FROM THE NM TO THE MM: ISOTOPES, ATOMIC-SCALE PROCESSES, AND CONTINENT-SCALE TECTONIC MODELLING

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Tectonic models for the evolution of an orogen start at the Mm scale, and use field work on smaller subunits at the km scale and rocks collected at the m scale. At the mm scale, minerals are identified, analyzed by mass spectrometry, their "cooling ages" assigned to a specific closure temperature, a cooling rate attributed to a particular tectonic regime, and a large body of self-referential literature is the product of an oiled machinery. Problems become apparent if one attempts to harmonize mm-scale science with the nasty little details that become apparent at even smaller scales. Atoms, the diffusing species on which the whole construction rests, are invisible to the naked eye (unlike the minerals mentioned above) and their actual behaviour is, or was, only accessible to indirect argumentations and simplified calculations. Increased computing power now allows calculating the transport of atoms in a crystal from the Schrödinger equation: results do not fit 19th century continuum physics for infinitely dilute solutions (Fick’s and Arrhenius’ "laws"). Moreover, improved nanochemical analyses allow characterizing the supposedly homogeneous mineral matrix. TEM images show how variable numbers of layers or chains of a pristine mineral are substituted in a non-periodic, non-predictable way by alteration products. EMP analyses show the almost ubiquitous presence of razor-sharp boundaries rather than Erf profiles. Disequilibrium recrystallization textures thus prevail over diffusive reequilibration; diffusion sensu stricto is shown to be a much slower process than heterochemical replacement. Alterability sequences are well known to surface scientists: e.g. halite, olivine, biotite, muscovite, zircon. Such sequences are reflected in the isotopic retentivity. The link only becomes clear at the nm scale: isotopic exchange occurs during the replacement
reactions that affect all rocks on their retrograde P-T evolution. This is sufficient to explain why zircons record higher isotopic ages than muscovites, which in turn undergo less isotope exchange than biotites etc. While there is a vague dependence on temperature (hydrothermal waters destroy biotite more thoroughly than meteoric ones) this dependence is not quantitatively amenable to infer a purely thermal evolution in neglect of more efficient isotope exchange promoters such as the availability of fluids.

What consequence should tectonic modellers draw? In their past, tectonicists have abandoned well-charted waters (e.g. an exceedingly vast body of literature on mio-and eu-geosynclinals) on the thrifty ground that it simply wasn’t true. As mineralogy and nanoscience make constant progress, their insights should not be fought against in the name of old paradigms, but should instead be the starting-point for new paradigms blending petrology, fluid inclusion studies, and molecular dynamics to understand major and trace element mobility in minerals.