too cold and glaciated or from getting too warm. However, we have concluded that the climate system is likely to become unstable if pushed very far outside of the Quaternary range.

The feedback effects of stratospheric aerosols (from volcanoes), tropospheric aerosols (from pollution), clouds, and the like, still leave much uncertainty about climate change. Nonetheless, the available evidence from the Phanerozoic (last 600 million years), Quaternary (2 million years), and Holocene (10,000 years) is consistent with our central hypothesis--that major changes in atmospheric CO_2 are likely to destabilize climate–even though the climate feedbacks themselves are not well understood.

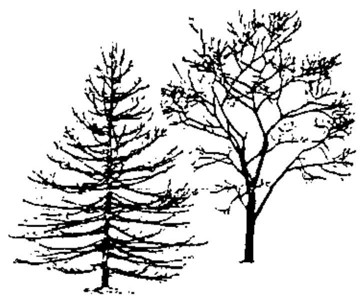
Our conclusion is that the prudent approach is to stabilize and then reduce CO_2 (and other radiatively-active trace gases) as soon as possible, at least until we have much better knowledge about precisely what level of elevated CO_2 would be likely to destabilize the climate system. (There is the theoretical possibility that lowered CO_2 could likewise destabilize climate, but this appears at present to be a very unlikely prospect.) We also base our conclusion on the paleoclimatic record which strongly suggests that major climatic shifts can take place in as little as 20 years, and that CO_2 at 354 ppm is already about 25 percent above preindustrial interglacial levels (and 75% above glacial levels). Since we do not know exactly what CO_2 levels might trigger major (and possibly irreversible) climatic change, and by the time we find out it may be too late to take preventive action, the prudent course is to first stabilize, then reduce.

Remineralizing Under Climate Uncertainty

Soil remineralization can be implemented under a wide range of climate change scenarios. It may take many years to resolve climate complexities and uncertainties, but remineralization can be carried out much sooner. As discussed in part one of this two-part series[21] as soil remineralization advocates, we must redouble our efforts to demonstrate and communicate to the research and policy communities that remineralization works.

Overall, the risks of climate change appear to be high, and the outcome seems much more likely to be harmful than beneficial--and possibly even catastrophic--to human civilization. Over the last few thousand years, climate changes of comparable (or perhaps lesser) magnitude have severely disrupted regional or continental human settlement patterns, with major impacts on food, water, health, and the viability of tribes, communities, and even nation-states and empires.[22]

Many climate researchers agree that one of the greatest risks is increased climate variability. The recent rash of record high and low temperatures (and precipitation)[23] cannot yet be clearly attributed to anthropogenic forcing. But these climate extremes provide a foretaste of what might be expected if the global climate were to be sufficiently destabilized. Many ecological and agricultural systems would be severely threatened if weather ex-



tremes continued for several years in a row. Indeed, short-term climate variability may turn out to be more important than long-term annual averages.

Thus it is incumbent that, as soil remineralization advocates, we urge remineralization action now to help stabilize atmospheric CO_2 and reduce the risks and mitigate adverse impacts under a range of climate change scenarios. We need to present soil remineralization as one of those actions that will be viable and helpful, regardless of what the climate future may hold. In essence, we need to uncouple soil remineralization from any particular climate change scenario, in order that remineralization may go forward years (and perhaps decades) before the climate debate ultimately may be settled. We have no time to lose. If we wait until climate uncertainties are resolved, it may well be too late to avert harmful consequences for human civilization.

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