

# The composition of the continental crust

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The general acceptance of the definition of the continental crust as the continental part of the outer shell of the planet above the Mohorovičić discontinuity dates back to the fifties of this century (A. Poldervaart: Crust of the Earth. GSA Spec. Pap. 62, 1955). Earlier authors as Clarke (1924) and Goldschmidt (1933) reported average chemical compositions of magmatic rocks or of what the latter author called the 'lithosphere'. Both averages were restricted to major units of the upper continental crust in our present definition.

Major divisions of the continental crust and their compositional characteristics should be based on geophysical properties. In a long profile of more than 3000 km through western Europe extending from the North Cape to the Mediterranean Sea refraction seismic properties have been evaluated for a typical cross section through the continental crust (D. Blundell *et al.*, *A Continent Revealed*. Cambr. Univ. Press 1992). This European Geotraverse (EGT) can be used to get a generalized crustal cross section because it penetrates 60 percent of old shields with 45.5 km average crustal thickness and 40 percent of younger fold belts with 30 km average thickness. The respective proportion of old and younger sections is conformable with the worldwide state of the continental crust. The average crustal thickness of 40 km can be divided according to seismic properties ( $\leq 6.5$  km/sec P-wave speed). Rudnick and Presper (1990) have compiled geochemical data from the literature for typical lower crustal rocks (granulites) from Archaean and post-Archaean felsic terrains and from mafic xenoliths. A one to one mixture of felsic granulites from Archaean and post-Archaean terrains with not much difference between the two age-divided groups has a tonalitic chemical composition. Mafic xenoliths from the lower crust contain element abundances of average N-MORB (Hofmann, 1988) with the exception of somewhat higher concentrations of the most incompatible elements in the former rocks. The upper relative to the lower continental crust is much better known from systematic chemical surveys based on surface exposures of rock units formed at different depth (Ronov and Yaroshevskiy, 1968; Shaw *et al.*, 1976; Taylor and McLennan, 1985). The listed authors reported a granodioritic bulk composition

for the upper half of the continental crust without much discrepancy between the individual estimates. A larger difference in compositional estimates and genetic aspects exists between our present investigation and the widely used calculation of the lower and bulk crust composition by Taylor and McLennan (1985). The latter authors assume that the lower crust comprises 75 percent of the total crust in contrast to our above listed 50 percent estimate based on the EGT seismic profile through Europe. Taylor and McLennan (1985) calculated the average lower crustal composition by removal of their upper from their bulk crustal composition and got a lower crust which is distinctly more mafic (54.4% SiO<sub>2</sub>) than average diorite or andesite as compiled by Le Maitre (1976) (57.7% SiO<sub>2</sub>). The former authors computed a dioritic bulk continental crust from their Archaean crustal composition (75 percent) and island arc andesites (25 percent). Their Archaean crust consists of a 2:1 mixture of mafic (MORB) and felsic (tonalitic to trondhjemitic) end members, which is in REE composition conformable with andesites (or diorites). The model proposed by Taylor and McLennan (1985) obviously overestimates the abundance of andesites and diorites at active continental margins and in the bulk crust. These authors stated that their model is constrained by the assumption of about 40 percent of the total heat flow at the average earth's surface being derived from the crust and 60 percent from the mantle. They have calculated that for the respective heat production a bulk crustal abundance of 9000 ppm K, 3.4 ppm Th and 0.9 ppm U is required. The large uncertainty in the mantle contribution to the surface heat flow causes the uncertainty of the proposed crustal model.

We have calculated the composition of the continental crust on the following base: The proportion of upper crust to lower felsic crust to lower mafic crust equals 1:0.6:0.4 as derived from the EGT seismic profile. The chemical composition of the upper crust is (with the exception of Ba and Ta) taken from Shaw *et al.* (1976) and that of the felsic and mafic lower crust from the averages of the respective granulites compiled by Rudnick and Presper (1990). The upper crust value of Ba has been taken from Taylor and McLennan (1985) and comparable compilations and the bulk crust

TABLE 1. Composition of the bulk continental crust

SiO <sub>2</sub>	61.5 %	Li	17.5 ppm	Ga	15.5 ppm	Eu	1.3 ppm
TiO <sub>2</sub>	0.68	B	9.3	Rb	76	Gd	4.1
Al <sub>2</sub> O <sub>3</sub>	15.1	F	526	Sr	334	Tb	0.65
Fe <sub>2</sub> O <sub>3</sub>	6.3	S	725	Y	24	Ho	0.78
MnO	0.10	Sc	16	Zr	201	Yb	2.0
MgO	3.7	V	101	Nb	18.5	Lu	0.36
CaO	5.5	Cr	132	Ba	576	Hf	4.9
Na <sub>2</sub> O	3.2	Co	25	La	25	Ta	1.1
K <sub>2</sub> O	2.4	Ni	59	Ce	60	Pb	14.8
P <sub>2</sub> O <sub>5</sub>	0.18	Cu	26	Nd	27	Th	8.5
		Zn	66	Sm	5.3	U	1.7

value of Ta was calculated from the primitive mantle and cosmic Nb/Ta ratio of 17.6. Our bulk crust has a tonalitic composition (see Table 1) and is very close to the felsic granulites of the former authors representing the felsic lower crust. Tonalites, trondhjemites and granodiorites can be explained on the base of ample experimental evidence as products of partial melts from the underplated mafic part of the lower crust. The felsic lower crust is the source of a majority of granitic partial melts which have intruded into the upper crust at active continental margins. The continental crust calculated by us has about twice the concentration of the heat producing elements (2100 ppm K, 8.5 ppm Th, 1.7 ppm U) of the crustal model suggested by Taylor and McLennan (1985).

The tonalites of the felsic lower crust are partly melting products of the mafic underplating and partly residual rocks of granitic melts. Because of this double character they are different in some element concentrations from intrusive tonalites. Residues contain on average distinctly higher concentrations of Sc, Cr, Co, Ni and heavy REE and lower concentrations of Sr, Cs (and Ba) than the former tonalites. Greywackes approach the chemical composition of intrusive tonalites with the exception of SiO<sub>2</sub>, Sr and Ba. This characterizes them as major objects of erosion at active continental margins and indicates the importance of tonalites as early products of magmatism generating new continental crust at plate boundaries.

From our bulk crust composition we can calculate the following ratios of important radioactive/radiogenic elements (or isotopes): Rb/Sr 0.22; Sm/Nd = 0.20; U/<sup>204</sup>Pb = 8.5. The Th/U ratio is 5. These results are in balance with the respective isotopic compositions of river waters or

the bulk crust at an average age of about 2 Ba.

The continental crust very probably behaves as a steady state system growing at active continental margins and losing matter through rivers, by subduction of continentally influenced ocean crust and by partial delamination of the lower crustal mafic layer. At the relatively low temperature and crustal thickness of old shields gabbro is partly converted into eclogite and sinks into the upper mantle peridotite if it is tectonically separated from the lower crust. It is to be expected that delaminated eclogite, which is partly a restite from the crustal fractionation by melts, has a small positive Eu anomaly. This would compensate the negative Eu anomaly of the most abundant crustal rocks. Mantle melts from which the crust has primarily grown have no Eu anomaly.

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