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Discussion

How soft is the crust?

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In a series of thermomechanical models of the lithosphere, applied to the determination of apparent elastic thickness, extension, and collision and exhumation, Burov and coworkers (cf. e.g. Burov and Diament, 1995; Cloetingh and Burov, 1996; Burov and Poliakov, 2001; Burov et al., 2001) model the ductile behaviour of the upper crust (sometimes of the whole crust) assuming a quartz-controlled rheology.

An extensive comparison of rheological input parameters used in geodynamic modelling (Fernàndez and Ranalli, 1997) has shown that the dry quartz rheology employed by Burov and coworkers results in a crust (or upper crust) which is about three orders of magnitude softer than in any other model claiming to use the same dry quartz rheology (in one case—Cloetingh and Burov, 1996—a different set of parameters was included for the purpose of comparison, but not used in the calculations). The same conclusion is reached by comparing Burov and coworkers' rheology with the review of lithosphere strength estimates by Kohlstedt et al. (1995).

Although experimentally determined rheological parameters show wide scatter, this usually results in uncertainties of the order of one order of magnitude or less in estimates of the ductile rheology of the crust of a given composition (see Ranalli, 1995, 1997). Any larger difference may conceal some problems with the input parameters. This would be particularly important in this case, as the models by Burov and coworkers are at the forefront in the present attempt to understand geodynamic processes, and their results are widely used to interpret tectonic features.

The equation for the strength of a material deforming in power-law creep is

$$\sigma = (\varepsilon/A)^{1/n}\exp(E/nRT)$$

where σ is the principal stress difference, ε the strain rate, T the absolute temperature, R the gas constant, and A, n, and E the creep parameters of the material. The creep parameters used by Burov and coworkers are given in Table 1, together with those compiled by Ranalli (1995, 1997) from a review of the literature, including parameters for wet quartz-controlled rheology for purposes of comparison.

The source of the values used by Burov and coworkers is given as Brace and Kohlstedt (1980) (cf., e.g. Burov and Diament, 1995, p. 3909). A check of this source reveals that the parameters appearing in the creep equation for dry quartzite (Brace and Kohlstedt, 1980, p. 6250, Eq. (5)) are indeed the same as those used by Burov and coworkers. However, the results of the calculations (see Brace and Kohlstedt, 1980, p. 6251, Figs. 4–6) cannot be reproduced using these parameters. On the other hand, they are reproduced if the parameter A in the creep equation is changed from 5×10^{6} to 5×10^{-6}. Eq. (5) of Brace and Kohlstedt (1980) contains a misprint in the parameter A, and this incorrect value is the one used by Burov and coworkers.

It is easy to check that the use of the correct parameter A gives values for ductile strength that are roughly in line with those used in other models (cf.

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Table 1
Creep parameters for quartz-controlled rheology

	A [MPa^{-n} s^{-1}]	n	E [kJ mol^{-1}]
Burov et al., 2001 (dry)	5×10^{6}	3.0	190
Ranalli, 1995, 1997 (dry)	6.7×10^{-6}	2.4	156
Ranalli, 1995, 1997 (wet)	3.2×10^{-4}	2.3	154

Fernàndez and Ranalli, 1997). For instance, using the same geotherm as Brace and Kohlstedt (1980)

$$T\ [\mathrm{K}] = 350 + 15z\ [\mathrm{km}]$$

the depth at which the ductile strength of dry quartz-controlled rheology becomes less than 100 MPa (for a strain rate of 10^{-15} s^{-1}) is ~ 19 km using Brace and Kohlstedt's (correct) parameter A (see Fig. 6 in Brace and Kohlstedt, 1980, p. 6251), and ~ 14 km using Ranalli's (1995, 1997) parameters (for comparison, the same depth for wet quartz-controlled rheology is ~ 10 km). Using Burov and coworkers' (incorrect) parameter A, the same depth is estimated to be < 1 km.

In summary, parameters derived from the rheology of dry quartz-rich rocks give creep strengths which, for average geotherms and strain rates, range from a few hundreds of megapascals near the top of the ductile zone to a few megapascals immediately above the continental Moho (that is, in the depth range 10–30 km). There is a broad order-of-magnitude convergence on these estimates in rheological modelling (see Kohlstedt et al., 1995; Fernàndez and Ranalli, 1997). The very soft crust in the models by Burov and coworkers (about three orders of magnitude softer than in other models) is due to the carrying-over of a trivial misprint in the original reference.

Geodynamic models allow an improvement of our quantitative understanding of plate tectonic processes. Burov and coworkers have made a very important contribution to the current progress. Unfortunately, the parameters they use result in a crustal rheology which is far too soft. The consequences of this error in terms of model results remain to be evaluated, but may be significant. It is therefore important that the error be corrected.

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