Magnesium Isotopes in Dolomites – Results for the Paleozoic of Eastern Canada and Significance for Exploration Models*

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Abstract

The processes that form high temperature dolomites are controversial, with end-members of 1) tectonically controlled early processes with rapid upward migration of high temperature fluids, and 2) burial-dominated late processes with regional slow migration of high-temperature brines. Magnesium stable isotope ratios in saddle dolomites, ultramafics and shales are presented and offer critical new data in the ongoing debate.

Hydrothermal saddle dolomites in eastern Canada overly diverse Precambrian and Paleozoic basements, which may have acted as Mg sources. The dolomites and potential Mg sources were chemically characterized (ICP-ES) and their $\delta^{26}Mg_{DSM3}$ and $\delta^{25}Mg_{DSM3}$ ratios measured (MC-ICP-MS). Column chemistry was used to purify the Mg in the digested samples prior to isotopic analysis.

The Lower Silurian dolomites (Th of 150 to 200°C) are related to fluid flow along foreland faults. The Mg^{2+} was interpreted to originate from Ordovician ultramafic slivers. Near the Silurian occurrences, Lower Ordovician dolomitized slope carbonates are associated with a transpressional fault. These two dolomites have yielded negative $\delta^{26}Mg_{DSM3}$ values ranging from −3.2 to −1.5‰.

Middle Ordovician dolomites (Th of 90 to 120°C) are associated with foreland faults that reach the Precambrian metamorphic basement. They yielded $\delta^{26}Mg_{DSM3}$ ratios of −1 to −0.7‰. Lower Devonian reef with massive replacement dolomite of magmatic origin (Th of 300 to 350°C) occurs at the junction of two transpressional faults. Even though the reef neighbours the ultramafic slivers, the dolomite has $\delta^{26}Mg_{DSM3}$ ratios around −1‰.

Linear relationships between dolomite $\delta^{26}Mg_{DSM3}$ and 1) $\delta^{18}O_{VSMOW}$ of the fluid and 2) $^{87}Sr/^{86}Sr$ in the dolomite suggest a link with the nature of the fluid and its source. Linear relationships between $\delta^{26}Mg_{DSM3}$ and Th of fluid inclusions indicate a thermal kinetic effect on Mg^{2+} incorporation in the dolomite.

Data from potential Mg sources are being gathered. Lower Ordovician ultramafics are serpentinized; the altered material has a tight range of $\delta^{26}Mg_{DSM3}$ values of −0.4 to −0.2‰. Lower and Upper Ordovician shales abound in the Lower Paleozoic basin. The shales have Mg isotope ratios that differ with age; the Lower Ordovician has yielded $\delta^{26}Mg_{DSM3}$ values of −0.8 and +0.1‰ whereas the Upper Ordovician has given $\delta^{26}Mg_{DSM3}$ values of −1.2 and −1‰.

Selected References

Lavoie, D., G. Chi, M. Urbatsch, and W.J. Davis, 2010, Massive dolomitization of a pinnacloe reef in the Lower Devonian West Point Formation (Gaspe Peninsula, Quebec); an extreme case of hydrothermal dolomitization through fault-focused circulation of magmatic fluids: AAPG Bulletin, v. 94/4, p. 513-531.

Lavoie, D., and D. Chi, 2010, Lower Paleozoic foreland basins in Eastern Canada; tectono-thermal events recorded by faults, fluids and hydrothermal dolomites: Bulletin of Canadian Petroleum Geology, v. 58/1, p. 17-35.

Pinet, N., D. Lavoie, P. Keating, and P. Brouillette, 2008, Gaspe Belt subsurface geometry in the northern Quebec Appalachians as revealed by an integrated geophysical and geological study; 1, Potential field mapping: Tectonophysics, v. 460/1-4, p. 34-54.

Young, E.D., and A. Galy, 2004, The isotope geochemistry and cosmochemistry of magnesium: Reviews in Mineralogy and Geochemistry, v. 55, p. 197-230.

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Geological Survey of Canada
Quebec and Ottawa divisions

Natural Resources Canada   Ressources naturelles Canada
Canada

Dolomite facts

Over 60% of remaining conventional oil and gas are in carbonate reservoirs

Of these carbonate reservoirs, dolomite is the most prolific type as exemplified by the Gawar Arab-D and North Field

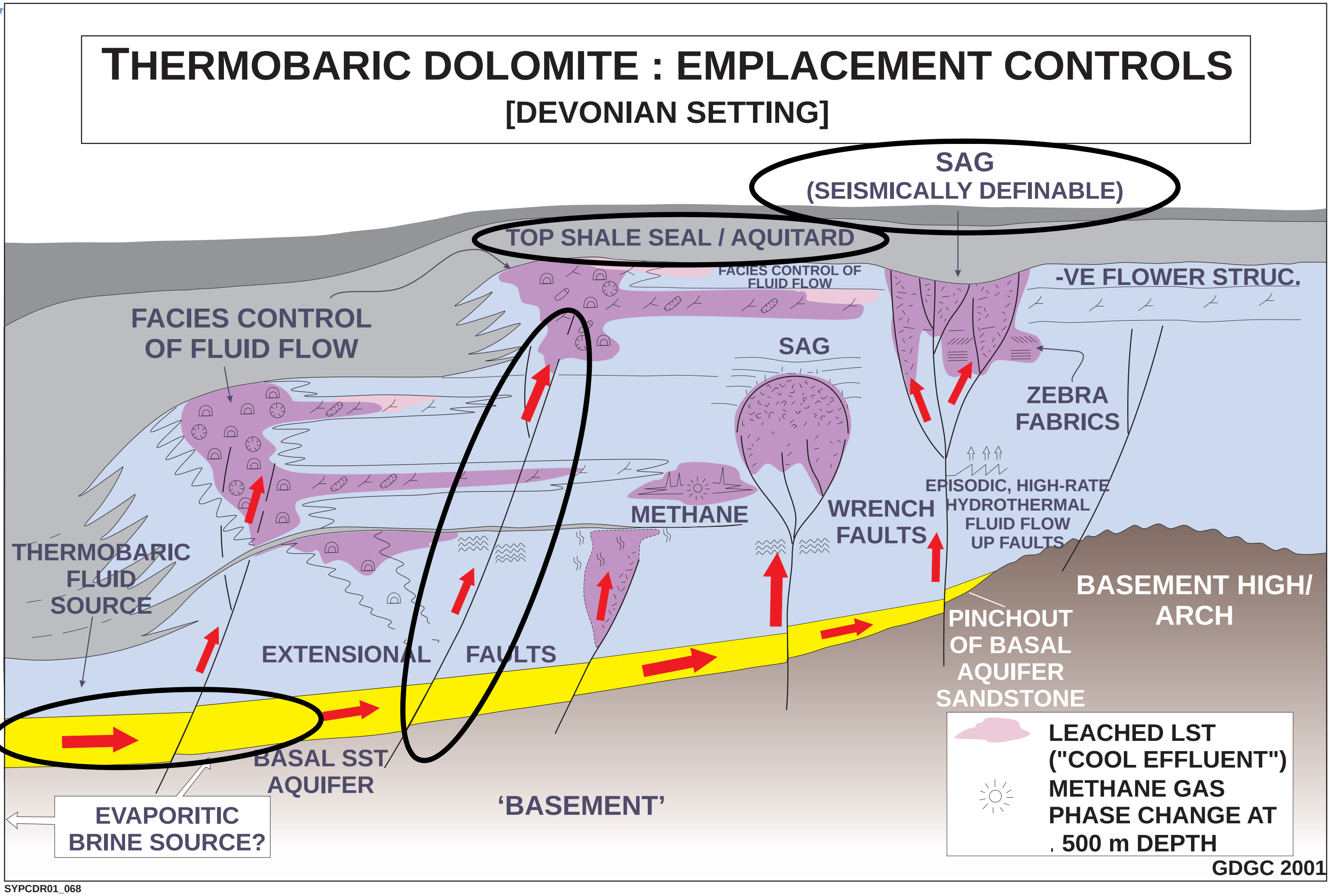
But there is dolomite and there is also dolomite

Different mechanisms and settings can result in dolomitization or dolomite precipitation

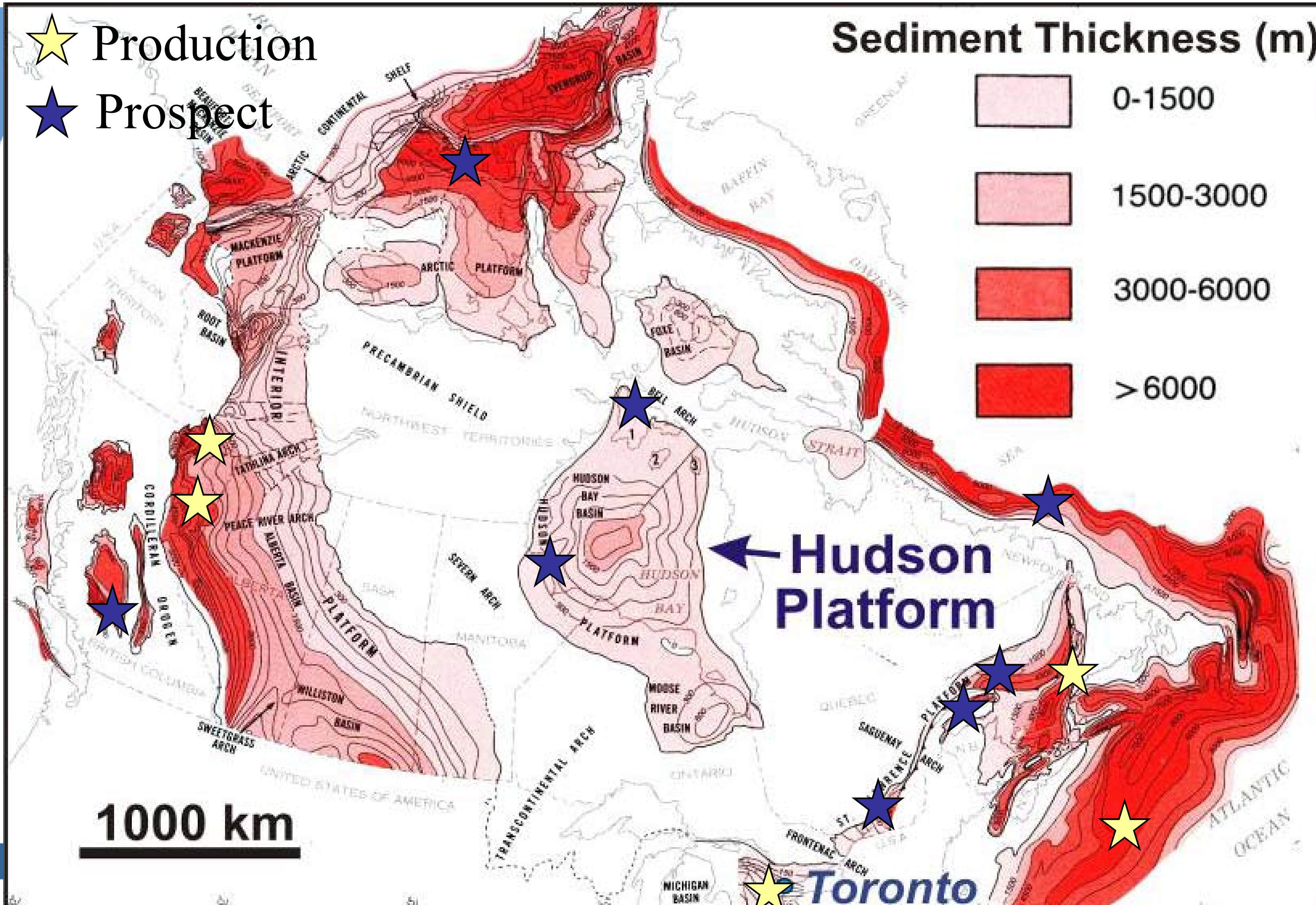
The precise origin for dolomitization has significant impact on exploration strategies

The HTD model

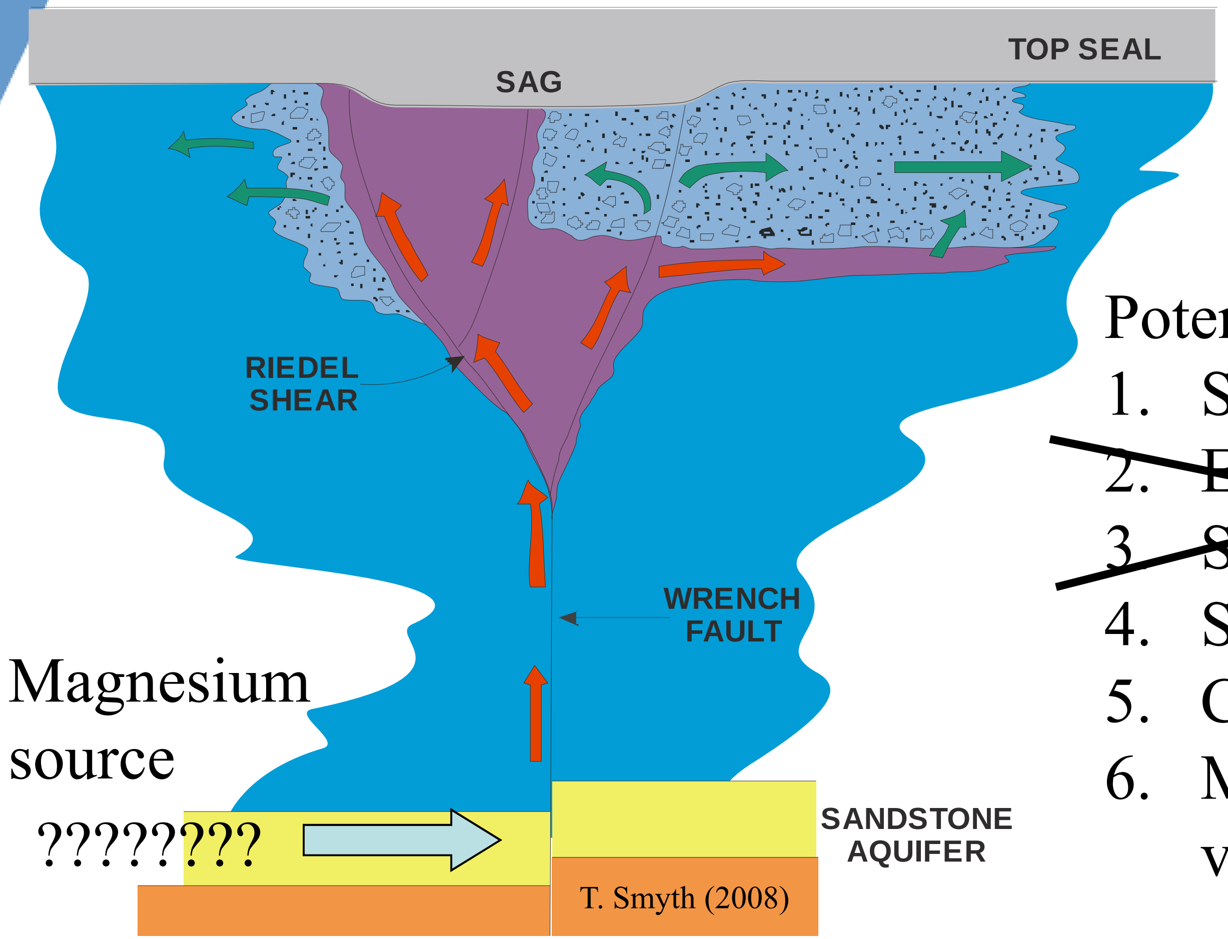
If dolomite results from early fault-driven fluid flow this has significant impact on exploration strategies



Interpreted HTD fields and prospects are numerous in Canada

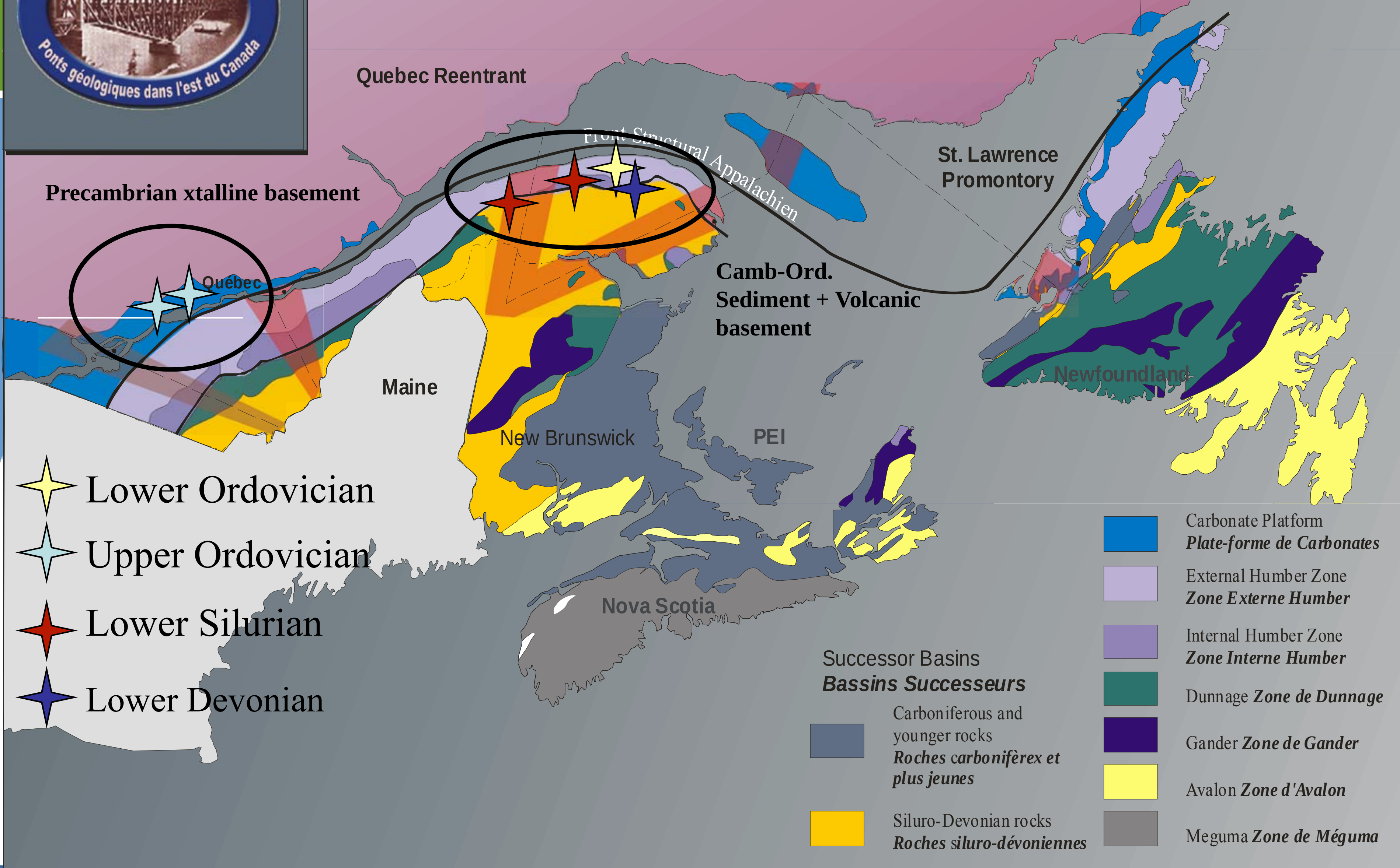


One of the (many) contentious points is the source of Mg for extensive dolomitization



Potential sources of Mg
1. Seawater
2. ~~Evaporite brine~~
3. ~~Sulphate leaching~~
4. Shale diagenesis
5. Crystalline basement
6. Mafic and ultramafic volcanics

Saddle dolomite samples from interpreted HTD in the Paleozoic of Quebec



A link between the Gaspé saddle dolomites and faults and mafic-ultramafic bodies

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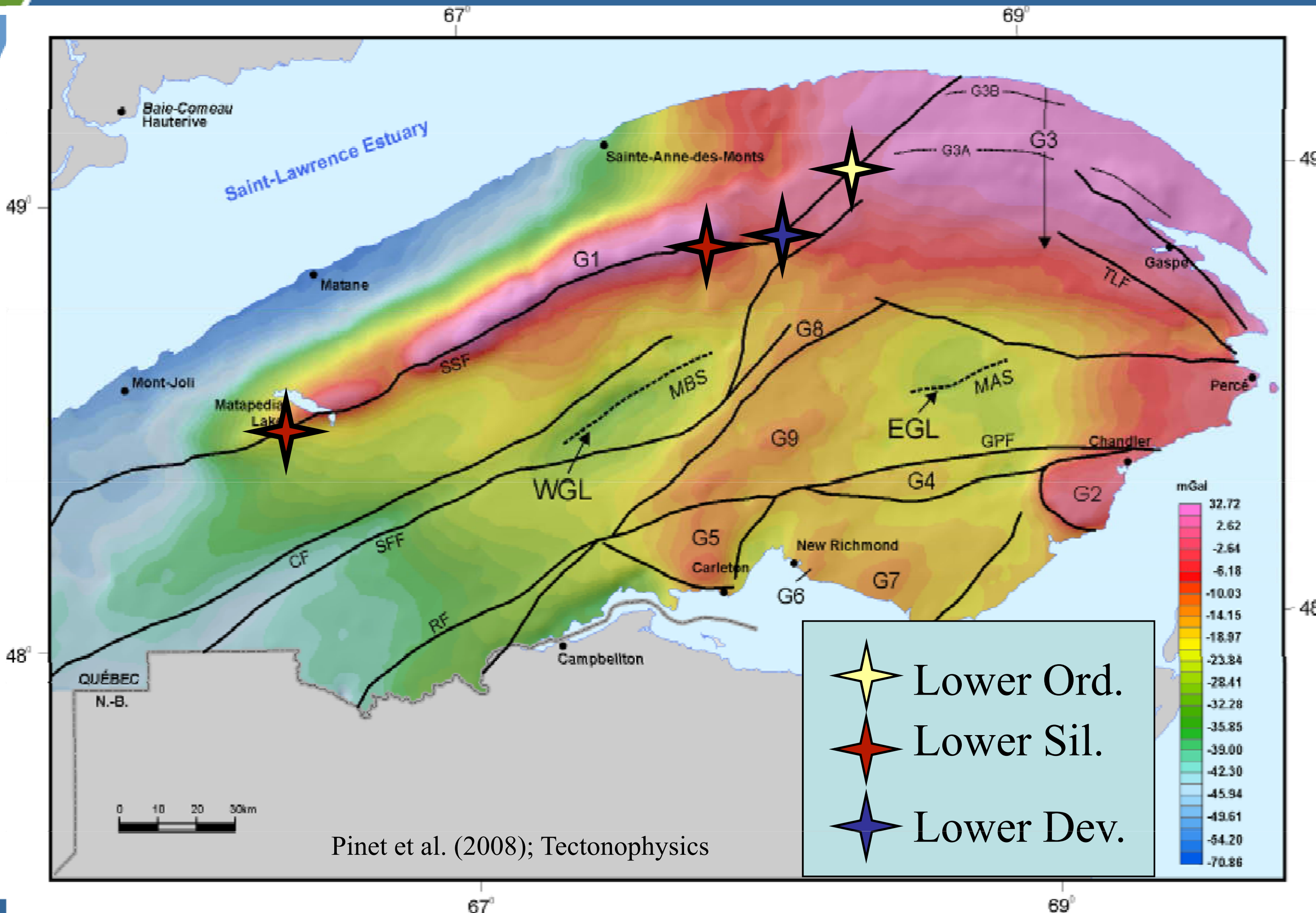
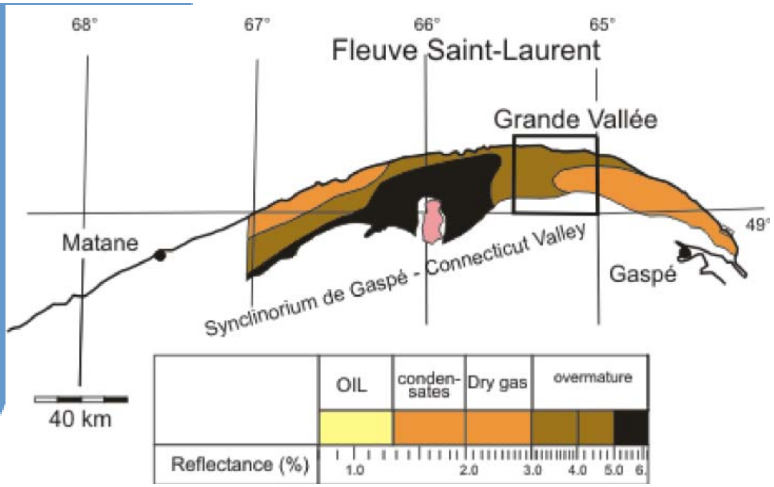


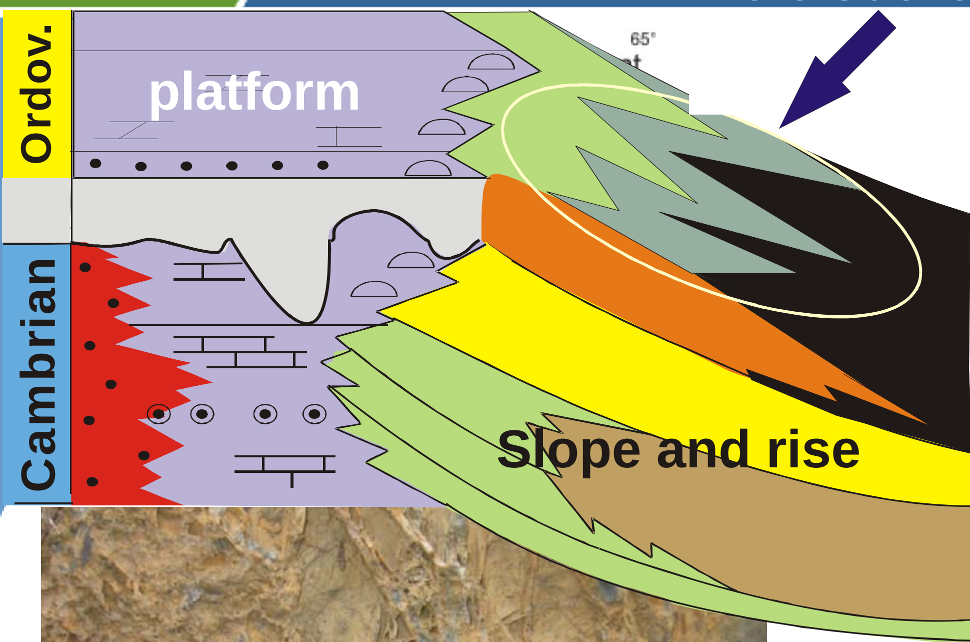
Pinet et al. (2008); Tectonophysics

Lower Ordovician
Slope carbonates in northern Gaspé

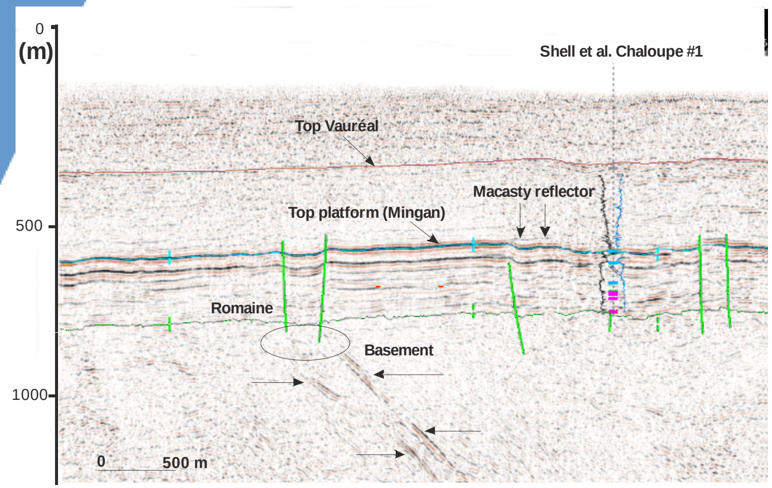


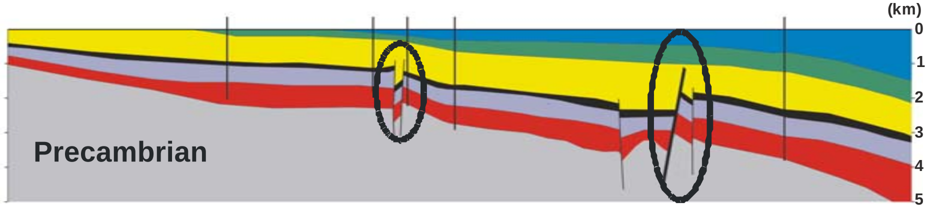
Lower Ordovician
Slope carbonates in northern Gaspé

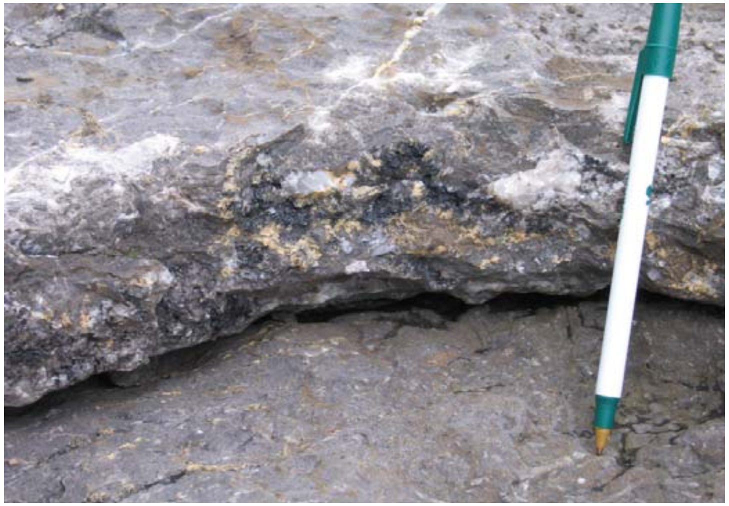
Rivière Ouelle



Upper Ordovician
TBR on Anticosti and southern Qc



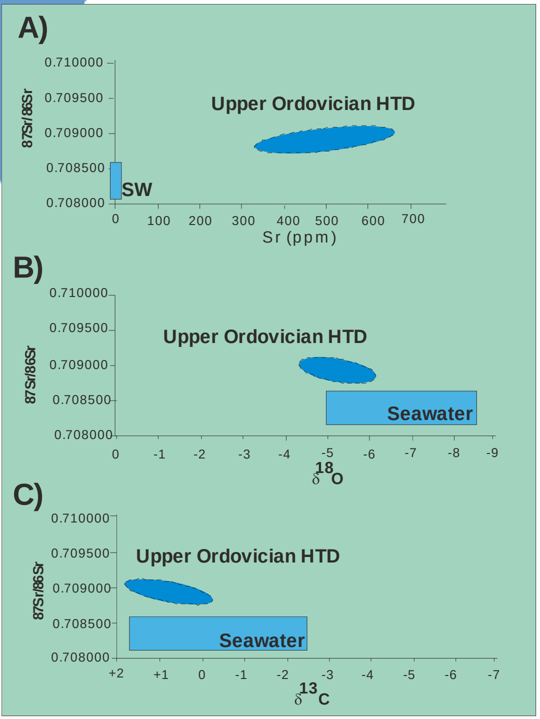




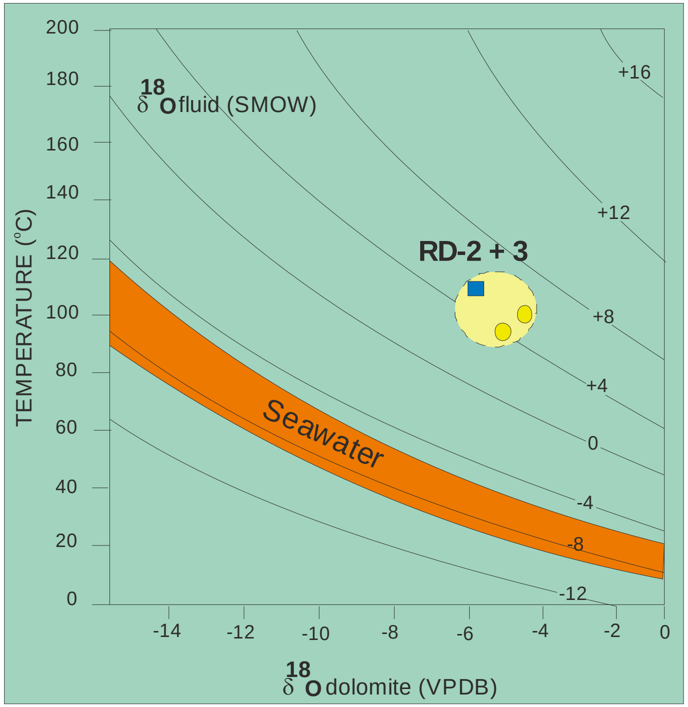
Lavoie and Chi (2010), BCPG

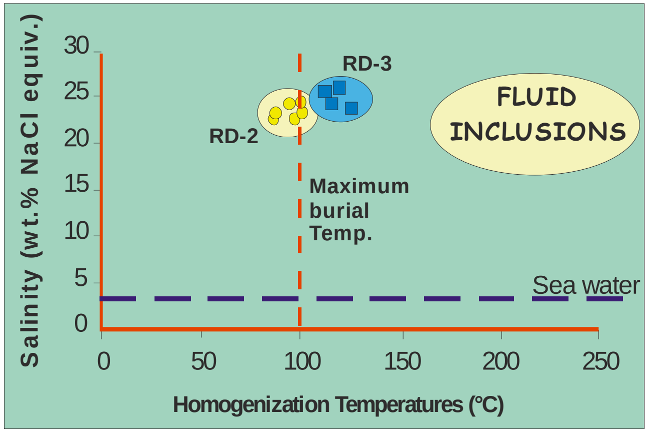
Geochemistry

Radiogenic!



Derived from an ^{18}O-rich fluid





>30ºC than max burial

Lavoie and Chi, 2010 (BCPG)

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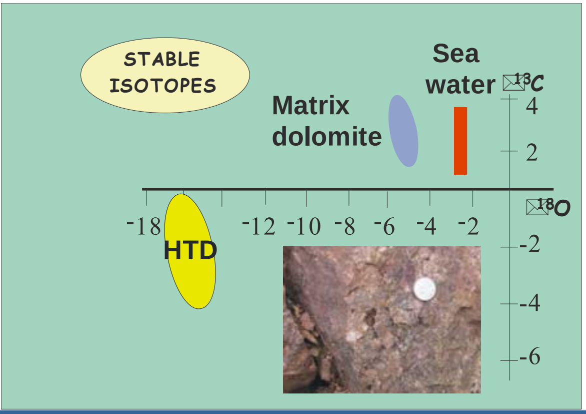
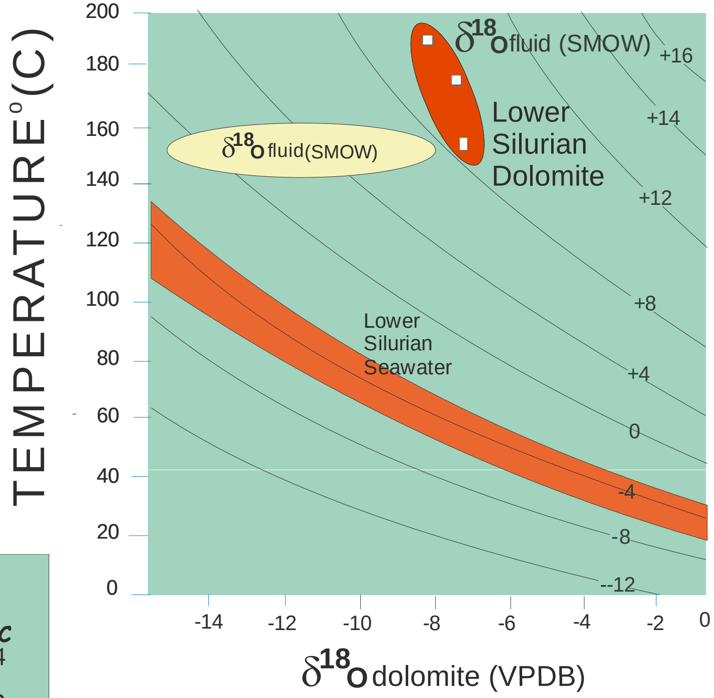
Lower Silurian
Massive dolomitization along faults

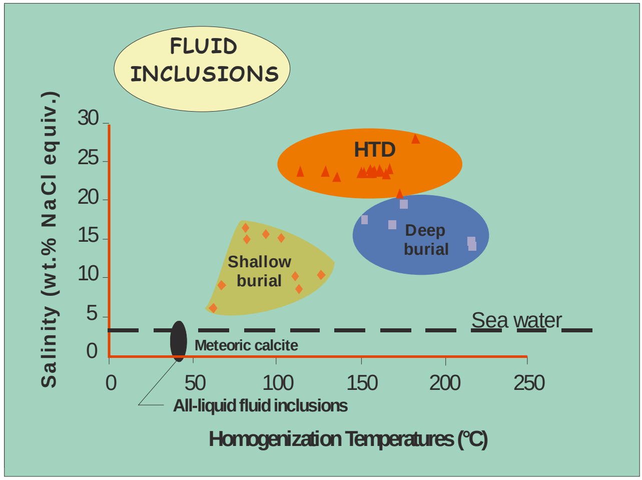
Geochemistry

δ¹⁸O – very negative





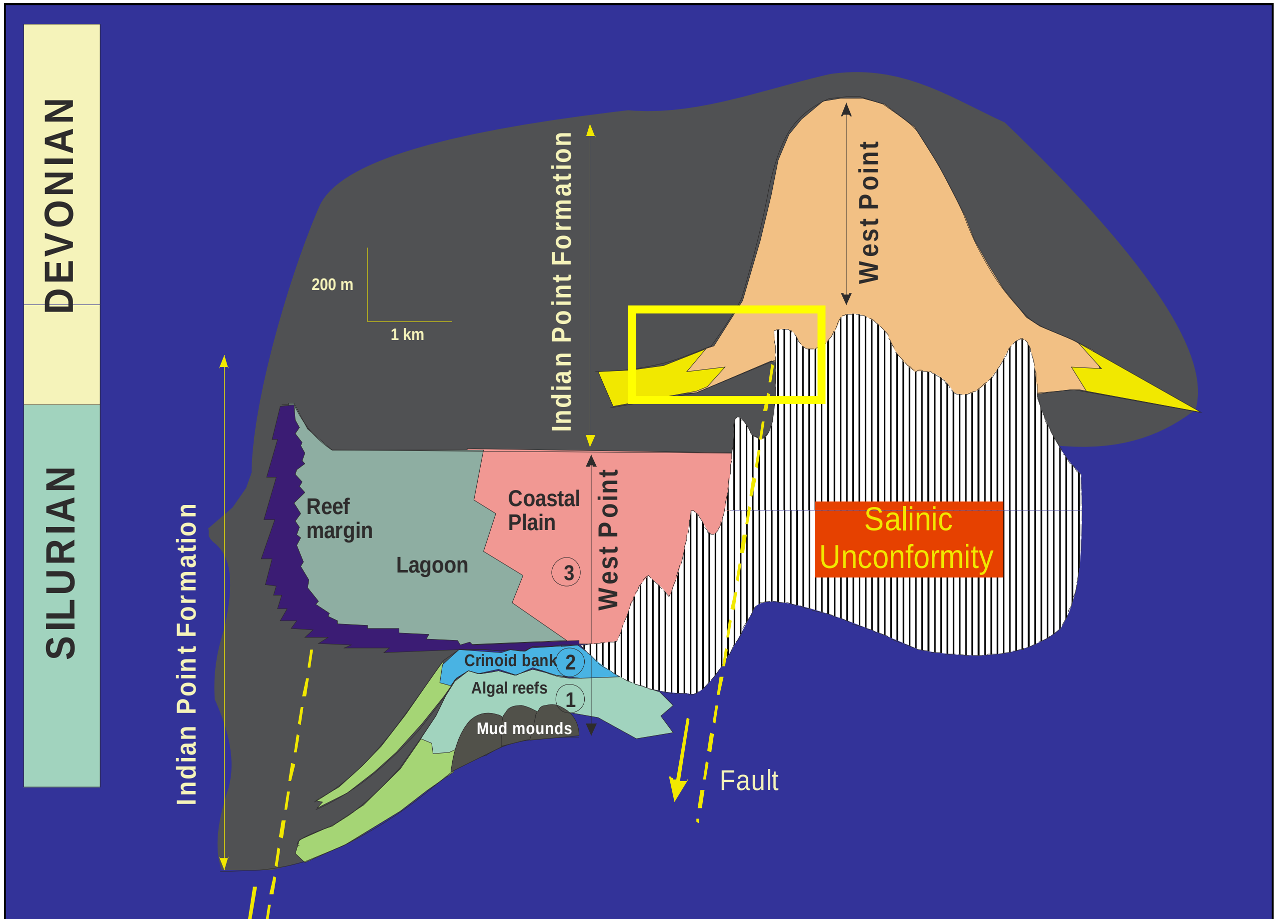
Precipitated out of a ¹⁸O-rich fluid



Very saline
Precipitated under less than 500 m of burial

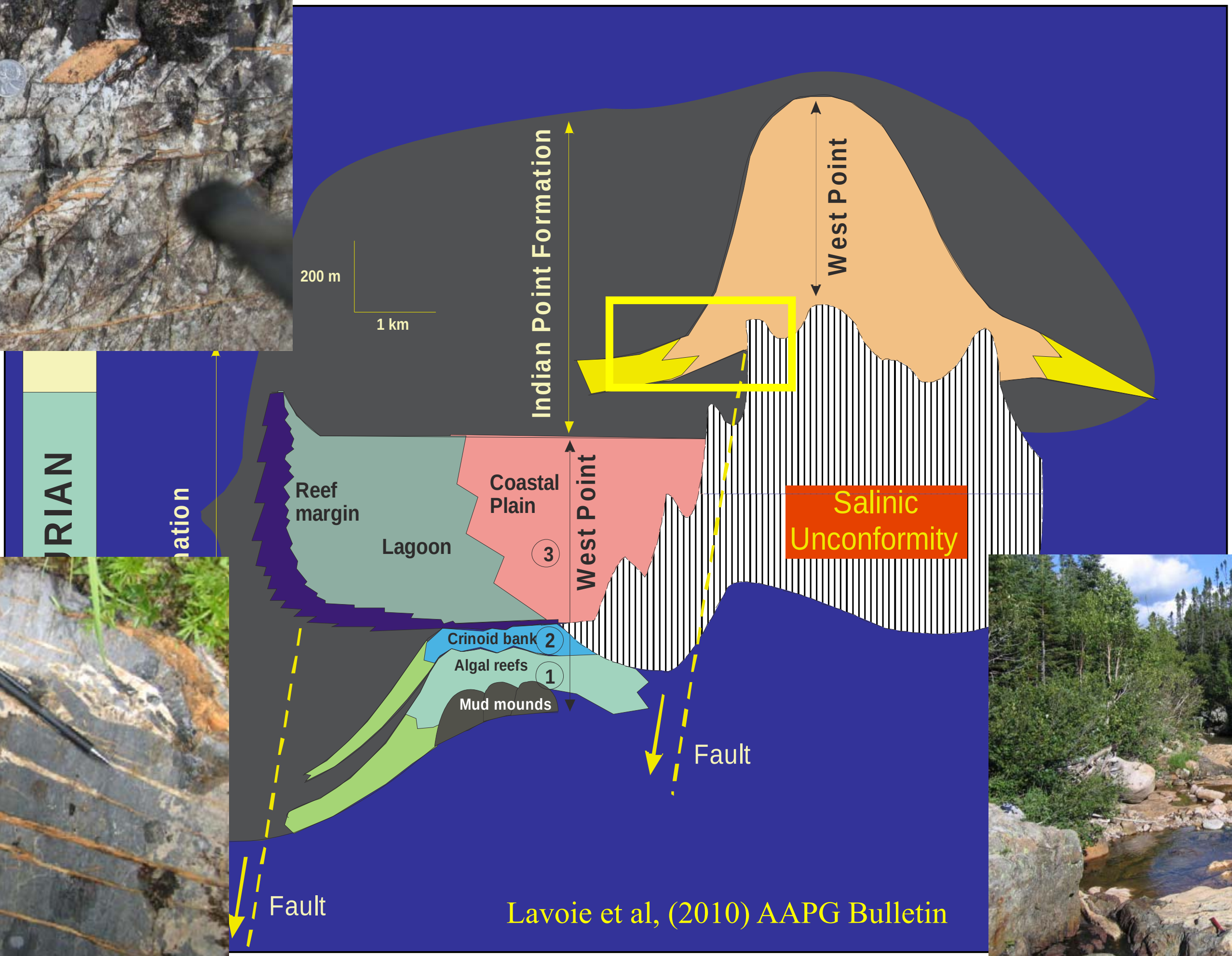
Lavoie and Chi, 2010 (BCPG)

Lower Devonian Magmatic-driven dolomitization along Devonian faults

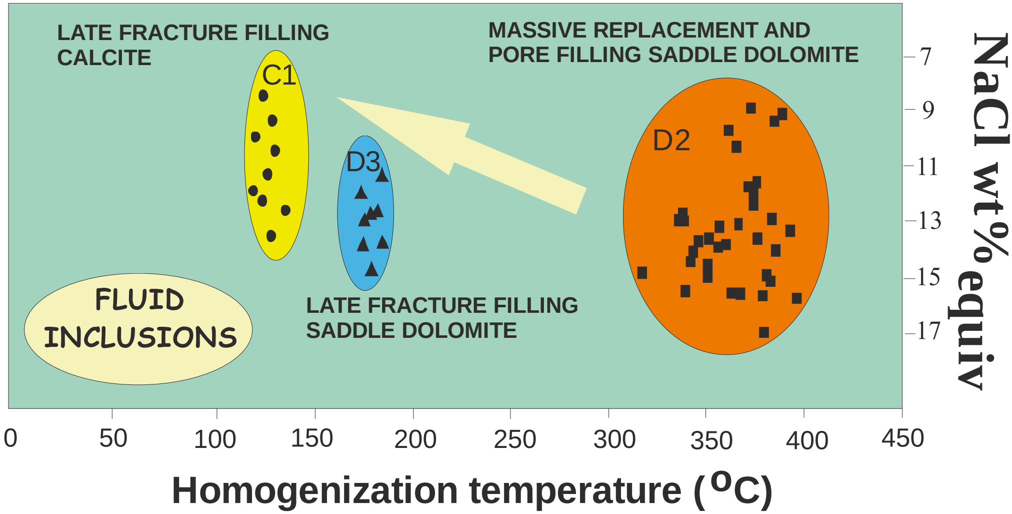


Lavoie et al, (2010) AAPG Bulletin

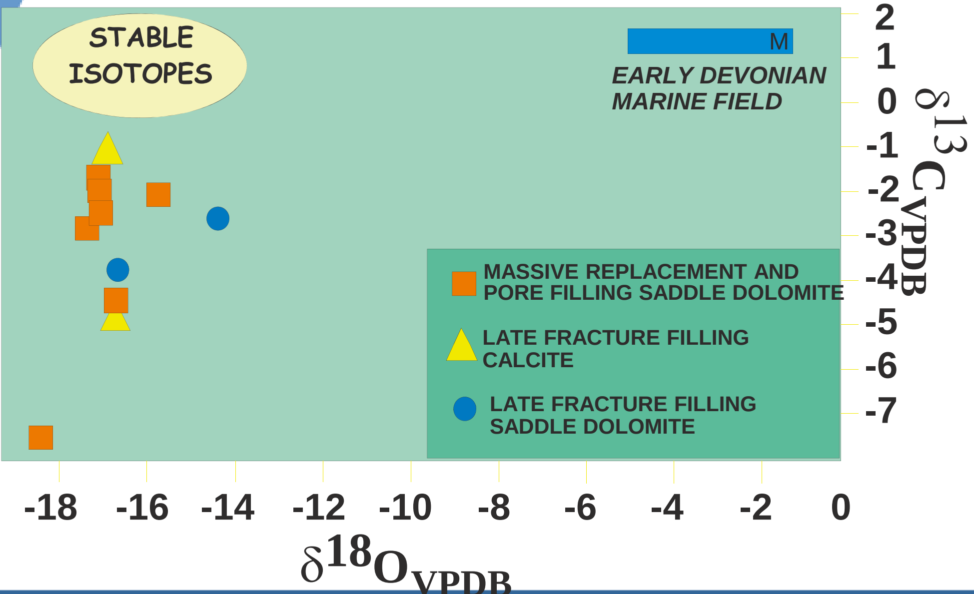
Lower Devonian Magmatic-driven dolomitization along Devonian faults



Geochemistry



Very negative in both $\delta^{18}O$ et $\delta^{13}C$



Extremely high temp of formation
Max burial temp is 150°C

Lavoie et al., 2010 (AAPG Bull)

Magnesium isotopes and dolomites
Fundamentals

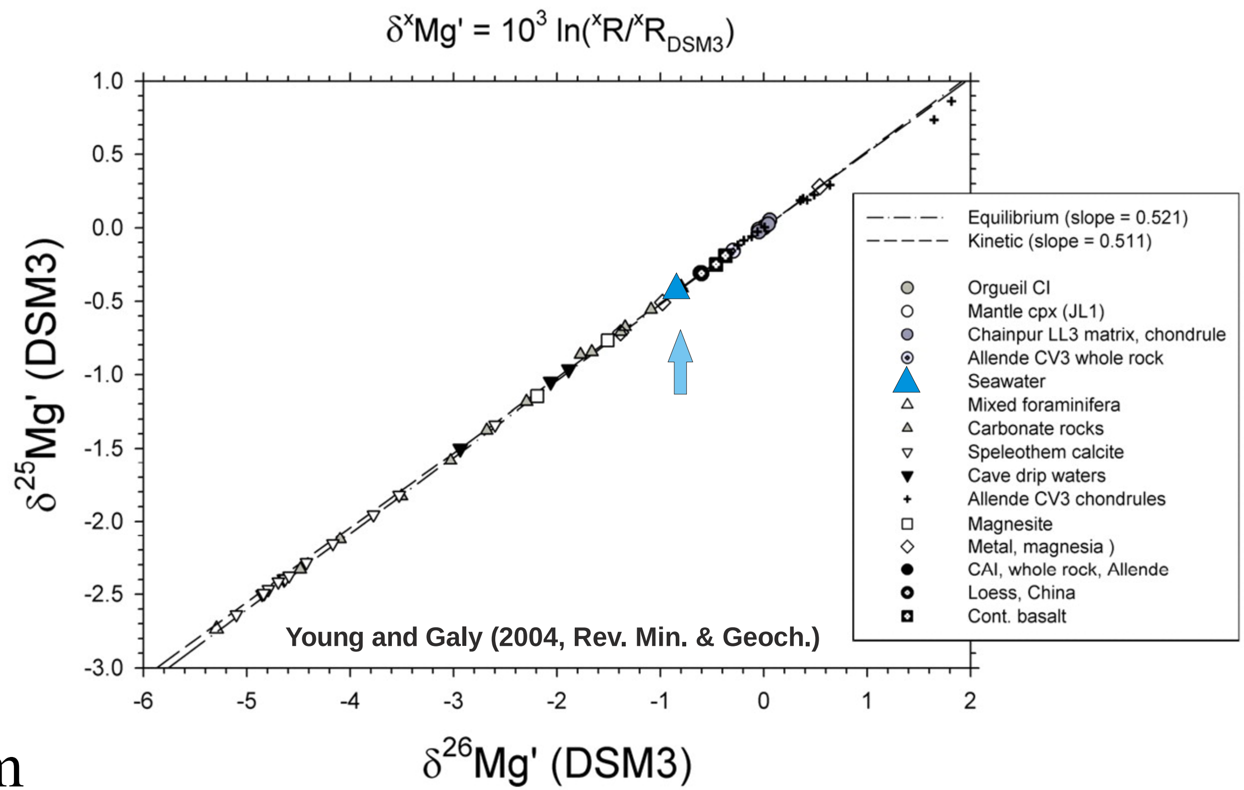
3 natural isotopes

^{24}Mg: 78.99%

^{25}Mg: 10%

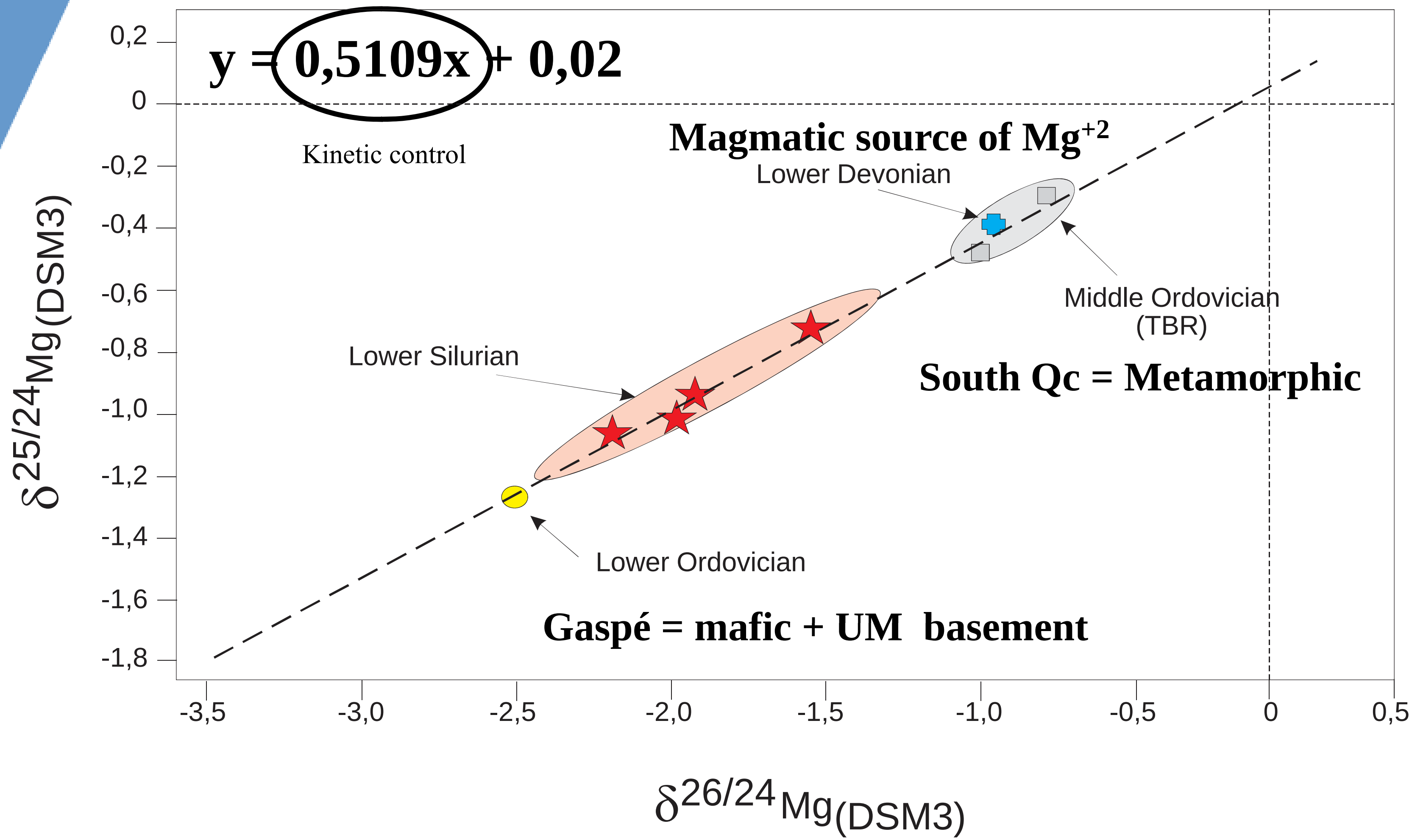
^{26}Mg: 11.01%

Seawater has a fairly constant δ^{26}Mg of -0,82‰



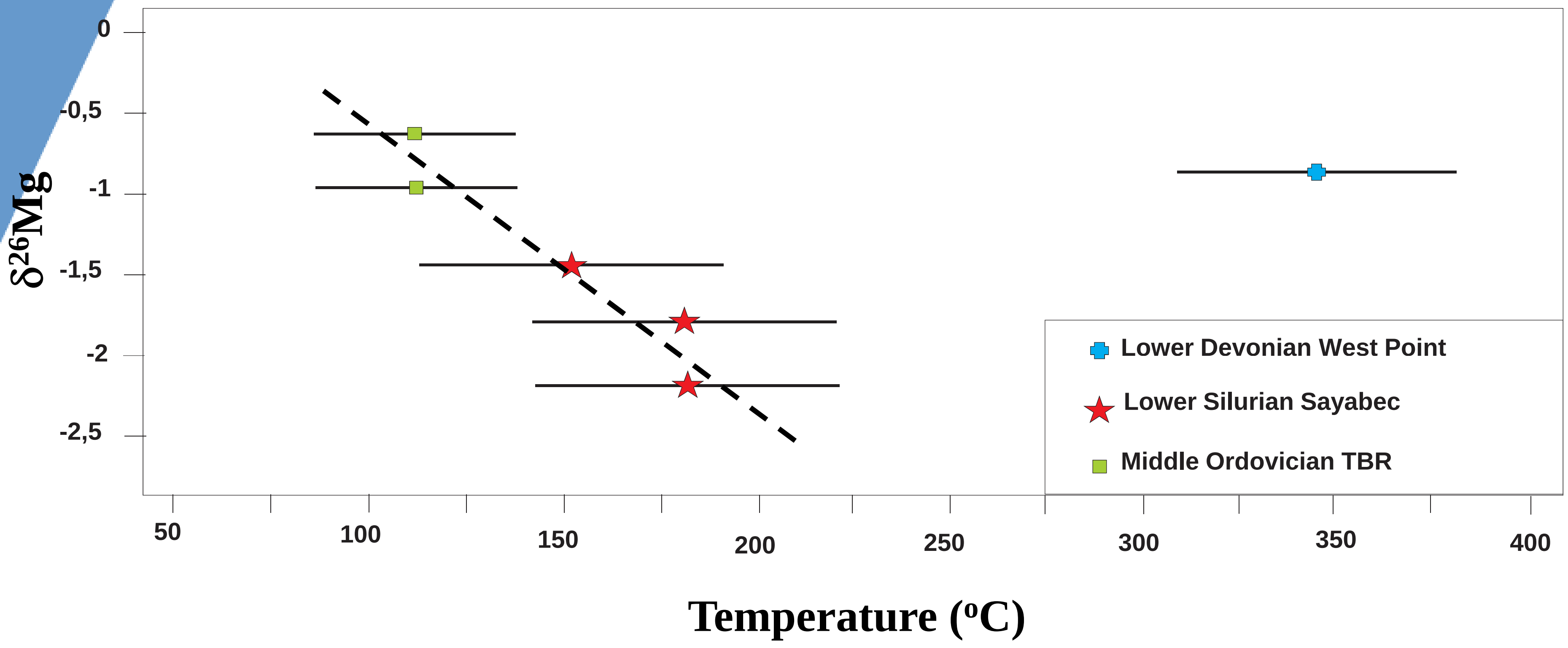
In a three isotopes system fractionation in isotopic equilibrium will generate a correlation slope of 0.521 whereas if fractionation is controlled by kinetic processes, then the slope is 0.511

Mg isotope data in Paleozoic saddle dolomite



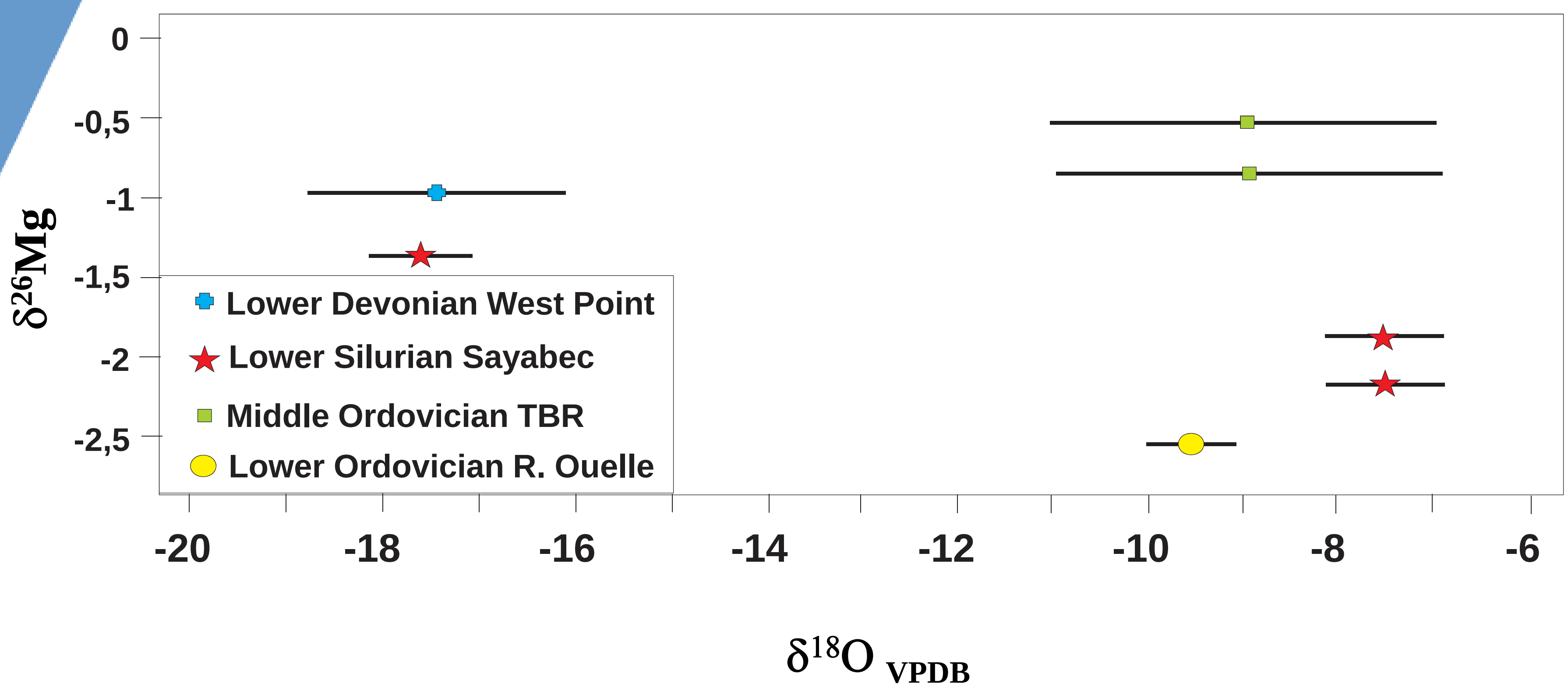
Mg isotope data in Paleozoic saddle dolomite

Temperature of precipitation (T_h of FI)



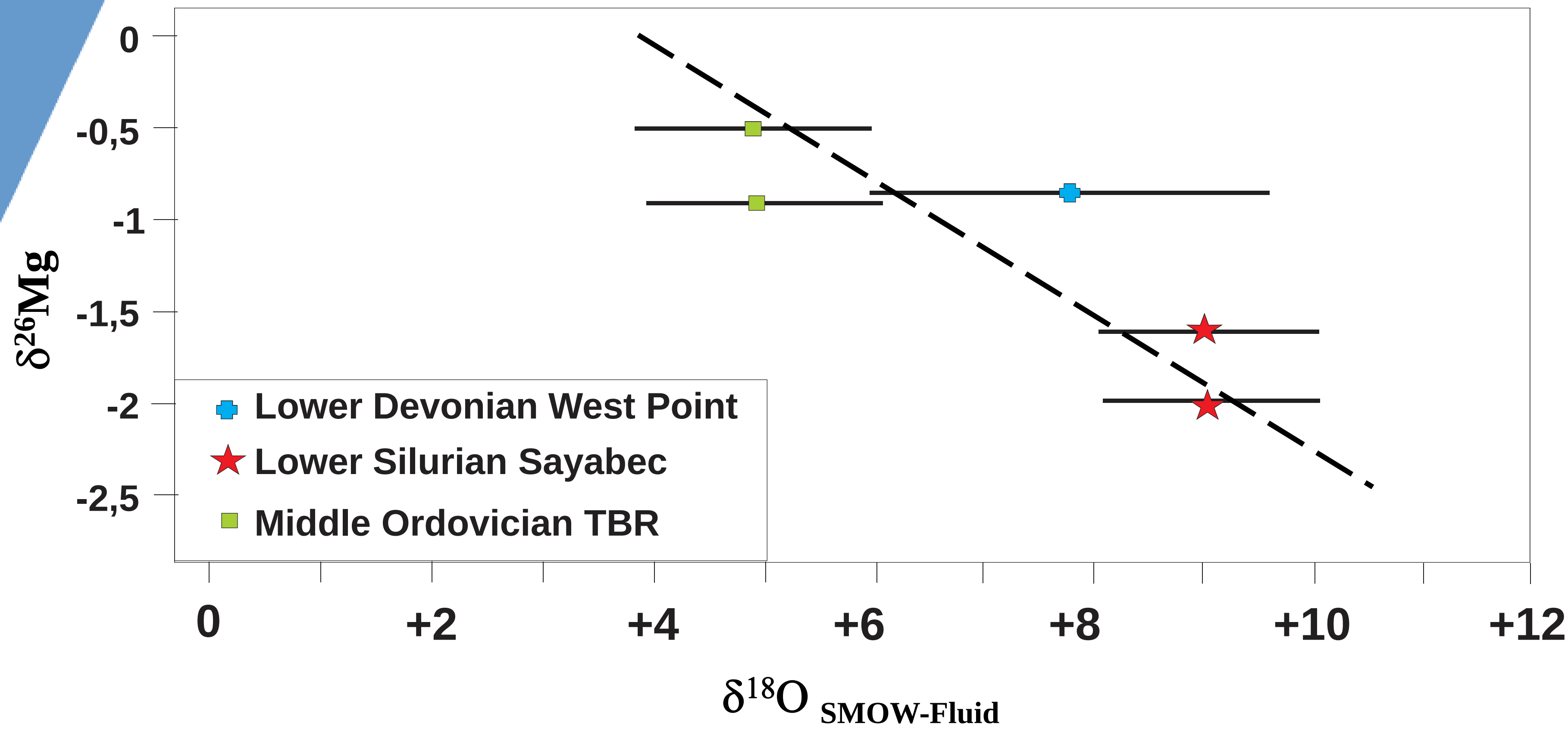
Mg isotope data in Paleozoic saddle dolomite

No relationship between $\delta^{18}O$ and $\delta^{26}Mg$



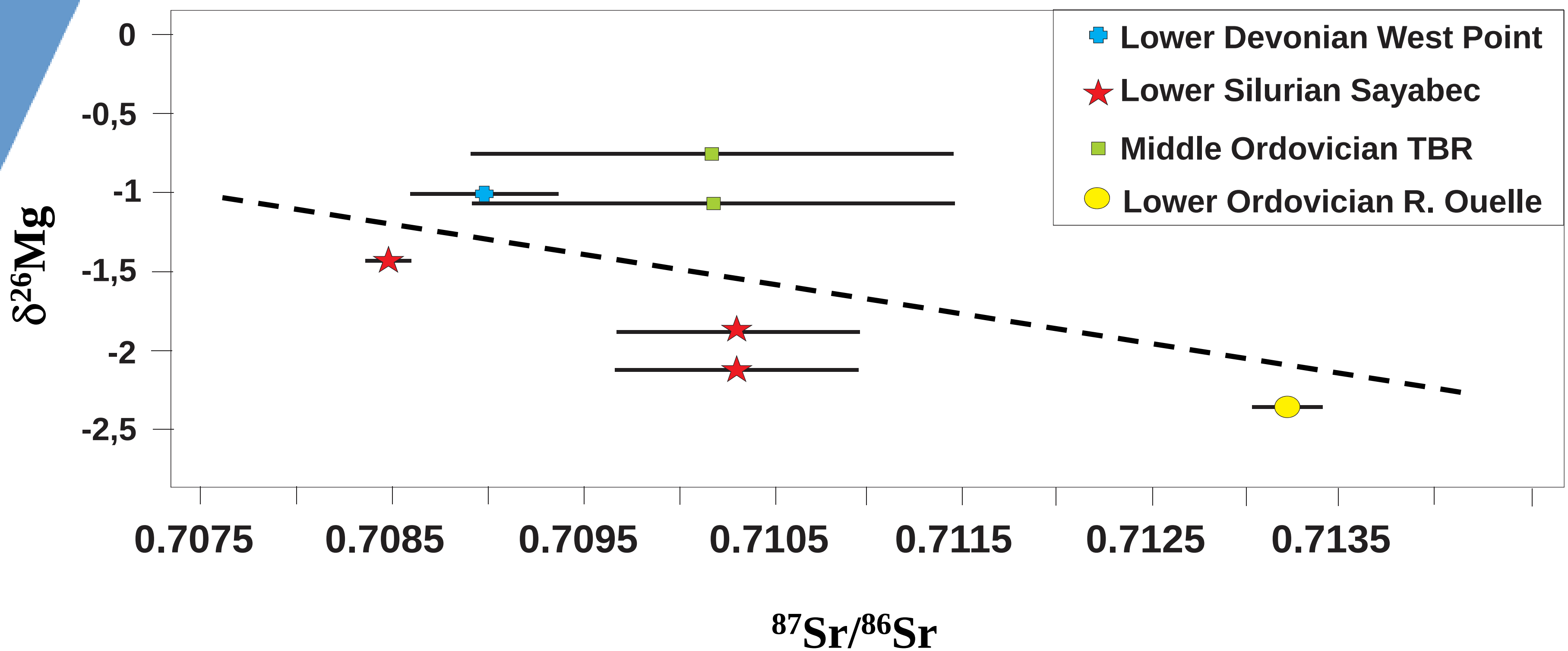
Mg isotope data in Paleozoic saddle dolomite

Relationship between fluid composition and $\delta^{26}Mg$



Mg isotope data in Paleozoic saddle dolomite

Relationship between fluid composition and $\delta^{26}Mg$



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Conclusions (very preliminary)

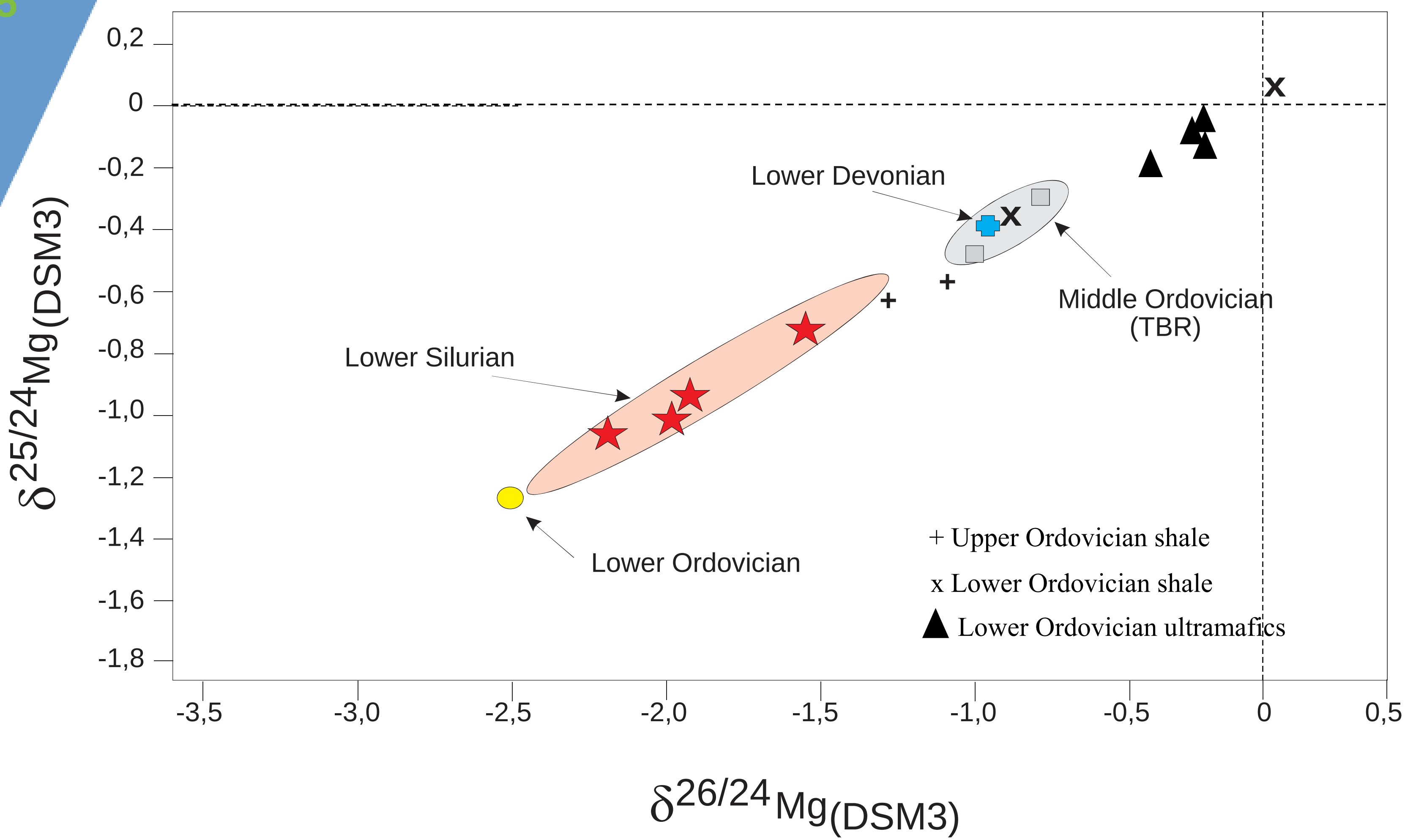
Mg isotopes ratios in high temperature saddle dolomites

1. Show spatial, basement-related variations with Ordovician and Silurian samples from Gaspé being depleted in heavy ^{25}Mg and ^{26}Mg compared to southern Quebec TBR HTD.
2. The Devonian pinnacle dolomite in Gaspé originates from a different fluid compared to adjacent Silurian and Ordovician dolomites (Magmatic fluid; Lavoie et al, AAPG Bull 2010).
3. **Kinetic control of isotopic fractionation** is detected in the relationship between $\delta^{25}Mg$ and $\delta^{26}Mg$ and between $\delta^{26}Mg$ and T_h of FI
4. The **composition of the fluid** (e.g, its source) also control Mg isotope composition as shown by the relationship between $\delta^{26}Mg$ and $^{87}Sr/^{86}Sr$ and $\delta^{18}O_{SMOW}$fluid

In progress and future works

1. Analyse matrix dolomites associated with the saddle ones
2. Analyse non-HTD dolomites (reflux, normal burial)
3. Analyse possible Mg^{+2} source (UM, mafic volcanics, shale)

Preliminary δ^{26}Mg data from potential Mg source rocks



Thank you!

For more info:

http://gdr.nrcan.gc.ca
and
http://gsc.nrcan.gc.ca/org/quebec/