Research orientations

- Informations "institutionelles" -

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Description :

Presentation of my research topics (for at least minimally geology-litterate readers)

Géologie et géo-tourisme

The Archaean spans the period 4.0 to 2.5 Ga before present. It is the oldest part of Earth history in which geological witnesses are preserved. The Archaean is an important period, because during this time, the Earth changed from an early, undifferenciated planet, shortly after the initial accretion, to a planet geologically more or less similar to what we can observe now.

Plate tectonics is the central geological process of modern Earth. The very existence of plate tectonics in the Archaean is, however, debated, as evidenced by two relatively recent papers with deliberately provocative titles, one by M. de Wit: "On Archaean granites, greenstones, cratons and tectonics : does the evidence demand a verdict ?"(Precamb.Res. 91:181-226, 1998) and the other by W. J. Hamilton: "Archaean magmatism and deformation were not products of plate tectonics"(Precamb. Res. 91:143-179, 1998)

Even assuming some form of plate tectonics operated during the Archaean, its modalities remain open to discussion: was Archaean plate tectonics a close analog to modern processes?

In particular, the existence of subduction of oceanic (rarely continental) lithosphere - a key process of modern plate tectonics - is specially contentious and is not unambiguously demonstrated before 2.7 Ga.

Modern-style subduction is characterized by convergent tectonic (thrust structures), arc-related (calc-alkali) magmatism and high pressure / low temperature geothermal gradients. Structures that can be interpreted as convergence-related are indeed described in the Archaean (although generally in the late Archaean, 3.0 - 2.5 Ga, and seldom earlier). A very common plutonic component of Archaean cratons, the TTG suite (Tonalite-Trondhjemite-Granodiorite -see below), which is formed by partial melting of garnet-present amphibolites, is commonly interpreted as being subduction-related and equivalent to modern arc magmas. But no instance of low geothermal gradients is so far reported in the Archaean, although the first results of our studies in Barberton area (see below) suggest that some of the rocks there might have recorded pressures above 10 kbar for temperatures not exceeding 700 C.

In summary, there are important uncertainties regarding Archaean geodynamic regimes. Furthermore, it is extremely likely that this period is very heterogeneous, with a progressive change from archaic towards modern tectonic styles. But both the details and the pace of this change remain unknown.

The Archaean is also a period of intense crustal formation; it is commonly assumed that, by the end of the Archaean, as much as 80 % of the present day crustal mass was already formed. However, from a geochemical point of view, Archaean juvenile crust was clearly different from present day crust (e.g. Martin, 1986, Geology 14:753-756 among others); while today's juvenile magmas are K-rich calc-alkaline, Archaean juvenile crust was, rather, Na-rich and trondhjemitic, defining what is known as a "TTG" series (Tonalite-Trondhjemite-Granodiorite). The TTG are formed by melting of hydrated basalt in garnet stability field. This probably occurs in a "hot" subduction setting, with the subducting oceanic crust undergoing partial melting (rather than dehydration and mantle metasomatism, like in modern calc-alkali magmas).

There are, however, alternative explanations. Another possibility is that locally, a crustal fragment (either continental or oceanic) can be abnormally thick, therefore bringing its base in garnet stability field. Partial melting of the deep crust would then be able to yield magmas with a TTG signature. In this case, subductions are not required to form TTG -and plate tectonics onset can be younger than expected.

Consequently, the question of continental crust genesis appears as intimately linked to the question of Archaean geodynamic style.

In the field, the bulk of the Archaean crust is made of "grey gneisses", orthogneisses collectively of TTG affinity. Another important component is the generally late, K-rich granitoids that make well-defined plutons intruding the grey gneisses. They are generally regarded as products of partial melting of the TTG gneisses, and therefore do not constitute new additions to the crust, but rather recycling of existing rocks.

Besides these two components (TTG melts and crustal recycling), however, it becomes more and more clear that other sources have been involved in the formation of Archaean plutonic rocks (both grey gneisses and late granites). Recent data suggest (see publications nb. ,) that (1) the sub-continental peridotitic mantle, and (2) fluids from the dehydrating subducting slab probably played a significant role.

Archaean crust-forming processes remain, as shown above, poorly constrained. Neither the sources, nor the petrological processes are completely understood. Additionally, the geodynamic context of Archaean crustal growth is ambiguous to say the least: did the Archaean crust form in "hot subductions"? Or rather, as sometimes suggested, in intra-plate (or non-plate) settings, with partial melting of the base of a thick crust?

To summarize, my research interests can be defined by the following two questions:

- How old is plate tectonics? When and how did it appear?
- How did the continental crust accrete? In light of the previous question, what is the relationship between crustal accretion and plate tectonics?

I'm more specifically interested in the magma generation processes during the Archaean, and how they can be indicators of the geodynamic setting existing during their formation and emplacement.

The secular evolution of these processes must also be kept in mind. In the Late Archaean, the situation was probably relatively similar to the modern geodynamics. This is probably not true, however, in the Early Archaean. Therefore, the question of the transition towards modern geodynamics is central to any discussion on Archaean geology.

My approach to answering these questions rely on a comprehensive, pluri-disciplinar study of mid- to lower-crustal domains. In the middle or lower crust (> 10-15 km), high pressures and temperatures allow for mineralogical transformations (metamorphism) and partial melting, that preserve valuable information about the conditions experienced by the rocks. Additionally, the juvenile magmas (formed below the crust) emplaced at mid-crustal levels still commonly preserve a relatively primitive signature, without only limited interactions with any pre-existing crust, allowing to study their origin. Three main groups of information can be obtained: Interpretation of rock fabrics (foliation, lineation, ...) to describe the strain pattern, and therefore gain information on the tectonic context, relative movements, etc. In particular, applying this approach to igneous or partially molten rocks allows to discuss the very tectonic context of the melting or the emplacement of the magmatic rocks.

Interpretation of metamorphic textures and mineral chemistry to calculate pressure-temperature conditions experienced by the rocks, and maybe even more significantly to try and describe the "Pressure-Temperature path" followed by a specific sample.

Interpretation of the geochemistry (isotopes, major and trace elements) of the magmatic rocks, allowing to discuss the processes that lead to their formation: nature of the source that melted, conditions of melting, subsequent magmatic evolution, etc.

Combining all information allows to propose a model of the thermo-mechanic evolution of the studied area, with its petrological consequences; in turn, this model can be interpreted in terms of a geodynamical setting.

I strongly contend that a good comprehension of processes occurring in this part of the Earth needs the use of several distinct tools, and the integration of all information into a model. Therefore, although I'm not really a specialist of any of the following tools, I'm reasonably conformable with:

- Tools and methods relating mapping and structural geology:
  - geological field mapping of high-grade (metamorphic, migmatitic and granitic) domains;
  - Geographical Information Systems (G.I.S.) tools such as MapInfo, ArcView (+ Spatial analyst);
  - Use of Digital Elevation Models (D.E.M) and satellite images.
  - field measurements and fabric interpretation, in particular in partially molten rocks (migmatites or partially crystalized melts);
  - interpretation of structures and textures related to melt-deformation interactions;
  - anisotropy of magnetic susceptibility.

- Tools of metamorphic and experimental petrology:
  - optical petrography;
  - Scanning Electron Microscope (S.E.M.);
  - interpretation of mineral chemistry and equilibria in terms of P-T conditions, including the use of softwares such as PERPLE_X by J. Connolly, ETH Zürich or THERMOCALC by T. Holland (Cambridge) and R. Powell (Melbourne.
  - gas vessel and piston-cylinder experiments;

- Tools of igneous geochemistry:
  - isotopic data (separation, chromatography, mass spectrometry);
  - interpretation and modelling of trace elements behavior (whole rock and minerals: LA-ICP-MS);
  - coupled major- and trace-elements modelling of melt compositions.

Among the above mentioned tools, the ones I'm the most familiar with are the ones related to igneous petrology and geochemistry, as will be discussed in the next section. However, I try to keep a broad perspective and to put together information belonging to all these different fields, and to keep focussed on the processes and their geological meaning, rather than the specific tools or scientific methods.