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Steady-state fluid flow as a complementary driver of mineralization and redistribution processes at unconformity-type uranium deposits in the Athabasca Basin, Canada

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Numerical modeling shows that faulting in a dilational regime may have driven oxidized uraniferous basinal fluids into reducing basement environment. In a compressional setting, basement fluids would have been injected into Athabasca Group rocks thereby precipitating uranium out of oxidizing basinal fluids.

The complementary fluid flow model based on steady-state conditions presented here rests on the following premises:

1. Convection is the predominant driving force in the Athabasca Group during seismically quiet times.
2. Each faulting episode disturbs the convection flow, which recovers within a certain time span.
3. The length of time between faulting events is long enough to re-establish steady-state conditions.
4. Rapid recovery of fluid pressure in dilation spaces prevents complete sealing of the fault.

Steady-state groundwater flow was investigated using a generic 3D finite-difference flow model of a typical unconformity-related uranium deposit in the Athabasca Basin. The parametrization of an assemblage of basement rocks overlain by sedimentary rocks of the Athabasca Group and intersected by a strike-slip or reverse fault was based on literature values. A regional gradient was selected that, at given hydraulic conductivities, produced flow velocities as modeled previously for thermal convection. The gradient was oriented at an oblique angle to the structure. No initial vertical gradients were applied. Mixing zones were defined by parallel orientation of basin and basement derived streamlines suggesting potential interaction to be expected under turbulent flow conditions.

Solute transport was simulated as advection modified by dispersion in order to circumscribe the extent of a hydrogeochemical plume in groundwater stemming from mobilized ore and alteration products.

The following streamline patterns are observed:

1. A structure with elevated hydraulic conductivity focuses the flow of fluids from a large volume of both basement and sandstone rocks.
2. Basinal and basement fluids cross the unconformity near the structure thus giving rise to chemical interaction with rocks and existing mineralization.
3. Mixing zones for fluids of varying provenience form in the immediate vicinity of the structure and within the structure above, at and below the unconformity.
4. The contrast of hydraulic conductivity of the structure and that of the wall rocks determines the vertical position of a mixing zone relative to the unconformity.
5. Solute transport circumscribes large potential geochemical halos in the Athabasca Group rocks and dispersion of limited size in the basement.
6. Vertical flow exists without the contribution of initial vertical gradients caused by thermal effects.

Fluid flow patterns under steady-state flow conditions localize mixing zones that coincide with observed distribution of mineralization and alteration in the basement, at the unconformity and in the Athabasca Group. Pre-Athabasca U-sources in the basement could be located within the range of scavenging basinal fluids crossing the unconformity in the upstream area. Basinal fluids entering mineralized structures may have caused the corrosion of existing U-mineralization and in reaction with basement fluids, the re-precipitation along the structure.

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