2014-01:

MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF ALTERATION IN HIGH-GRADE METAMORPHIC ROCKS - PHASE II

This two-phased project focuses on rocks altered by a hydrothermal fluid and metamorphosed at a high grade will being or after having been altered. The 2013-04 and 2014-01 projects allowed the development of a normative calculation for high-grade metamorphic rocks (Phase I) and to propose diagrams and indices to interpret metamorphic paragenesis (Phase II). The tools developed during these projects are available in LithoModeleur 3.60 (standard only) and 3.63 (for the complete set of tools).

Phase II of the project produced six diagrams; a general diagram and the other five dedicated to the alteration of Si, CO_2, Ca, NaK-Al, and FeMg-Al. These charts allow the user to visualize metamorphic paragenesis, compare samples between each other, and to eliminate the main type(s) of alterations that affected a given set of rocks. Large databases of fresh rocks–magmatic and sedimentary–as well as many examples of altered rocks, allowed for the positioning of the different types of rocks on these diagrams to be constrained with high precision.

Phase II of the project was also the opportunity to propose several alteration indices, whose calculation can be customized by the user. To assess the relevance and performance of different methods, these alteration indices were systematically compared against both the mass balance derived from the modelling of precursors and the indices of the Low-Grade CONSOREM standard. These comparisons allowed the identification of the principal marker minerals of different types of alteration.

The marker minerals of alteration in high-grade metamorphic rocks:

- Ca alteration: **wollastonite** and **grossular** or anorthite-lawsonite-clinozoisite when grossular is not stable.
- Si alteration: **quartz.**
- CO_2 alteration: **carbonates** or **graphite** and Fe-Mg-Ca silicates.
- Fe alteration: **garnet**-**cordierite** or iron oxides for extreme cases.
- Mg alteration: **cordierite.**
- Fe-Mg alteration: the presence of Al minerals (cf. **aluminosilicates** or **staurolite, chloritoid, carpholite, spinel**) is possible, especially if the destruction of feldspars is greater than the quantity of introduced Fe-Mg.
- Na-K acid alteration (leaching and hydration): **white micas**, or an assembly of 2/3 **alkali feldspar** and 1/3 **aluminosilicates** if the white micas are not stable.
- Na-K alteration (addition of Na-K): **alkali feldspar.**
- Leaching, argillization: Al-rich minerals.
- **Biotite**: felsic rocks having undergone an Fe-Mg alteration. The biotite then reflects the felsic composition of the fresh protolith.
- **Anthophyllite** and other Fe-Mg minerals: mafic rocks having (or not) undergone alteration. These minerals reflect then the mafic composition of the fresh protolith.

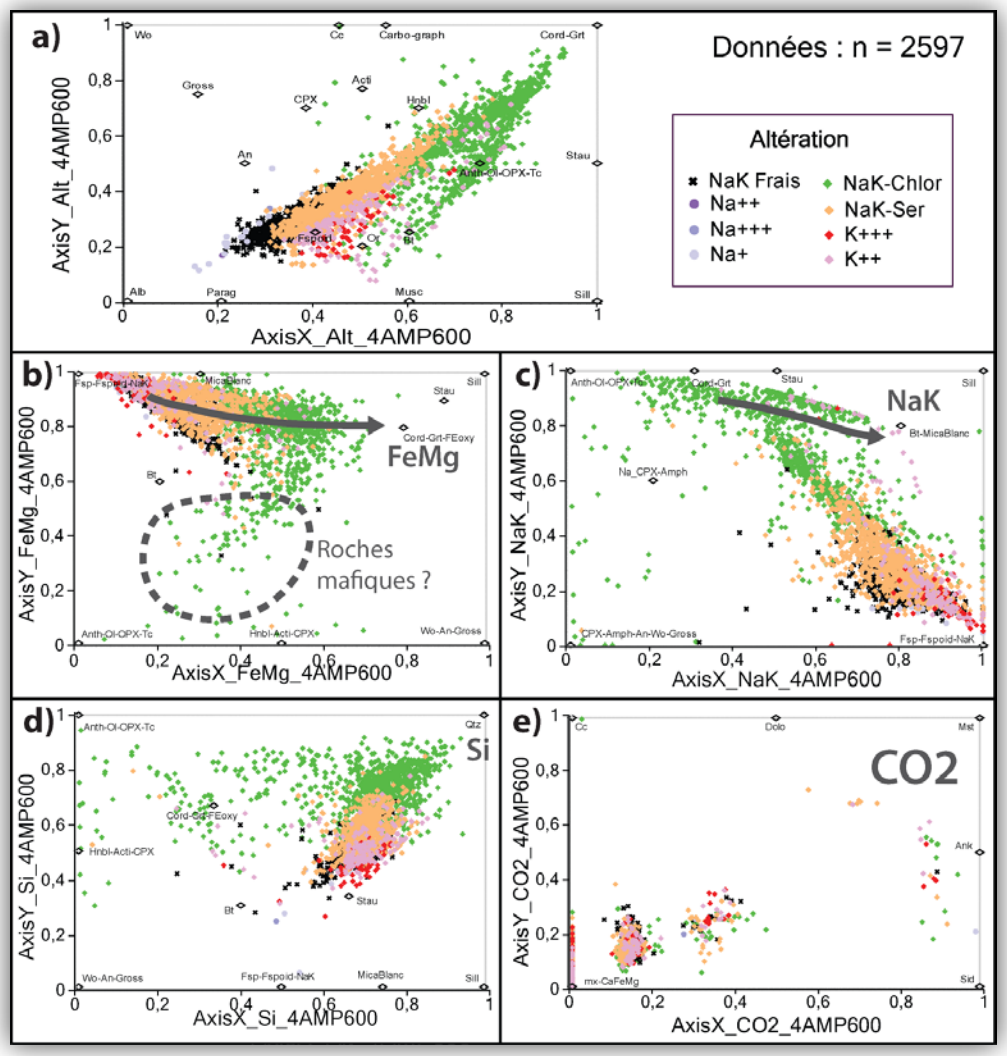

Figure 1. Diagrams of representative felsic rocks from Coulon *volcanogenic massive sulphide* (VMS) deposits (samples from Virginia, now Osisko Gold Royalties Ltd), having been altered then undergone high-grade metamorphosis: (a) general diagram, (b) Fe-Mg diagram, (c) Na-K diagram, (d) Si diagram, and (e) CO_2 diagram.

Project 2014-01: Summary sheet	
Objectives	➢ Develop a method to identify and quantify alteration in high-grade metamorphic rocks. ➢ Use normative minerals from the high-grade standard (2013-04 Project) to develop diagrams and indices to quantify hydrothermal alteration.
Results and innovations	➢ Development of six (6) diagrams to visualize the types and intensity of hydrothermal alteration. ➢ Seven (7) proposed indices to quantify the alteration. ➢ Test of this approach on many natural examples. ➢ Integration of diagrams and developed indices into the CONSOREM LithoModeleur software.