Climate and Parent Material Controls Over C Storage and Dynamics in California Upland Soils

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Summary

A horizon C storage is governed by climate parameters, peaking where intermediate levels of temperature and precipitation coincide. Compared with granitic soils, basalt soils are generally finer textured, but we found no discernable difference between granite and basalt soils along the climate transects, so our data do not support the hypothesis that texture controls bulk C storage.

Whilst bulk C is controlled by climate, its distribution across laboratory-separated fractions is governed primarily by texture and/or aggregation, and only secondarily by climate parameters.

Relative to basalt soils, we found more mineral-bound C per unit clay and more sensitivity of mineral-bound C to clay in granite soils. So, although texture is an important parameter governing soil C storage, the manifestation of that effect depends on parent material. We do not believe this to be a mineralogy effect (kaolins dominate the clay phases of both soils types), but it may be linked to differences in aggregation structure.

The chemically recalcitrant C fraction was higher in basalt than in granite soils and showed distinct responses to texture in the two soil types.

Objectives

Our objective is to understand how parent material affects soil organic carbon stability directly and in conjunction with climate. There are two phases to this project:

A. To use laboratory fractionation followed by accelerator mass spectrometry (AMS) natural abundance radiocarbon (^{14}C) measurements in paired pre- and post-bomb samples to determine carbon dynamics in A horizons of a basalt climate transect and compare with existing results for a granite climate transect.

B. To conduct laboratory incubations and use ^{14}C measurements of evolved CO_2 to determine the relative influence of climate and parent material on the dynamics of more rapidly cycling organic material in the O and A horizons.

Existing data from the California cooperative soil vegetation survey, a reconnaissance of California forest ecosystems, enabled direct comparison of three pairs of granite and basalt soils along the climate transect (Allardice et al. 1983; Begg et al. 1985). As shown in figure 1, despite higher clay content of the basalt soils, especially in the B horizon, pairs of granite and basalt soils have surprisingly similar bulk % C profiles. Yet the lower C/clay ratio of the basalt soils would suggest a higher proportion of mineral-associated organic matter, with higher degree of humification, lower C/N ratios, and, potentially, a less dynamic response to climate.

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Approach and Procedures

Table 1 describes the two climate transects, one on Plio-Pleistocene vesicular olivine andesitic basalt soils, on the southern flank of the Cascade range (Lydon et al. 1960; MacDonald and Lydon 1972) and one on Jurassic granodiorite, on the western slope of the Sierra Nevada range. These soils, initially sampled during the course of the California cooperative soil-vegetation survey between 1954 and 1973, were re-sampled in 1992 (granite) and 2000 (basalt). In selecting candidates for our study, a key criterion was constancy of parent material. Because the higher-elevation Cascade soils were formed from ashy and/or andesitic material, our basalt transect does not extend as high as its granite counterpart.

Table 1. *Soils used in this study. Source: (Allardice et al. 1983; Begg et al. 1985). The Walong series was not included in (Trumbore et al. 1996) and is listed solely for comparison with Guenoc in Figure 1.*

Sierra granite transect soils:

Series	MAP (cm)	MAT (° C)	Elev (m)
Fallbrook	31	17.8	470
Walong*	76	15.6	549
Musick	94	11.7	1240
Shaver	102	8.9	1780
Corbett	106	8.0	1950
Chiquito	127	3.3	2890

Cascade basalt transect soils:

Series	MAP (cm)	MAT (° C)	Elev (m)
Guenoc	68	16.1	430
Jimmerson	91	13.9	774
Cohasset	63	9.4	989
Arkright	101	13.3	953
Cohasset 2	139	7.8	1588

Along the granite transect (Trumbore et al. 1996) used density followed by acid base hydrolysis to isolate three soil carbon pools with distinct turnover times (see description in Trumbore and Zheng 1996). Along the basalt transect we use essentially the same method, but following on the results of exploratory work, we made three important adjustments: We remove roots to minimize variability in the % C of bulk soil and ^{14}C of the light fraction. We sonicate before density separation to improve the separation between mineral-free and mineral-associated organic matter. And we remove the iron-dominated pool (> 3g/cc), which can cycle very rapidly, before performing acid/base hydrolysis on the halloysite-dominated dense fraction (2-3 g/cc).

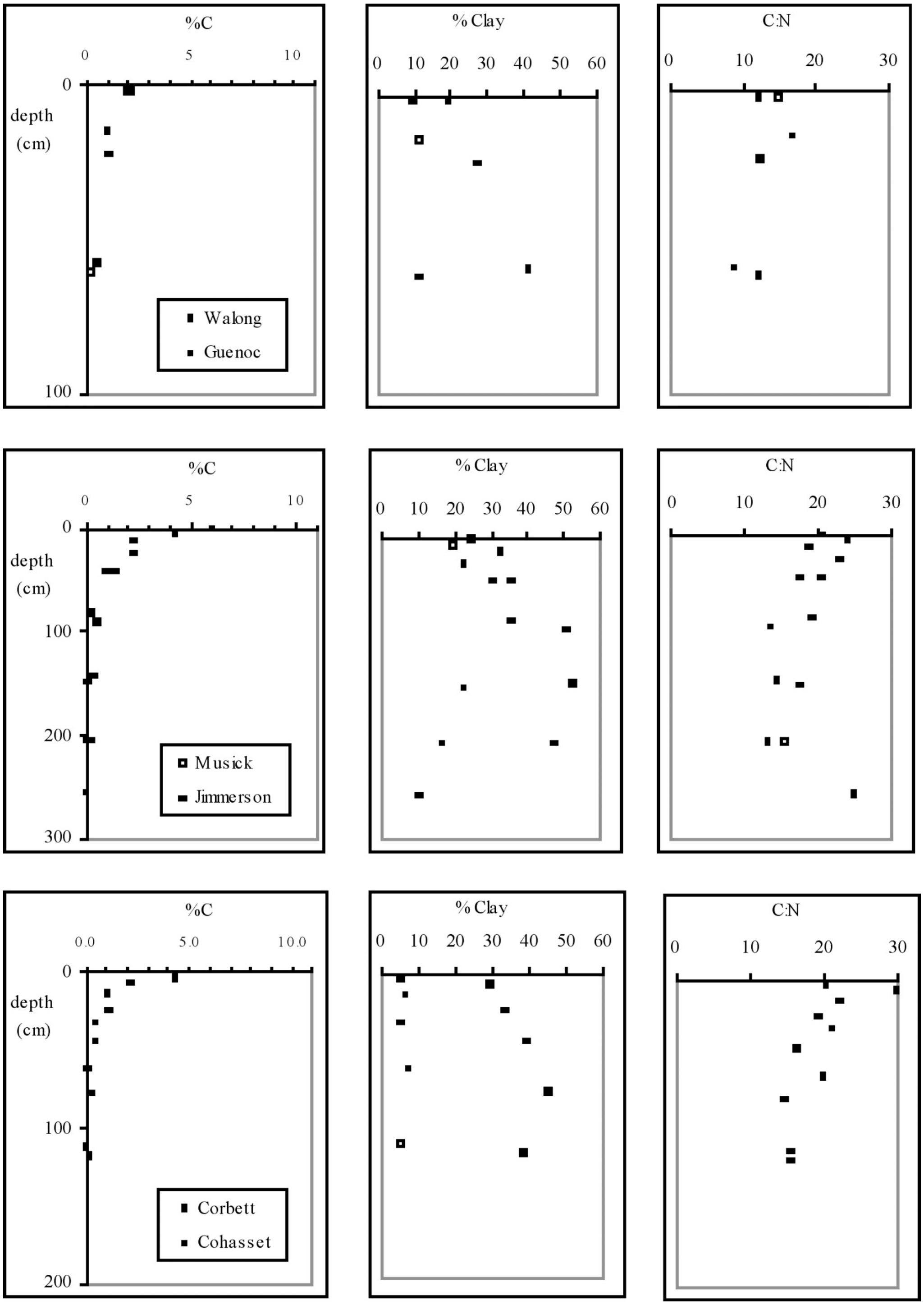

Figure 1. % C, C/N, and clay depth profiles for three pairs of granite and basalt soils that experience very similar mean annual temperature and precipitation (Allardice et. al. 1983 and Begg et. al. 1985).

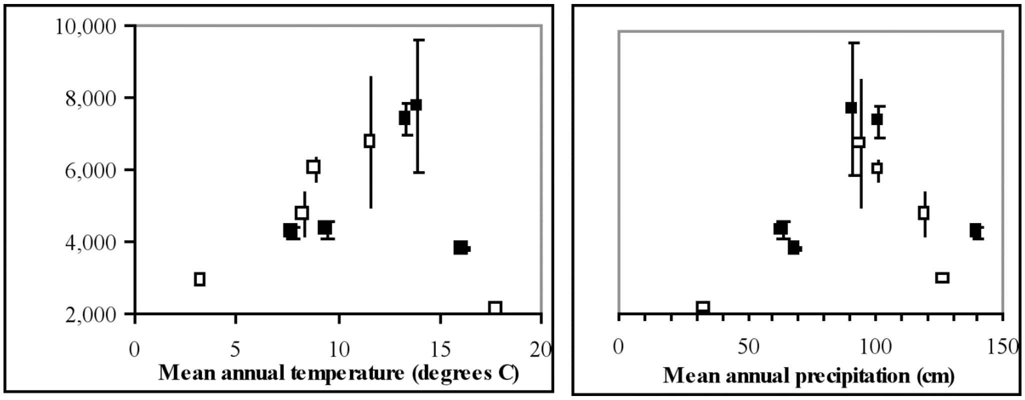

Figure 2. C inventory to 20 cm by mean annual temperature and precipitation. C inventory to 20 cm was estimated based on cumulative C functions of the form cumulative C = a ln [(b+depth)/b]. The concordance correlation between measured and estimated C inventory averaged 0.999 and was greater than 0.997 for all cases. Error bars represent the range in values for modern versus archived soils and reflect variability in measured % C, bulk density, and coarse fragment values.

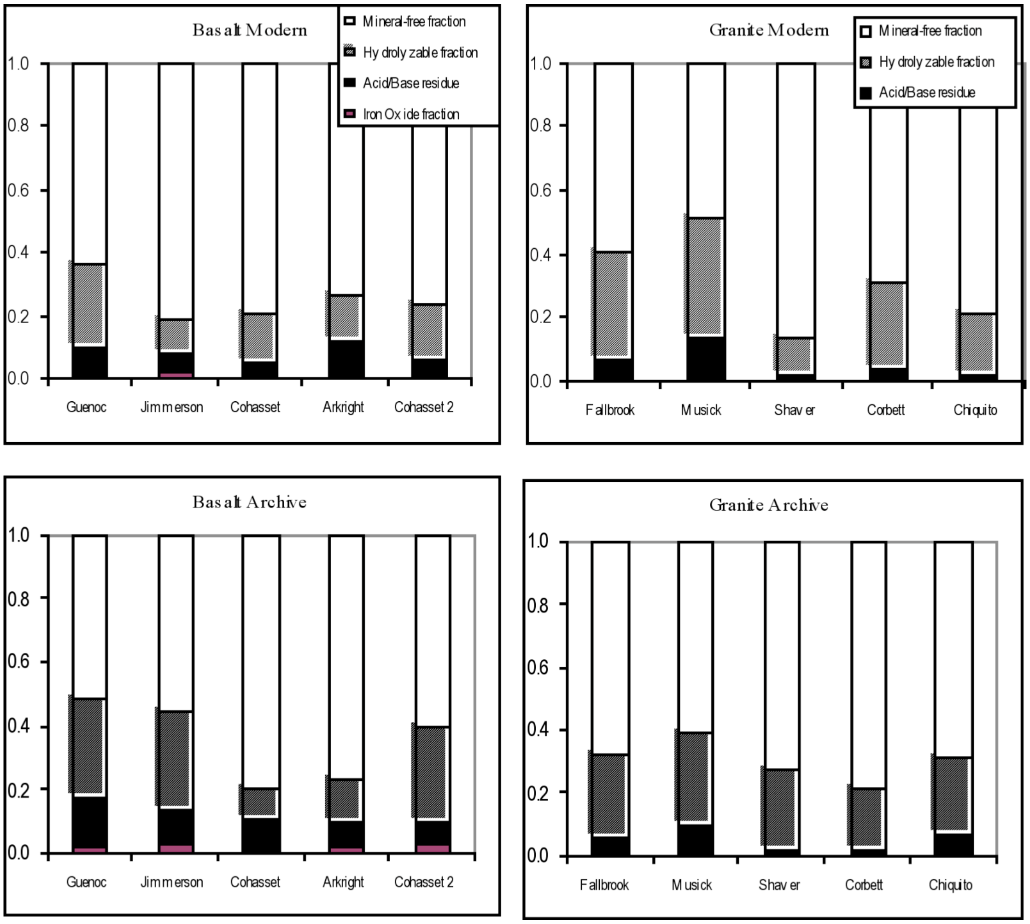

Figure 3. Proportion C across laboratory fractions by soil and sampling date (A horizon only).

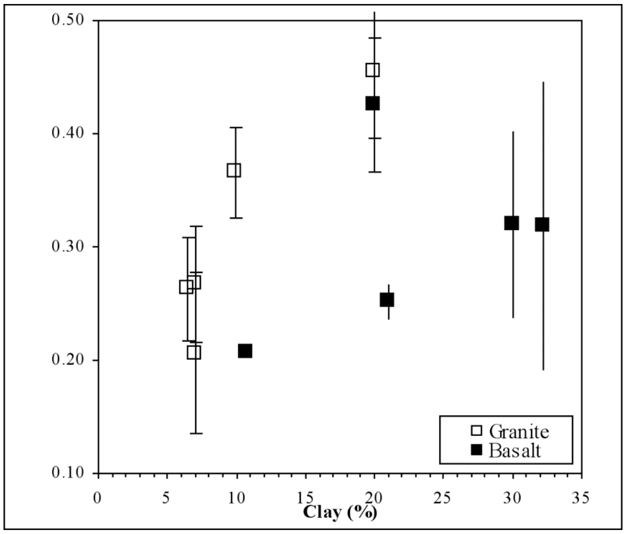

Figure 4. Mineral-bound C as proportion of total C by % clay. Error bars represent the range between modern and archive results.

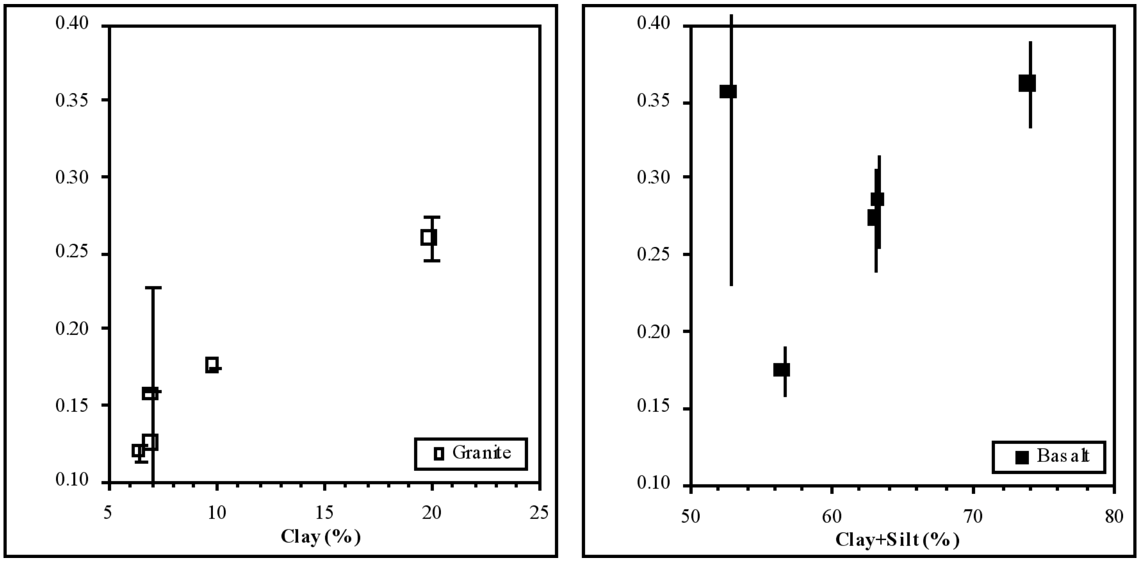

Figure 5. Chemically recalcitrant C as proportion of mineral-bound C by texture for granite and basalt soils. Error bars represent the range between modern and archive results.

Results

Depth-adjusted C inventory estimates by mean annual temperature (MAT) and mean annual precipitation (MAP) are shown in figure 2. Despite gaps along the transect and differences in the relative position of basalt and granite soils, the data suggest that C inventory peaks near MAT equal to 14 º C and MAP equal to 90 cm, with no discernable difference between granite and basalt transects.

Basalt soils were separated into three density fractions (<2, 2-3 and >3 g/cc) and one chemical fraction, whereas granite soils were separated into two density fractions (<2 and >2 g/cc) and one chemical fraction. The proportion C by laboratory fraction is shown in figure 3. The mineral-free fraction (< 2 g/cc) has the highest proportion of C (48-87%) and, of the mineral-bound C (>2 g/cc), 47-91% is captured by the hydrolysable fraction (CtHyd/CtMin), 9-48% by the acid/base residue (CtRes/CtMin) and, in the basalt soils, 3-15% is captured by the iron oxide (>3 g/cc) fraction (CtFe/CtMin).

As shown in figure 4, the proportion of C that is mineral-bound (CtMin) is related to clay content, and when Guenoc, an outlier, is excluded, clay explains 94% of the variability across basalt soils (n=4) and 88% of the variability across granite soils (n=5); MAP explains an additional 5% variability in the basalt soils and 2% in granite soils. As shown in figure 5, the resistance of mineral-associated carbon to acid base hydrolysis is greater in basalt than granite soils, and is largely explained by texture; clay in granite soils, but clay + silt in basalt soils. Clay explains 93% of the variability in CtRes/CtMin across granite soils (n=5), and MAT explains 99% of the residuals for all but Chiquito, the coldest site (n=4). Once Cohasset, an outlier is excluded, Clay+Silt explains 94% of the variability in CtRes/CtMin across basalt soils (n=4), and MAT explains 0.997% of the residuals (n=4).

Discussion

Whereas our previous work on the basalt soils included B horizon results, this research is restricted to A horizons, which are most relevant to climate and land use change. Along both transects, bulk % C is controlled by climate, peaking at intermediate levels of temperature and precipitation. This is where both primary productivity and clay concentrations reach a maximum, and similar trends have been noted by Harradine (1954) and Dahlgren et al. (1997) for Sierra soils. As expected based on paired % C profiles, there were no differences in C inventory between granite and basalt soils, although variability between archive and modern values, which reflects differences in % C, bulk density, and coarse fragment values, was in some cases quite large.

We used sonication to disrupt the very strong basalt soil aggregates, which probably liberated low-density intra-aggregate C into the mineral-free fraction. Had we not sonicated the basalt soils, we would have extracted less mineral-free C, and correspondingly more mineral-associated C. In acknowledgement of this bias, we use the term ‘mineral-bound’ rather than ‘mineral-associated’ C to designate the >2 g/cc fraction; it probably represents only C sorbed directly to mineral surfaces and excludes other ‘loose’ C occluded within aggregates. With the exception of Musick, the granite soils generally have weak aggregation, and would therefore contribute very little intra-aggregate low-density C to the mineral-associated fraction.

The proportional distribution of C in different soil fractions – in particular the ratio of mineral-bound C to total C (CtMin) and ratio of acid/base residue C to mineral-bound C (CtRes/CtMin) – is primarily explained by texture.

On average, CtMin per unit clay is higher in granite than basalt soils. Observing a similar trend, Harradine (1954) speculated that granite soils had higher availability of humus adsorption spots or more active Al and Fe irons per specific surface area than basalt soils (Harradine and Jenny 1958). But this explanation is inconsistent with the fact that x-ray diffraction data indicate that the clay minerals in both soils types are predominantly low activity kaolins (kaolinite in the basalt soils and halloysite in the granite soils) and the basalt soils have higher levels of iron oxide.

CtMin is more sensitive to clay in granite than basalt soils. This may be because in the strongly aggregated basalt soils, new humus adsorption sites are only available on clay located on the outer layer of aggregates, whereas in the weakly aggregated granite soils, all clay can potentially provide new humus sorption sites.

Finally, CtRes/CtMin, the proportion of chemically recalcitrant C, is greater in basalt than in granite soils, and is governed by clay in granite soils but clay+silt in basalt soils. The chemically recalcitrant fraction either represents chemically recalcitrant humus compounds or humus compounds that are protected by chemically resistant mineral structures. A priori there is no reason to suspect that soil mineral differences promote difference in humus composition; it is more plausible to believe that the observed differences are due to incomplete dissolution of the clays and microaggregate structures (ground to 200um) encapsulating the humus.

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