COMPOSITION OF EARTH'S CONTINENTAL CRUST AS INFERRED FROM THE COMPOSITIONS OF IMPACT MELT SHEETS

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The composition of the continental crust is a required datum when testing models of crustal genesis, crustal evolution, crust-mantle relation-ships, and many other global geochemical processes. Unfortunately, this datum has been as elusive as it is important. Initial efforts to determine the composition of the continental crust focussed on lithologies currently exposed at the surface. It was soon realized, however, that the composition of the upper crust could not be used as a proxy for the entire crust. This was particularly evident when one considered continental heat flow [*e.g.*, 1,2], because the abundances of heat-producing elements in the upper crust often imply greater heat flow than is measured, suggesting these elements are less abundant in the lower crust. Since K, Th, and U are not homogeneously distributed in the crust, it seems likely that other chemical abundances may also change with depth. Consequently, efforts in recent years have been designed to determine the composition of the lower crust.

Samples of the lower crust are available in the form of granulite terrains and granulite xenoliths, and both have been used to infer the bulk composition of the lower crust. However, there are two problems with this approach. First, there is a wide range of compositions (from felsic to mafic) in both sets of samples [*e.g.*, 3-5], so it is difficult to select a meaningful average composition. Second, there is a tendency for the granulite terrains to be dominated by felsic compositions while granulite xenoliths are dominated by mafic compositions, making it again difficult to select a meaningful average in the spectrum of compositions. These data, in addition to seismic velocity studies [*e.g.*, 6], indicate the lower crust is heterogeneous in a way that is not yet understood.

An alternative way to approach this problem is to use analyses of impact melt sheets in large impact craters. Previous studies of impact cratering processes have shown that shock melting is a bulk melting process and that it produces a homogeneous melt which is a mixture of all the lithologies involved [*e.g.*, 7-9]. In the case of the Chicxulub impact event, for example, which produced a ~180 km diameter crater [10-12; *cf.*, 13,14], this means that the upper and lower portions of the crust in the Maya block should have been melted and thoroughly mixed. Consequently, one should be able to analyze the composition of the impact melt sheet inside this (and other) impact craters to determine the composition of the continental crust. In other words, impact melt sheets in large impact craters are essentially XRF beads of the entire continental crust.

One of the largest impact craters on Earth is the Chicxulub structure, which is a relatively young (K/T boundary) crater that penetrated a carbonate and evaporite platform sequence, recrystallized sandstones, granitic gneisses, and mica schists. Clasts of each of these lithologies are found in the polymict breccia within the impact crater [15,10,16]. However, in general, the basement lithologies involved in the impact event are poorly characterized. Most of what is known about the basement lithologies of the Maya block comes from outcrops along its southern margin where there is a metamorphic sequence called the Chuacús Series which is composed of amphibolite, mica schist, gneiss, marble, quartzite, and metavolcanics [*e.g.*, 17]. Stratigraphically above the Chuacús Series is a thick sedimentary sequence called the Santa Rosa Group. There are various intrusions throughout the sequence, including a large number of Permian to mid-Triassic granites. Thus far, it is not clear if these specific lithologies are representative of the basement in the northern part of the Maya block where the Chicxulub impact occurred, although we infer that the basement is, in general, granodioritic based on the composition of the impact melt within Chicxulub [10,18,16]. The upper part of the basement (down to depths of 12 to 14 km [12]) also seems to have a Pan-African age [*e.g.*, 19,20], based on U-Pb analyses of zircons excavated from the crater [21]. Unfortunately, none of the outcrops or ejecta samples provide any information about the age or composition of the lower portion of the crust.

Based on impact cratering scaling relationships, the shock associated with a crater the size of Chicxulub should have induced melting throughout the crust to a depth of about 29 to 34 km [12], which is very similar to the 30 to 35 km depth to the base of the Maya block inferred from seismic surveys [22]. Several samples of the impact melt within Chicxulub have been previously analyzed. One of these, C1N10 (Table 1), does not contain unmelted clasts and may be the best bulk sample of the melt [16]. For comparison, several previous estimates of continental crust compositions are also tabulated below. In general, the Chicxulub melt sample is similar to previous determinations of the continental crust, but it also suggests the crust (at least the Maya block) is slightly more siliceous and potassic than the composition inferred in the most recent study of the continental crust [23].

Another large impact site is the Sudbury structure, which is the eroded remnants of a ~250 km impact crater [9] that was produced 1.85 Ga [24]. Because it is eroded, many of the target lithologies deep in the crust at the time of the impact event are exposed. The youngest lithology affected by the impact event was the Nippissing Diabase. Older units include 8 to 15 km of Proterozoic supracrustal rocks of the Huronian Supergroup (*e.g.*, Lorrain arkose, Gowganda wacke, Mississagi quartzite), Archean mafic and felsic intrusions, Archean granite-greenstone terrain of the Abitibi Subprovince, and Archean high-grade gneisses of the Levack Complex [25, 26, 9]. These and other lithologies were melted to produce a melt sheet which then differentiated to form the Sudbury Igneous Complex. The composition of the Sudbury Igneous Complex (Table 1) is very similar to the composition of the Chicxulub melt sheet, even though they were produced in two different crustal blocks. Again, this composition suggests the continental crust may be slightly more siliceous and potassic than the composition inferred in [23].

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Table 1. Estimated bulk compositions of the continental crust.

	Previous Estimates of the Composition of the Continental Crust												Chicxulub	Sudbury
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
wt. %														
SiO_2	61.9	63.9	60.2	57.8	61.9	62.5	63.8	58.0	64.8	57.3	63.2	59.1	64.4	64.34
TiO_2	1.1	0.8	1.0	1.2	0.8	0.7	0.7	0.8	0.51	0.9	0.7	0.7	0.5	0.76
Al_2O_3	16.7	15.4	15.2	15.2	15.6	15.6	16.0	18.0	16.1	15.9	14.8	15.8	14.9	14.93
FeO	6.9	6.1	7.1	7.6	6.2	5.5	5.3	7.5	4.8	9.1	5.60	6.6	4.6	6.67
MgO	3.5	3.1	3.9	5.6	3.1	3.2	2.8	3.5	2.7	5.3	3.15	4.4	2.8	2.91
CaO	3.4	4.2	5.8	7.5	5.7	6.0	4.7	7.5	4.6	7.4	4.66	6.4	5.5	4.11
Na_2O	2.2	3.4	3.2	3.0	3.1	3.4	4.0	3.5	4.4	3.1	3.29	3.2	4.3	3.27
K_2O	4.2	3.0	2.5	2.0	2.9	2.3	2.7	1.5	2.0	1.1	2.34	1.9	2.7	2.97

Compositions 1-10 were compiled by [27]. Composition 11 is from [28], 12 is from [23], 13 is from [16], and 14 is from [9].