Imaginer de nouvelles compositions de verre ?

Pourquoi se poser cette question?

Volume du verre d'emballages (bouteilles, pots, flacons..) ~ 2,6 millions tonnes

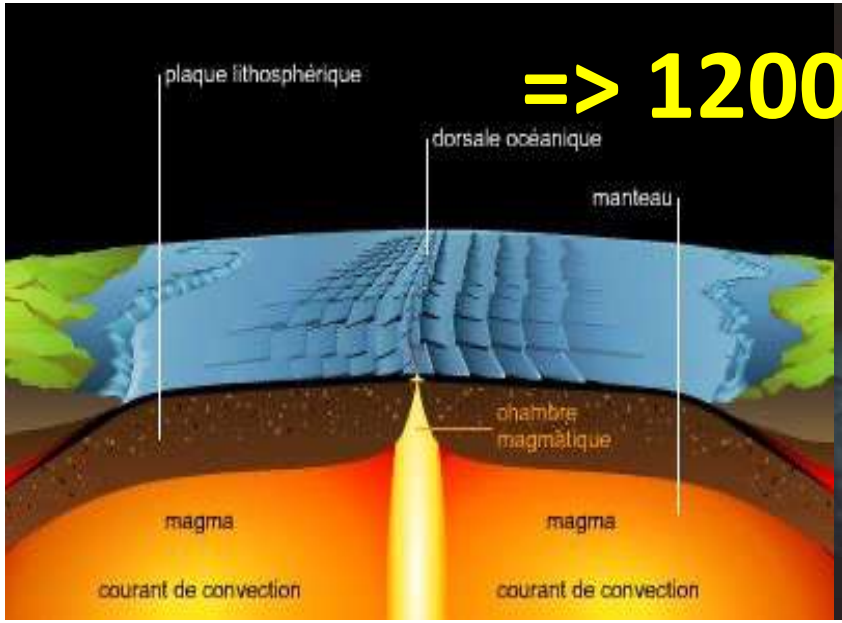
Volume de calcin ~ 2,2 millions tonnes

Quel est le plus grand producteur de verre au monde?

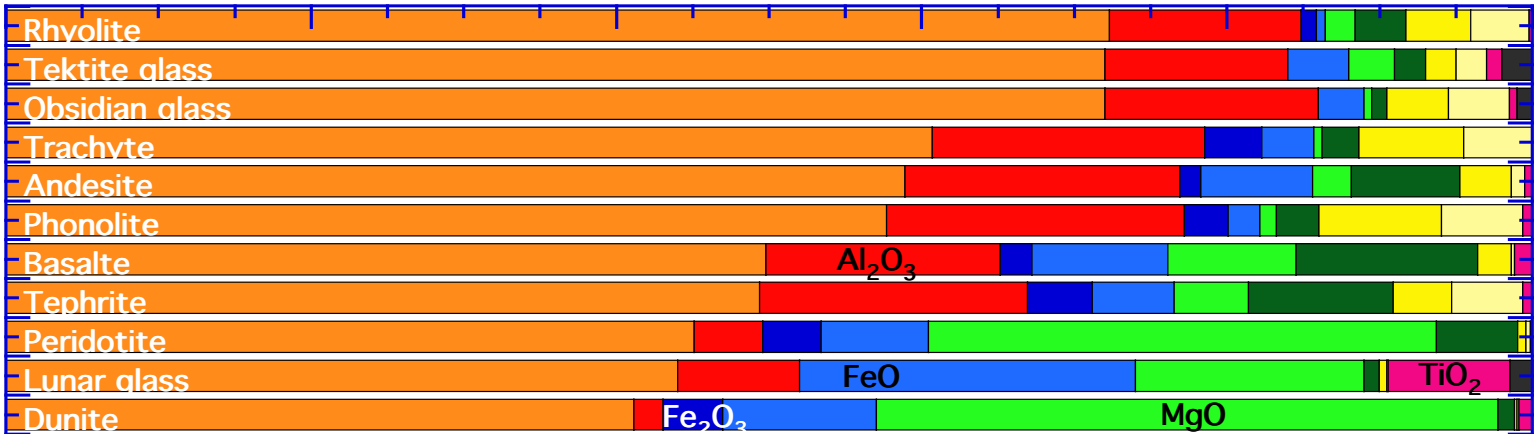
Industrie verrière : 140 millions de tonne par an

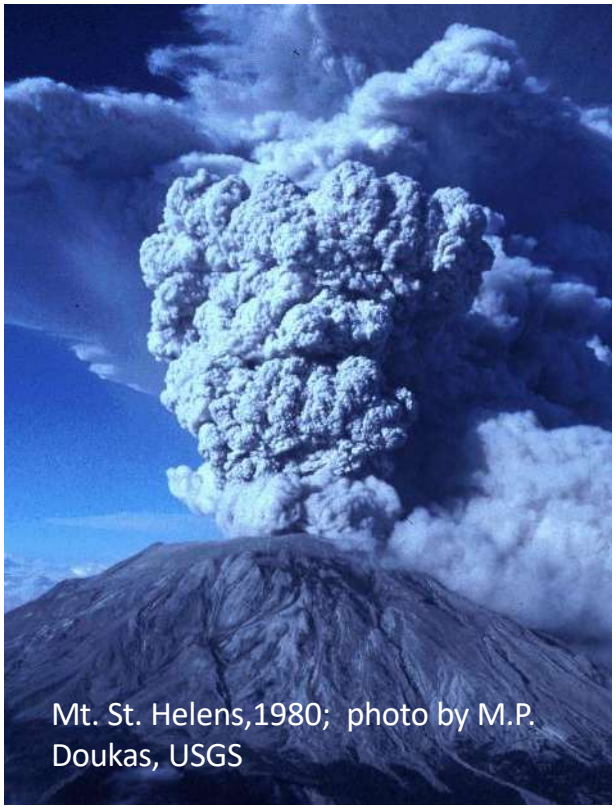
~72millions verre plat

La Terre : 37900 millions de tonne par an

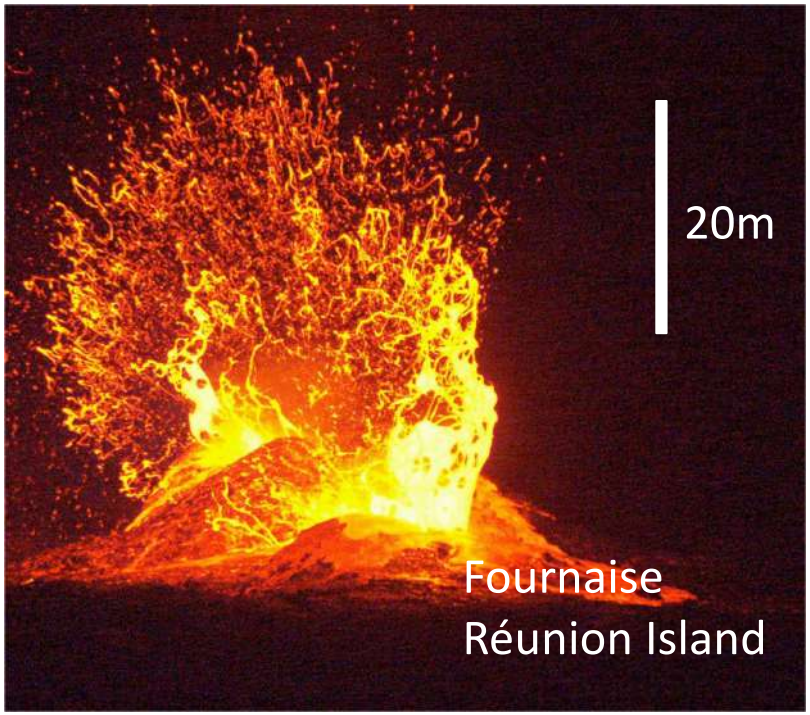


=> 1200 tonne/seconde

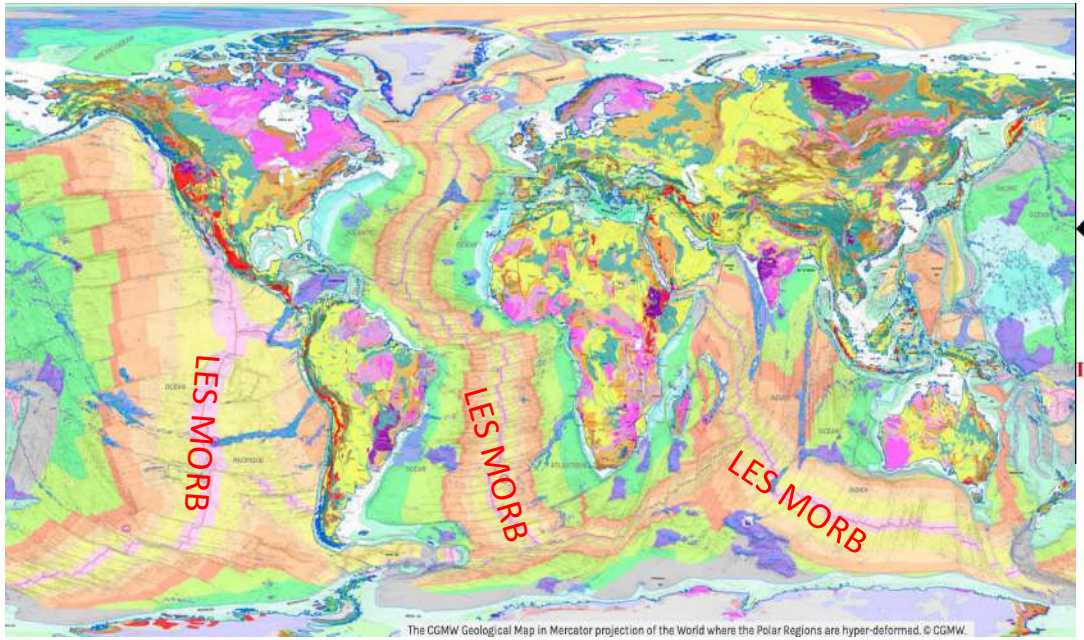


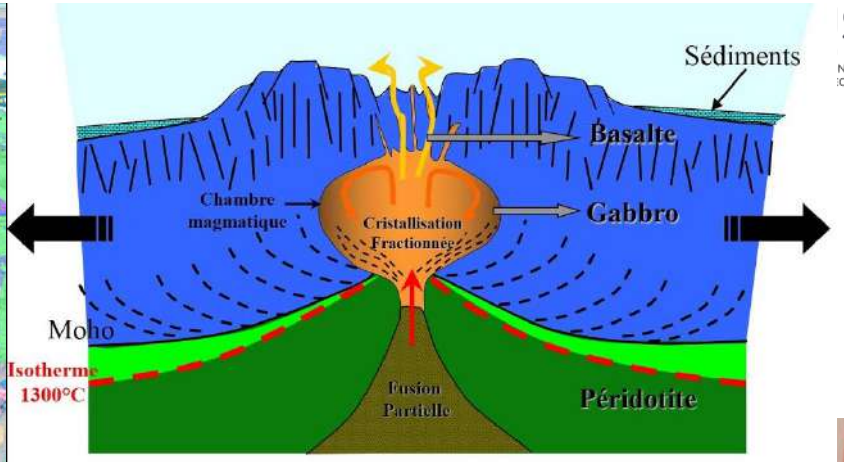


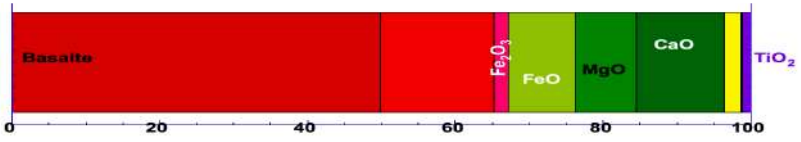
Mt. St. Helens,1980; photo by M.P. Doukas, USGS



✓ *Où trouver du verre autour de nous ?*







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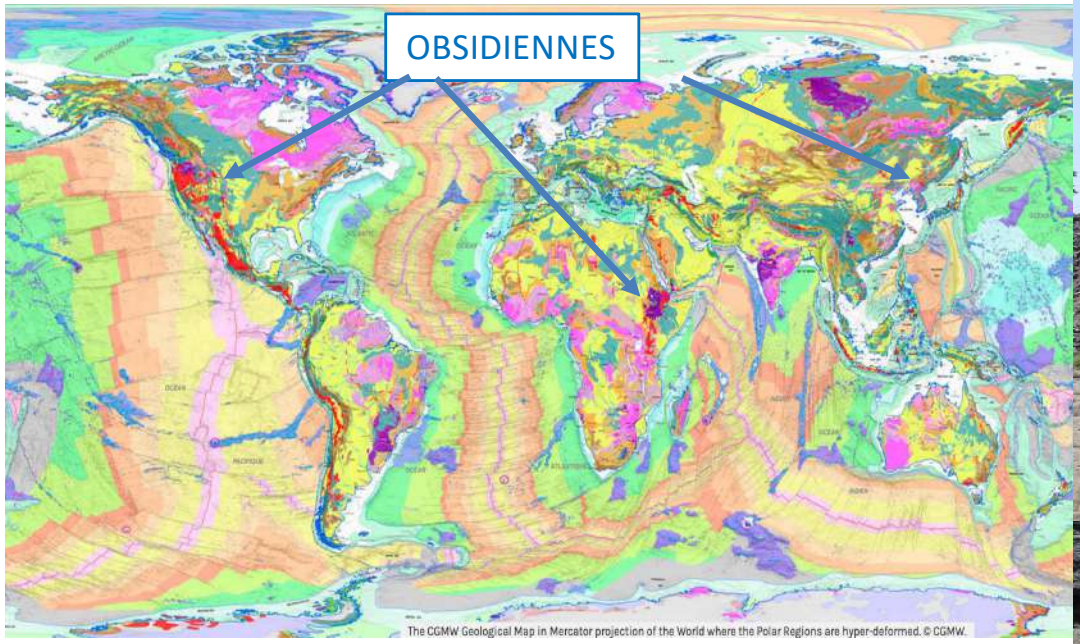
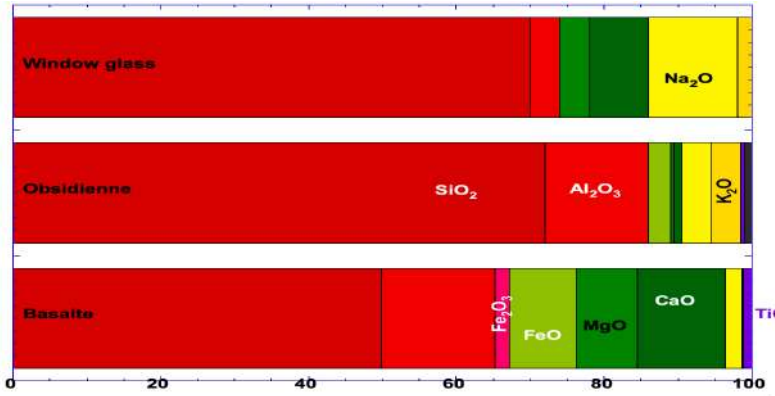
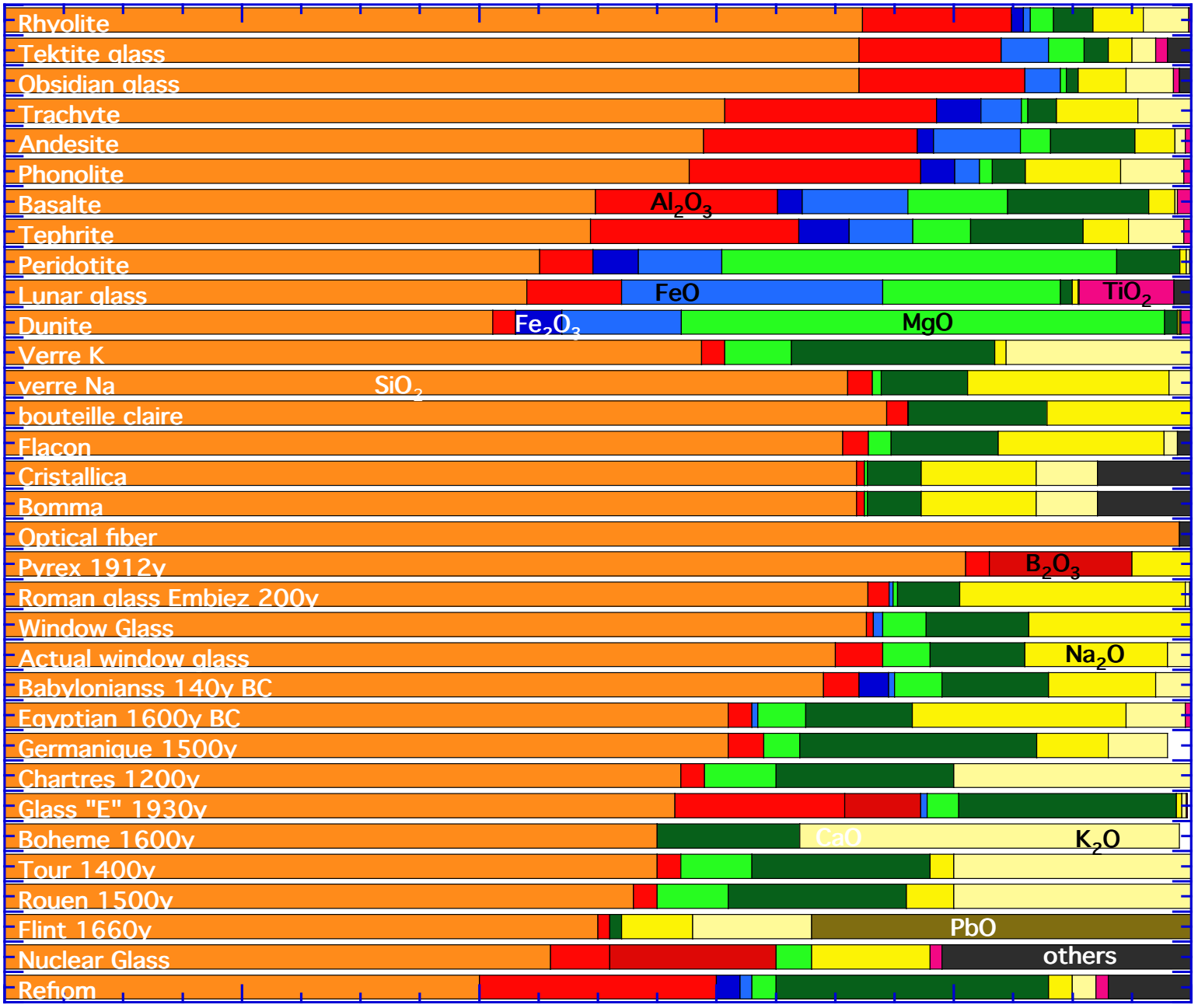


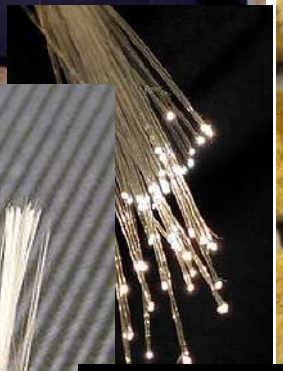



Rhyolite
Tektite glass
Obsidian glass
Trachyte
Andesite
Phonolite
Basalte
Tephrite
Peridotite
Lunar glass
Dunite
Verre K
verre Na
bouteille claire
Flacon
Cristallica
Bomma
Optical fiber
Pyrex 1912y
Roman glass Embiez 200y
Window Glass
Actual window glass
Babylonianss 140y BC
Egyptian 1600y BC
Germanique 1500y
Chartres 1200y
Glass "E" 1930y
Boheme 1600y
Tour 1400y
Rouen 1500y
Flint 1660y
Nuclear Glass
Refiom
Al_2O_3
FeO
TiO_2
Fe_2O_3
MgO
SiO_2
B_2O_3
Na_2O
CaO
K_2O
PbO
others
0
20
40
60
80
100



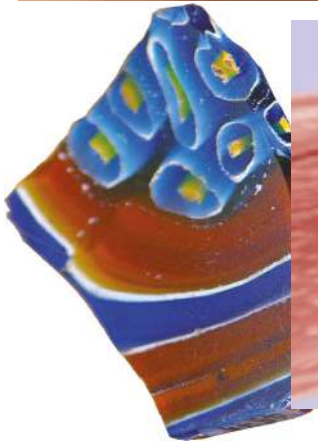
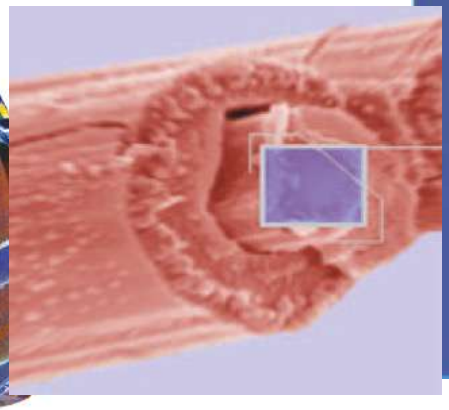


Encore plus pratiques...
les nouvelles formes
de verre à feu PYREX
Sedlex
jugez des prix...







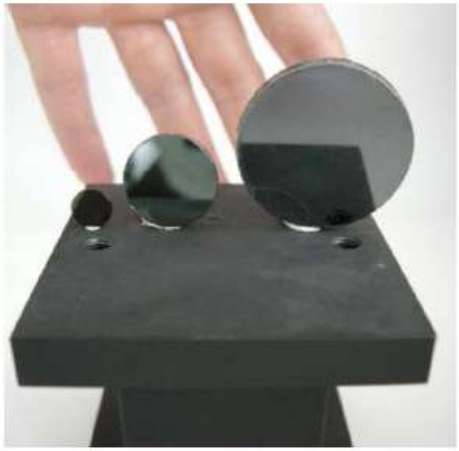
ivadent website




Verre métallique

Laser glasses

Verre de phosphate

Image visible



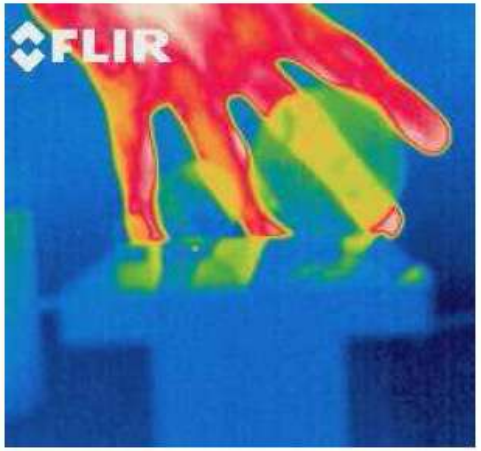
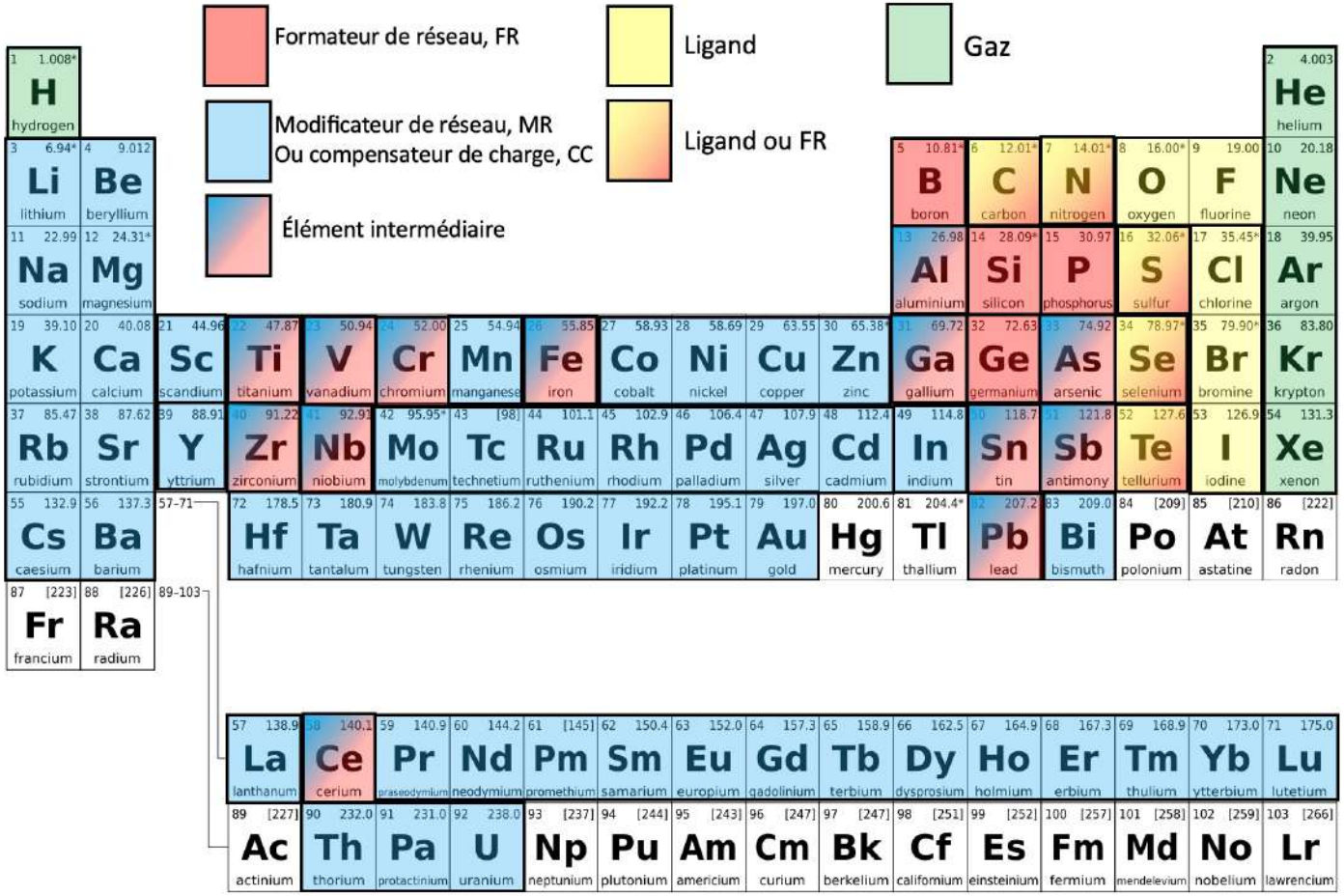


Image caméra thermique 8-12µm

Verre organique : le caramel

Source : écoles et ateliers UTSV, www.ustverre.fr



Comptes Rendus
Géoscience — Sciences de la Planète
2022, Vol. 354, Special Issue S1, p. 1-14
https://doi.org/10.5802/crgeos.171

Glass, an ubiquitous material / *Le verre, un matériau omniprése*

Glass, an ubiquitous material

Le verre, un matériau omniprésent

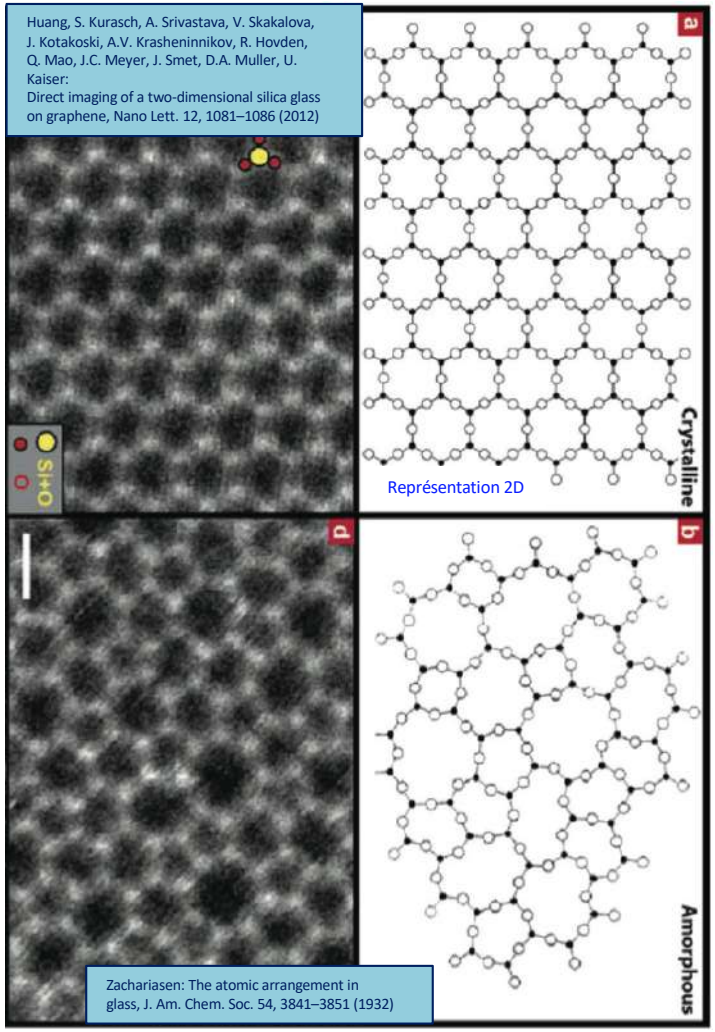
Daniel R. Neuville[a]

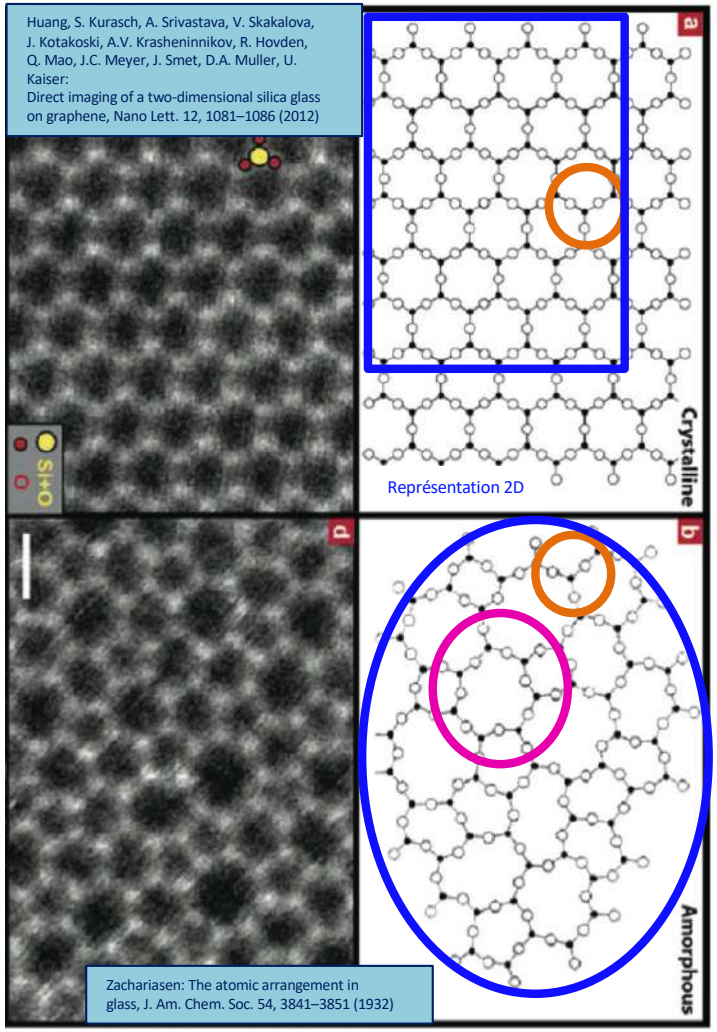
Tous les éléments et toutes les liaisons chimiques:
- covalentes
- ioniques
- métalliques
- Van der Waal's
- Hydrogène

=> Verre d'oxydes, de chalcogènures, métalliques, d'halures, organiques et toutes les combinaisons possible

Qu’est ce qu’un verre ?

✓ Quelques grandes notions sur le verre : Structure et propriétés





Structure à courte distance :

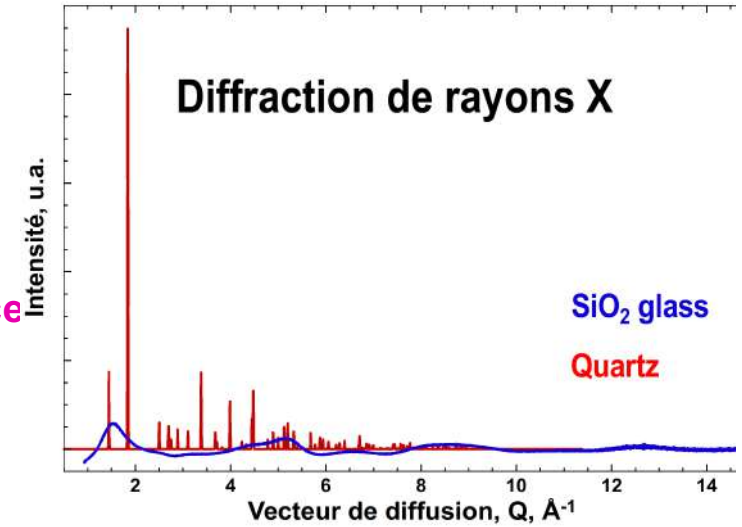
– coordinence, longueurs de liaisons, angles de liaisons

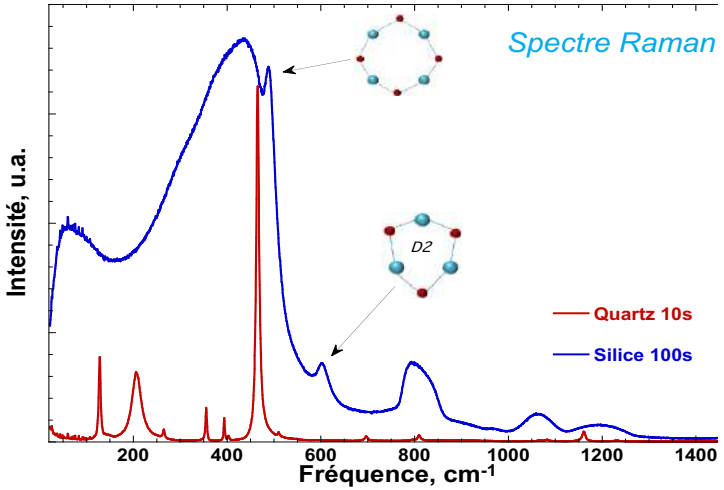
Structure à moyenne distance

– angles entre les unités de base
– connectivité entre les unités de base (liaisons par sommet, arête …)
– dimensionnalité du réseau, anneaux

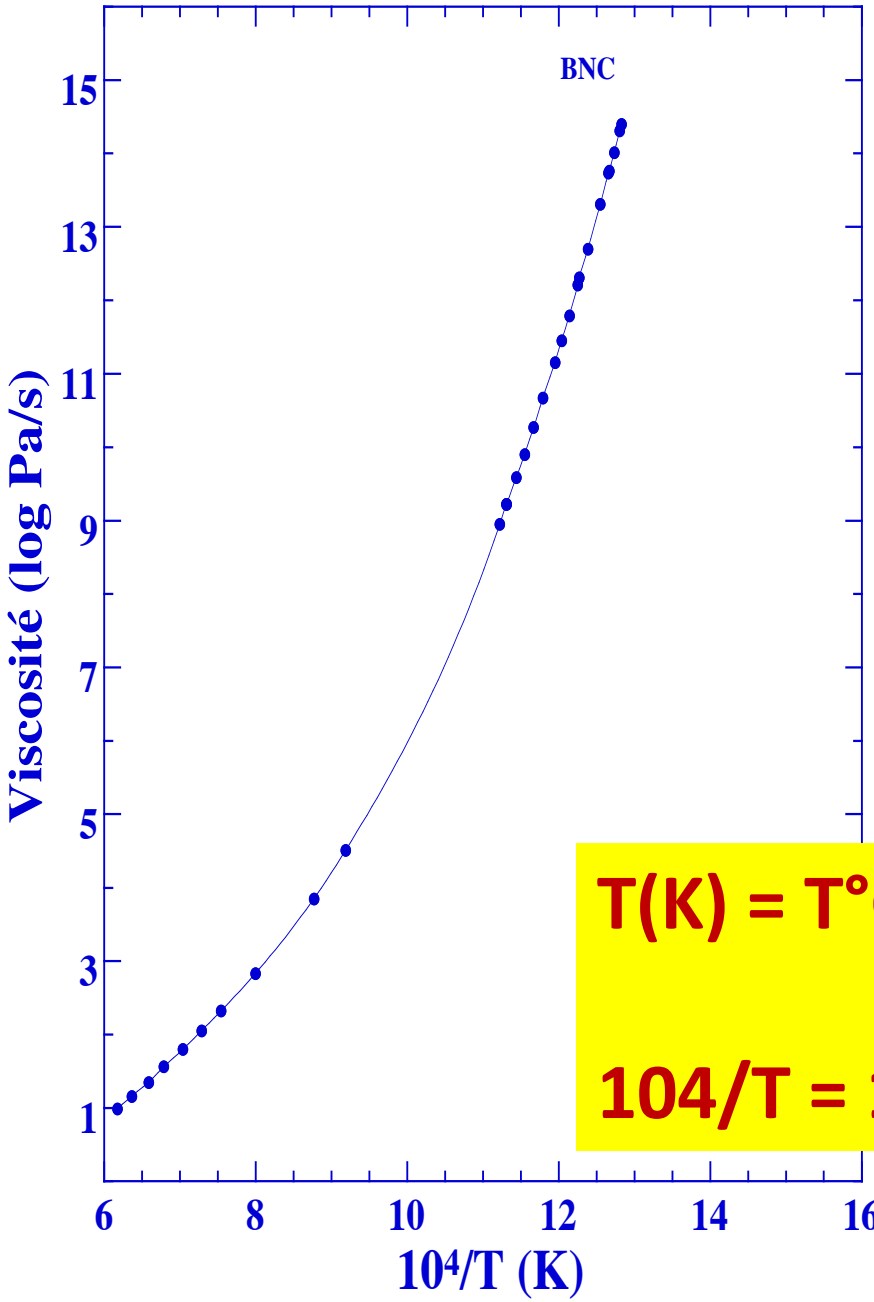
Structure à longue distance

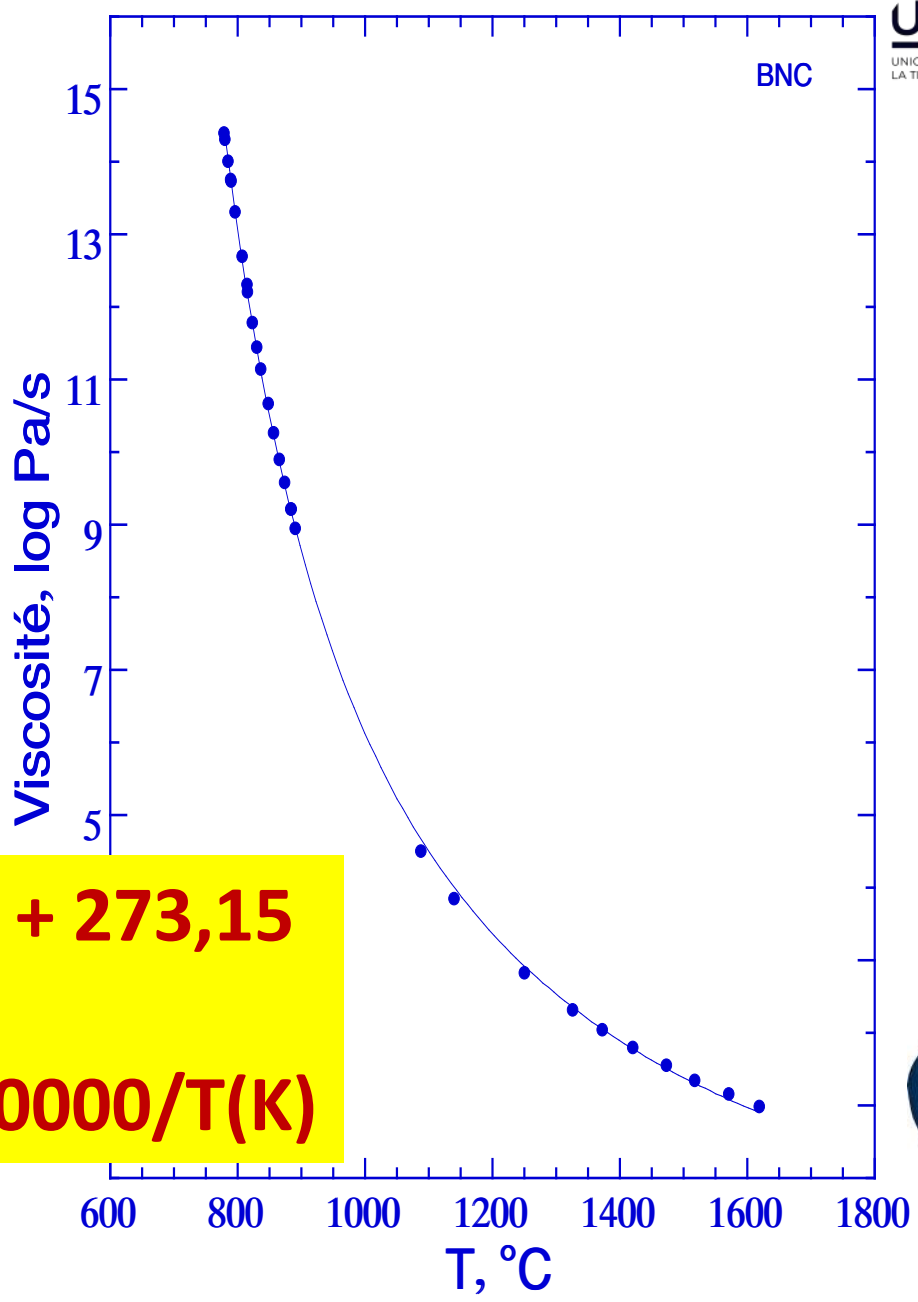
(pas périodique !) :
– séparation de phase
– inhomogénéité





Qu'elle est la principale propriété d'un verre ?

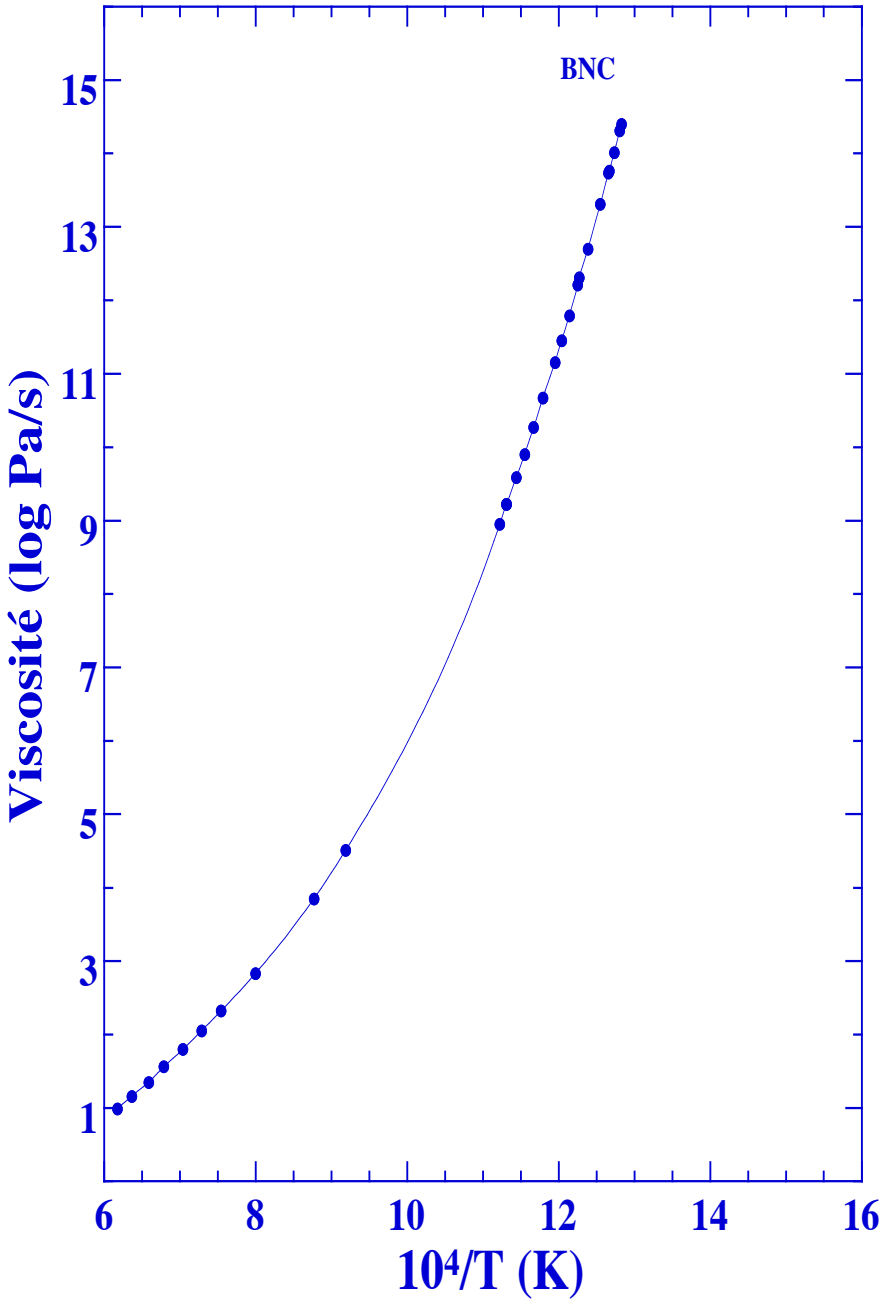


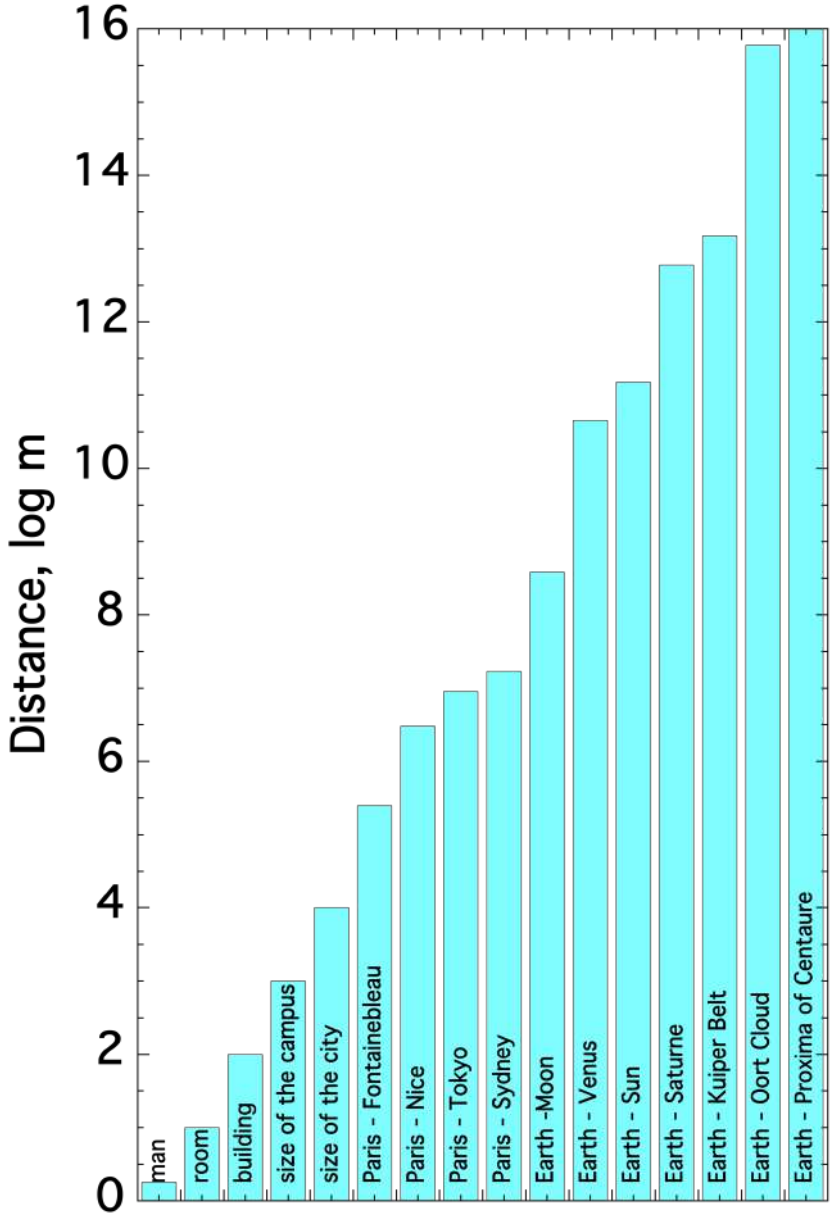


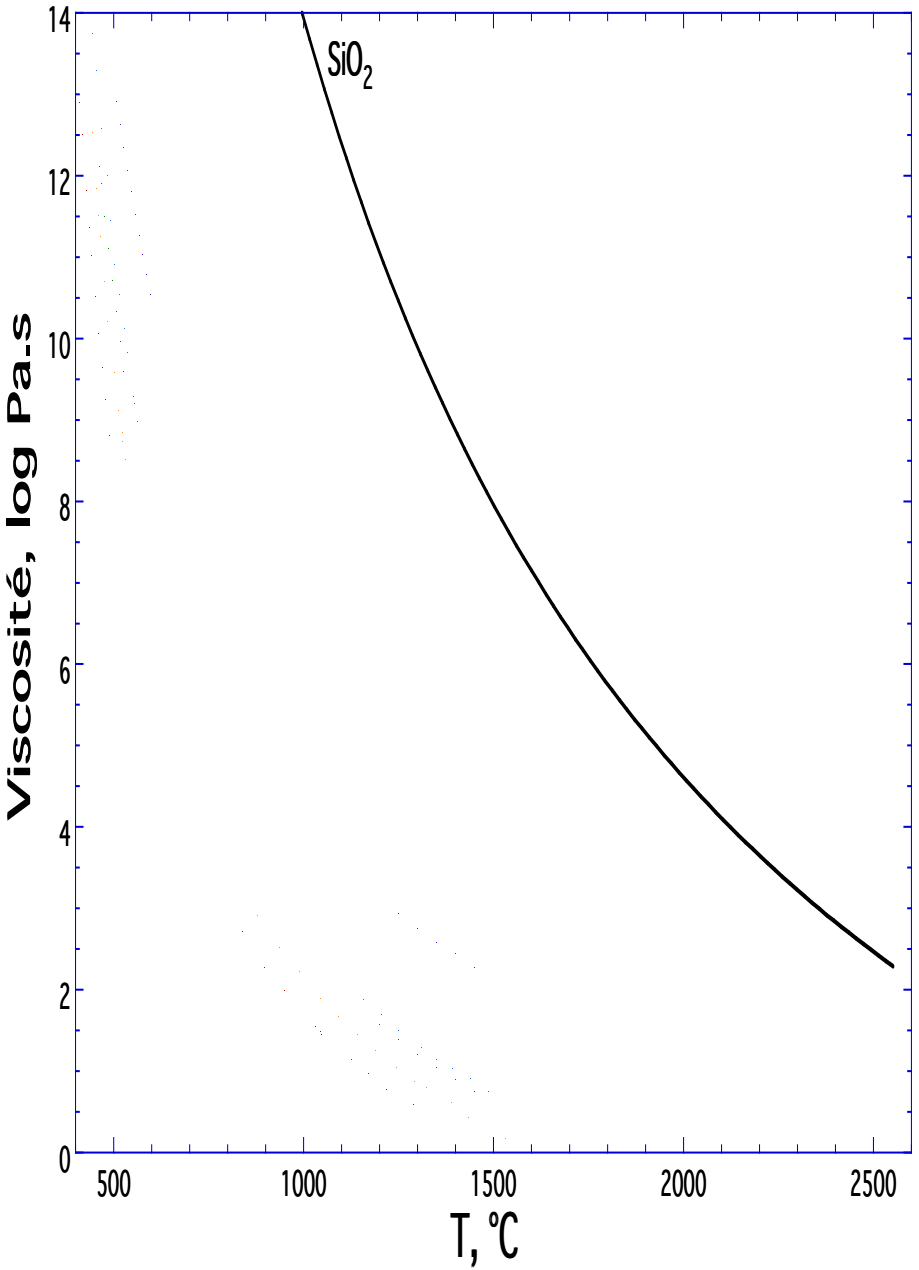
T(K) = T°C + 273,15

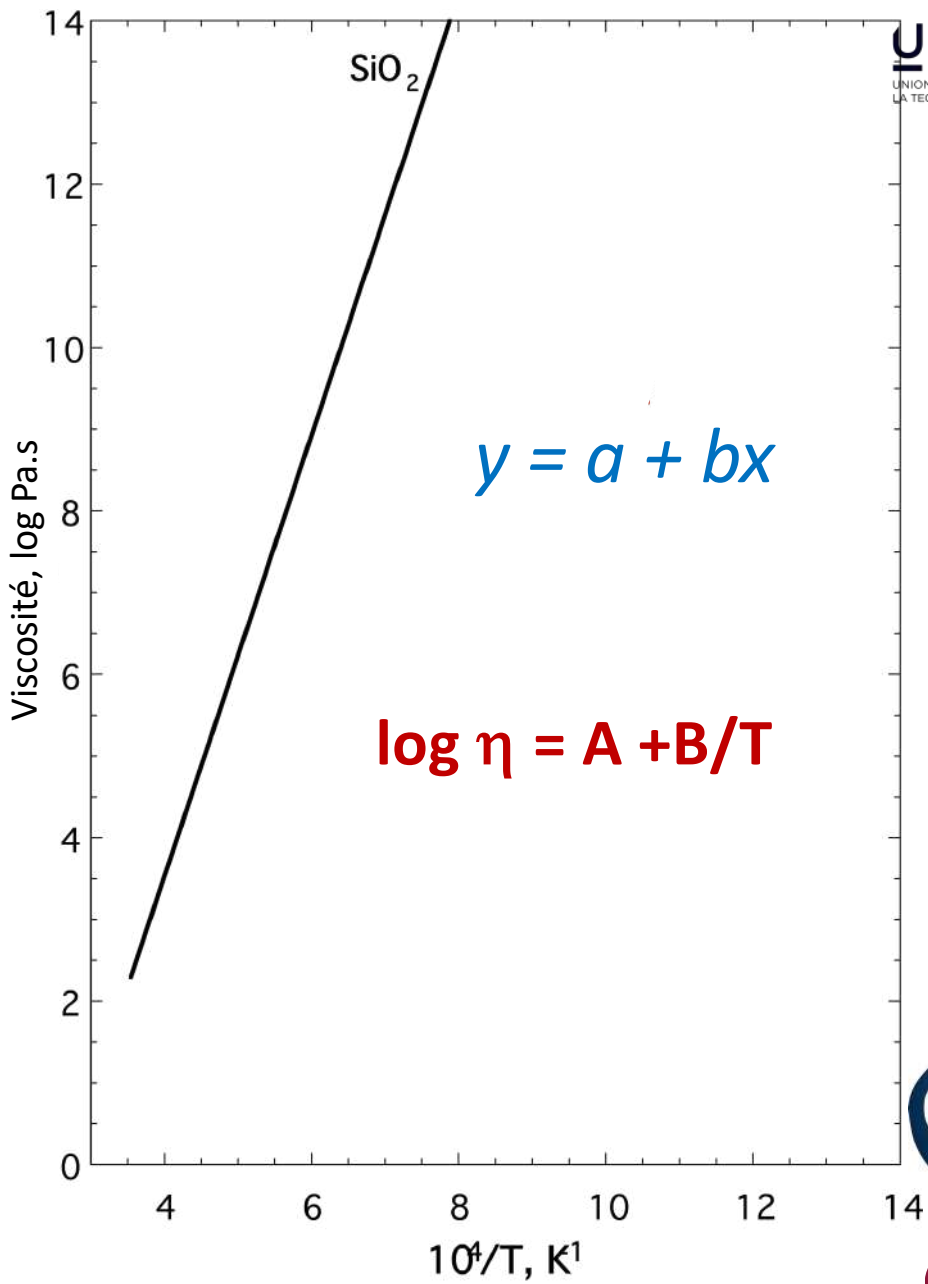
104/T = 10000/T(K)

Grand nombre -> difficile à mesurer



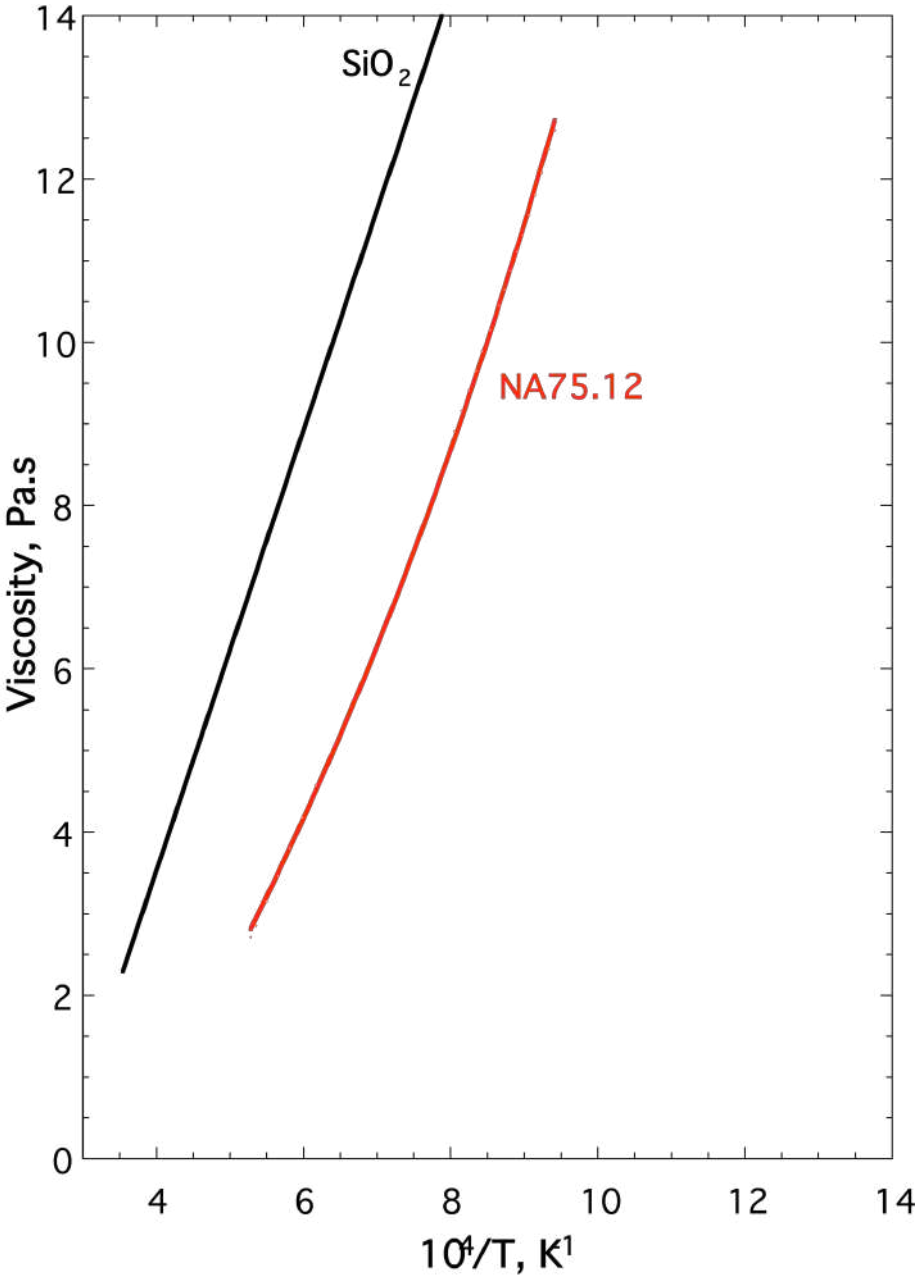






$y = a + bx$

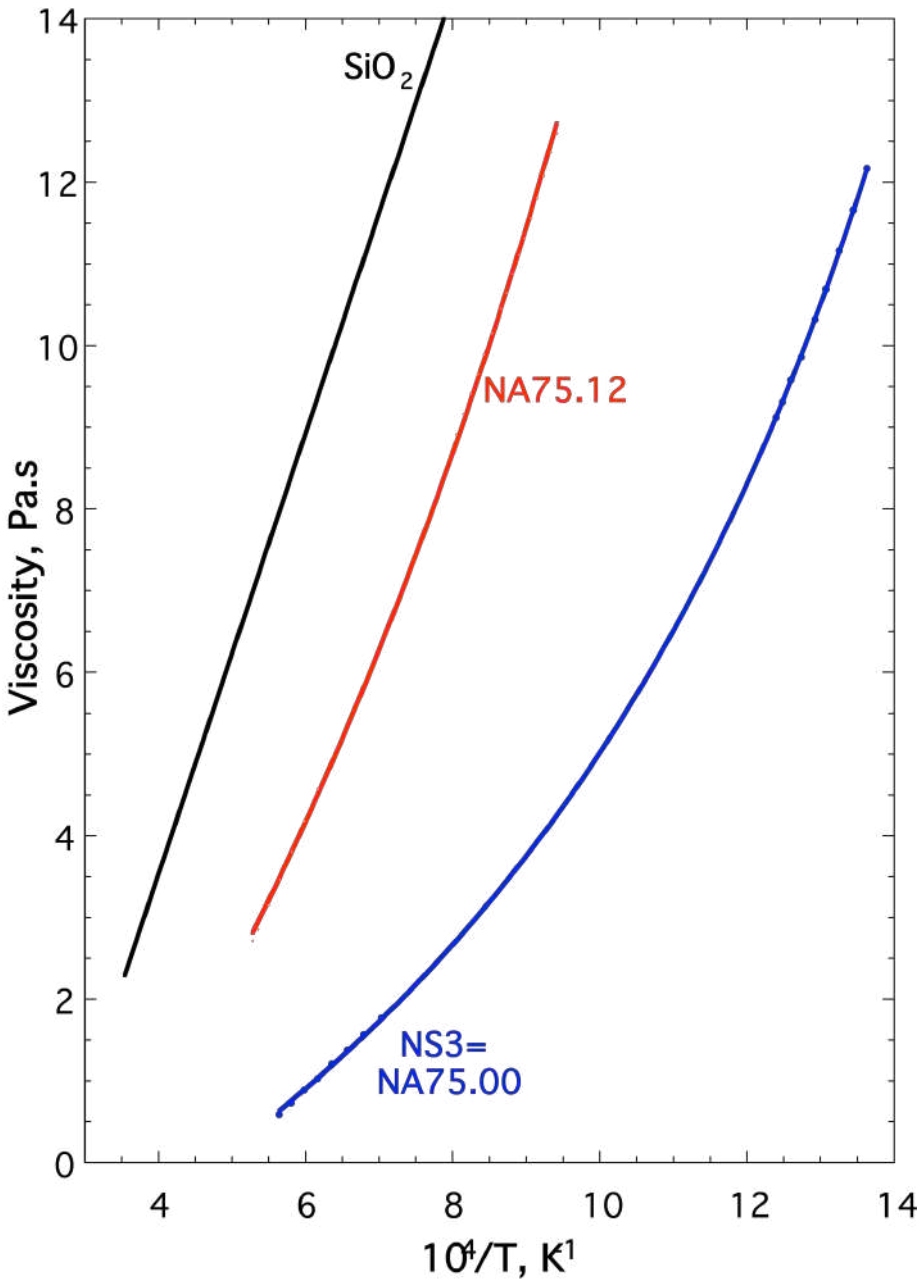
$\log \eta = A + B/T$



Modèle d'Arrhénius

$$\log \eta = A + B/T \qquad (1)$$

Mais, cette loi ne fonctionne que pour quelques systèmes silicatés, SiO_2, $NaAlSi_3O_8$ (NA75.12)…



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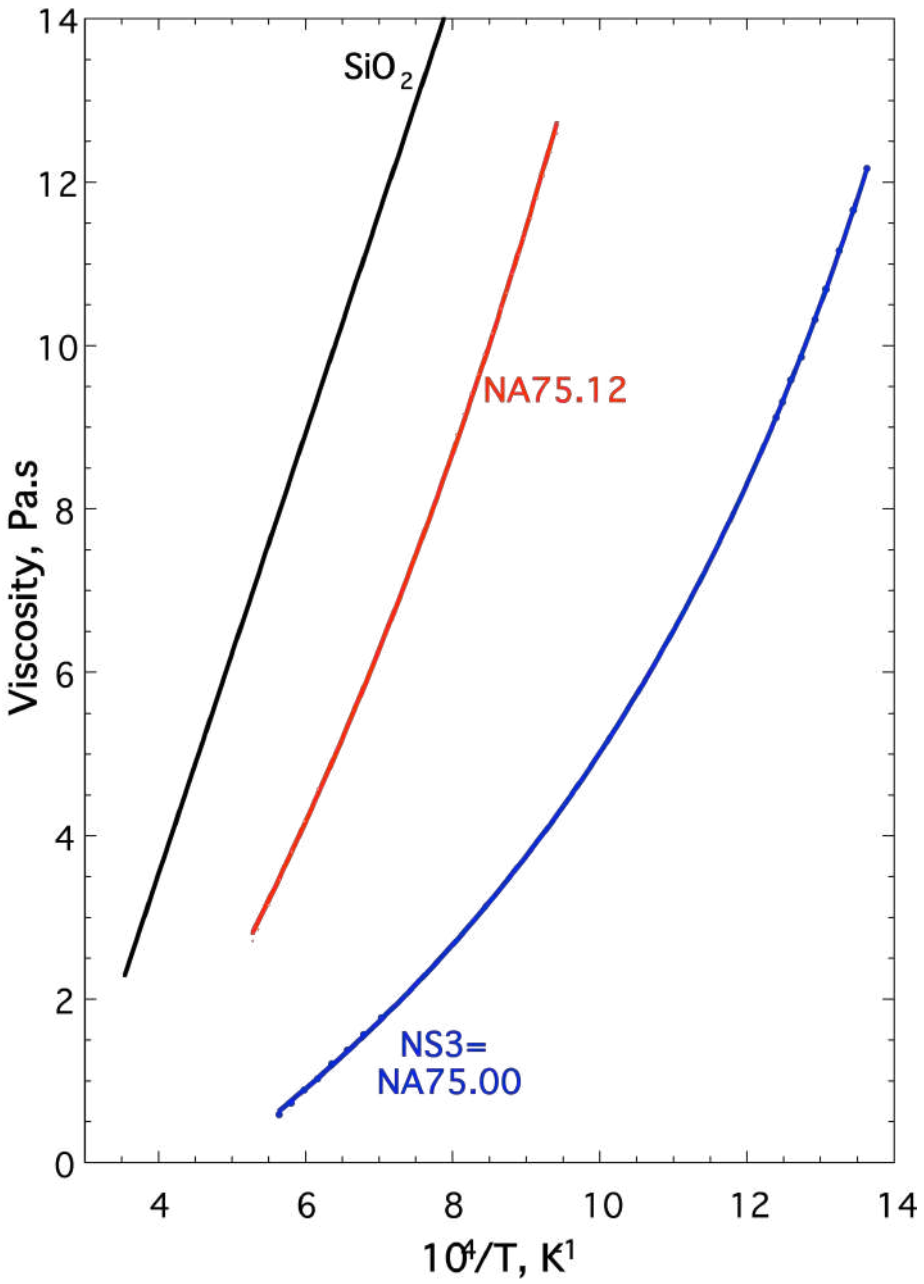
Mais… cette loi ne fonctionne que pour quelques systèmes silicatés, SiO_2, $NaAlSi_3O_8$ (NA75.12)…

Dans le cas d'un silicate de sodium, **NS3**, l'énergie d'activation est de 2000kJ/mol à 1000K et de 300kJ/mol à 1800K, donc l'équation (1) ne peut pas reproduire correctement des changements continus lorsque la température varie.



Modèle d'Arrhénius

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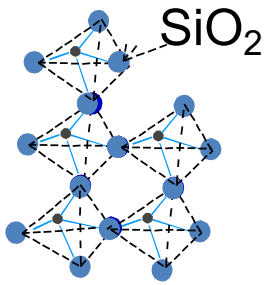
Modèle Tamman-Vogel-Fulcher, TVF

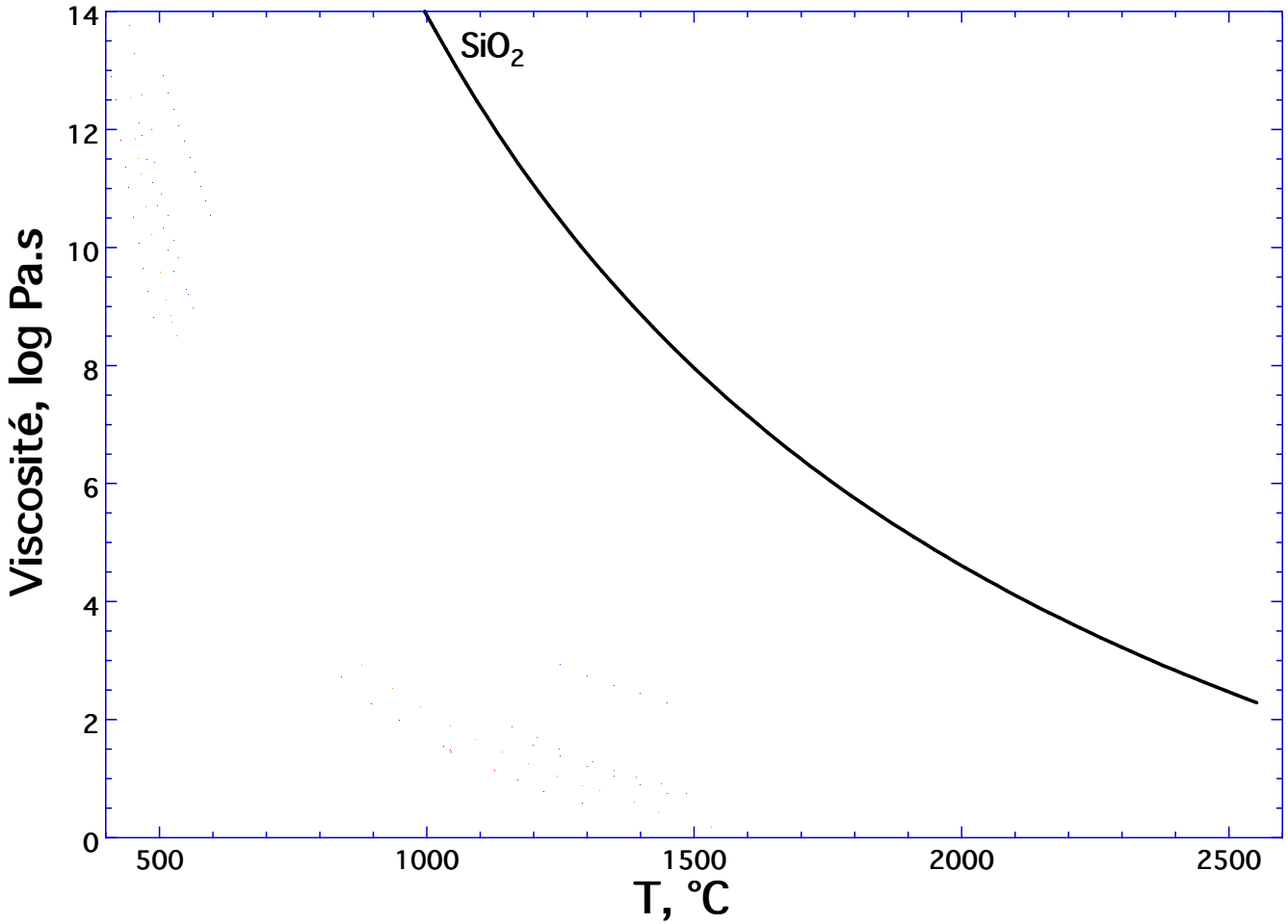
$$\mathrm{Log}\ \eta = A + B/(T-T_1)$$

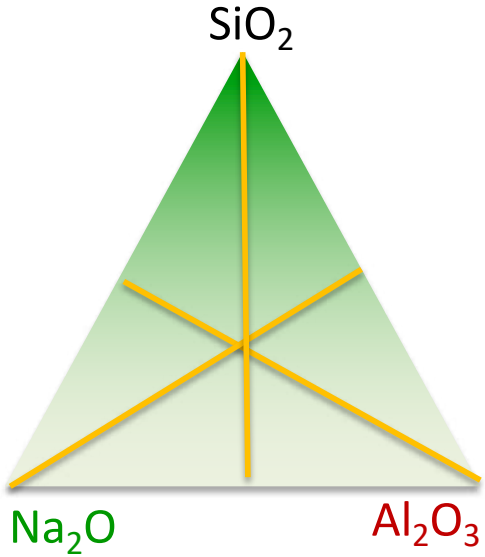
A, B, T_1 sont des paramètres ajustables empiriques qui permettent de reproduire les données.

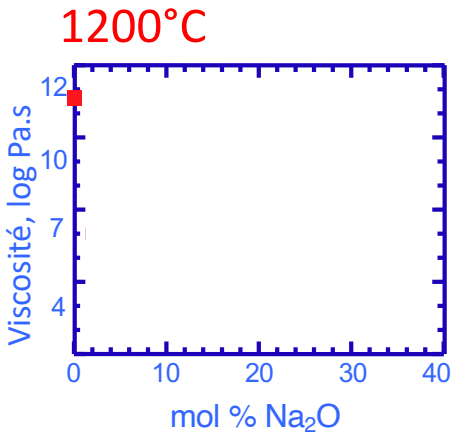
A sans signification

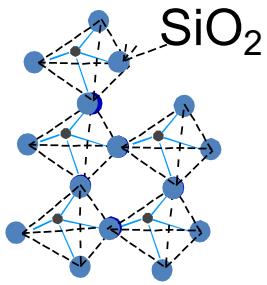
B peut correspondre à une énergie d'activation

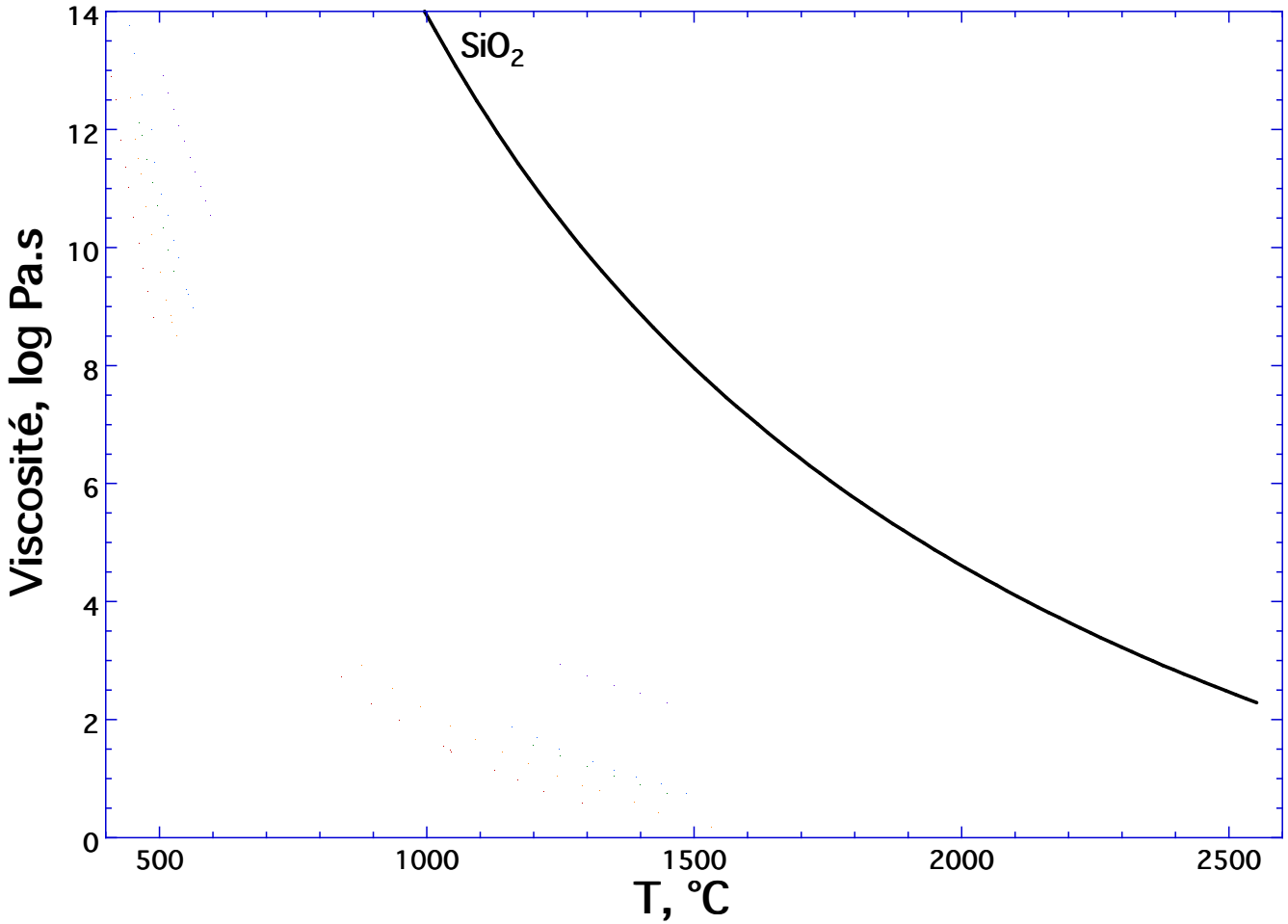

SiO2

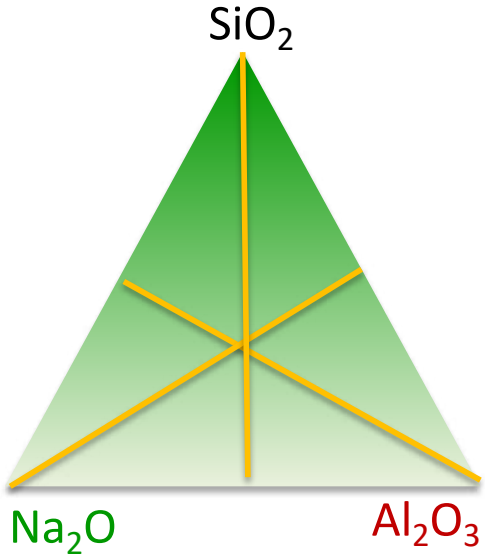

SiO2
Viscosité, log Pa.s
T, °C
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

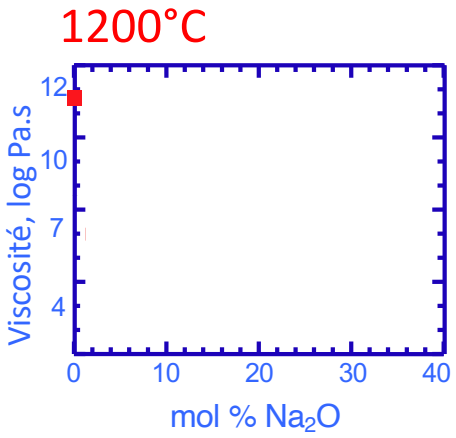

SiO2
Na2O
Al2O3

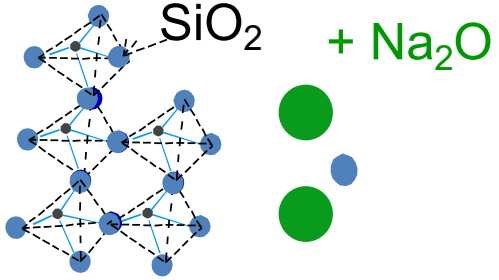

1200°C
Viscosité, log Pa.s
mol % Na2O
4
7
10
12
0
10
20
30
40

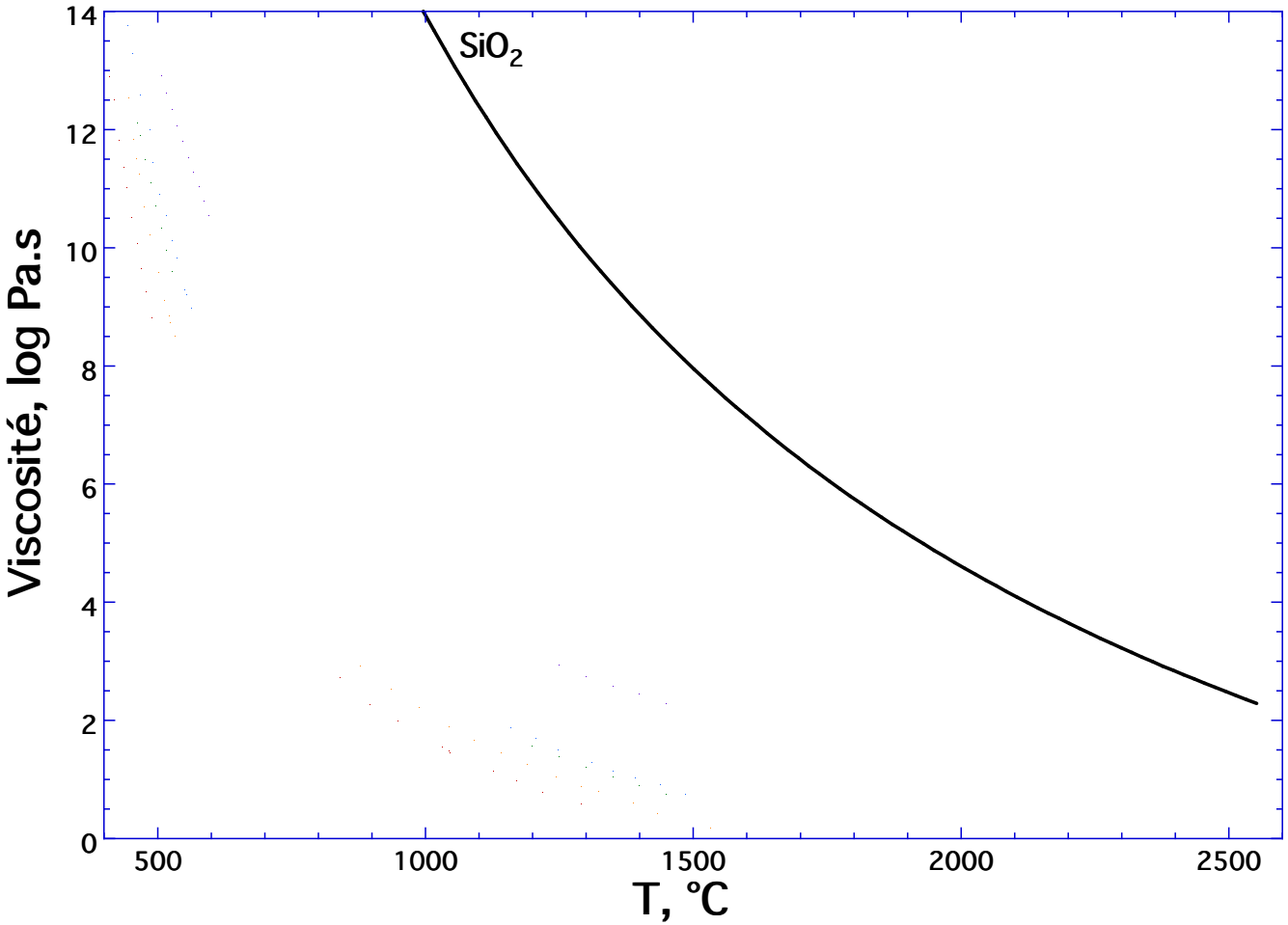

SiO2

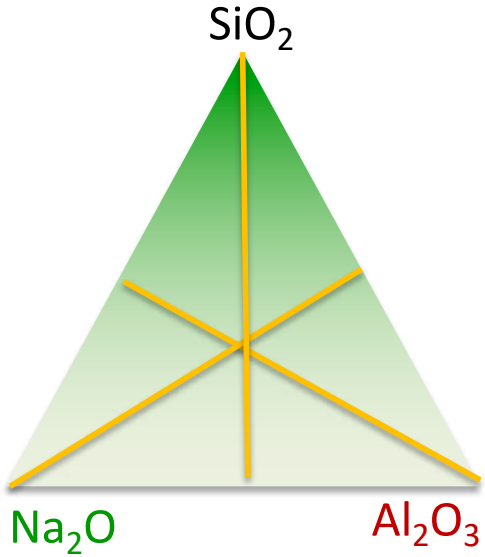

SiO2
Viscosité, log Pa.s
T, °C
14
12
10
8
6
4
2
0
500
1000
1500
2000
2500

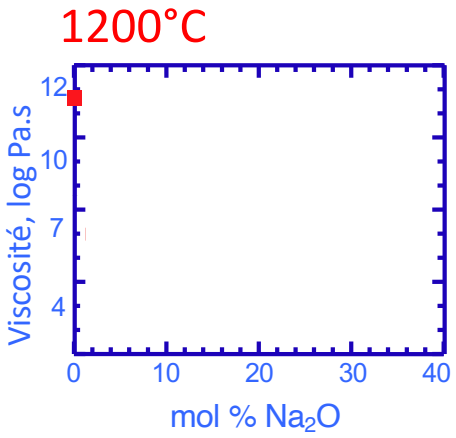

SiO2
Na2O
Al2O3

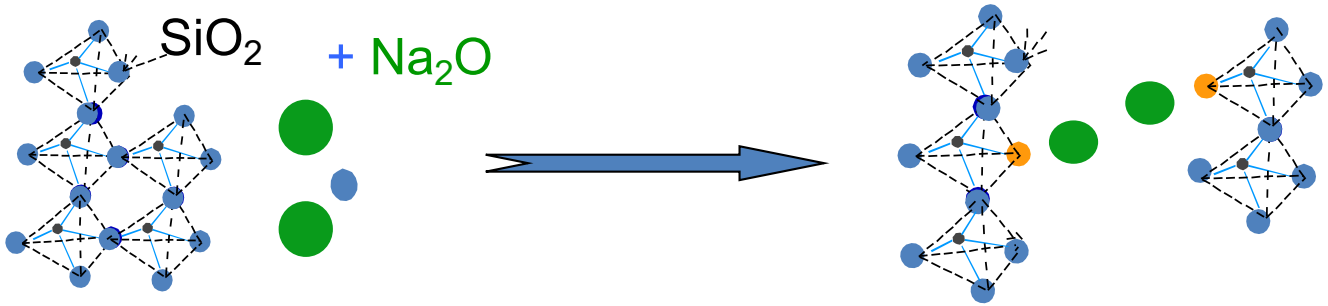

1200°C
Viscosité, log Pa.s
12
10
7
4
0
10
20
30
40
mol % Na2O

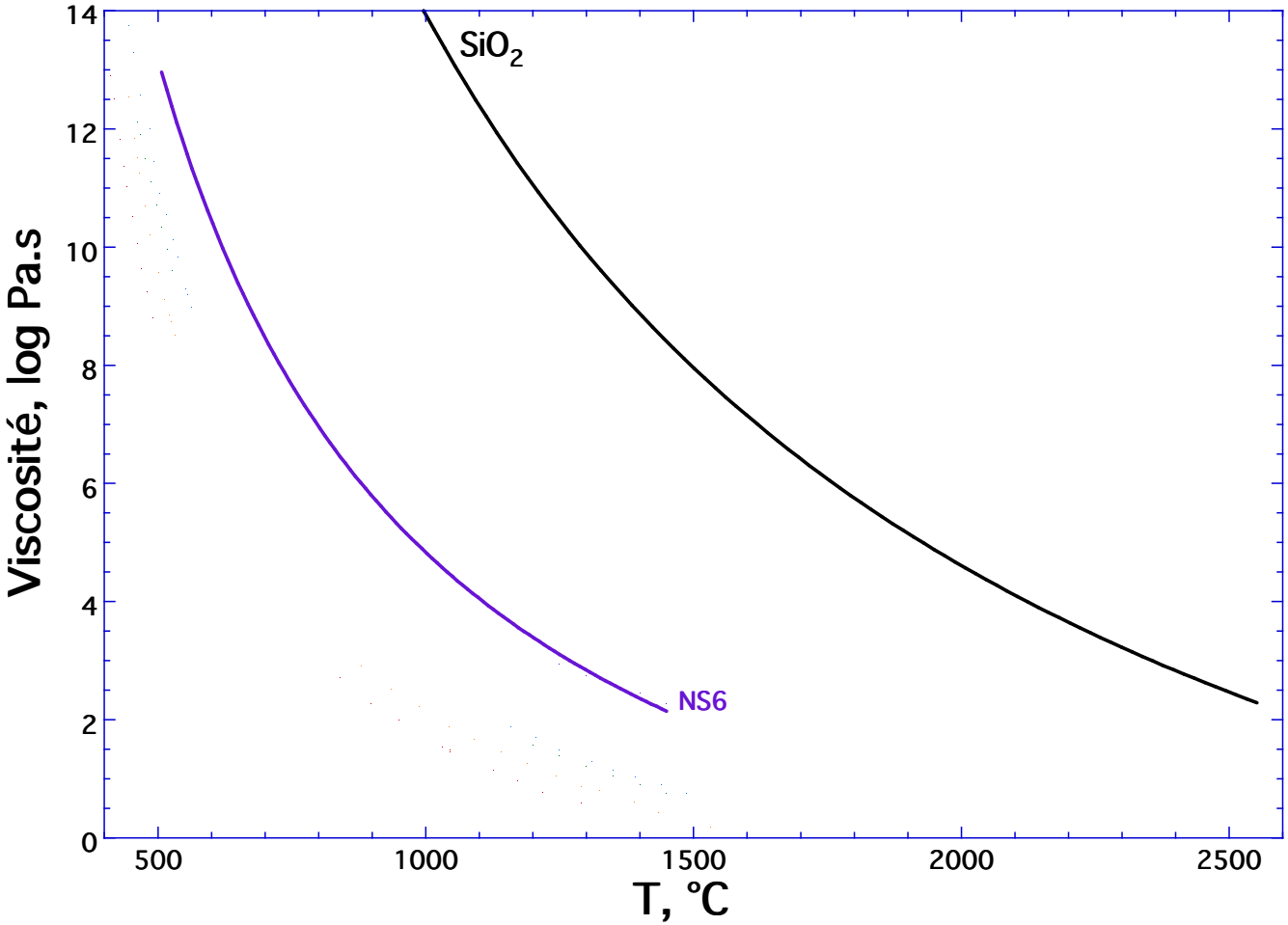

SiO_2
+ Na_2O

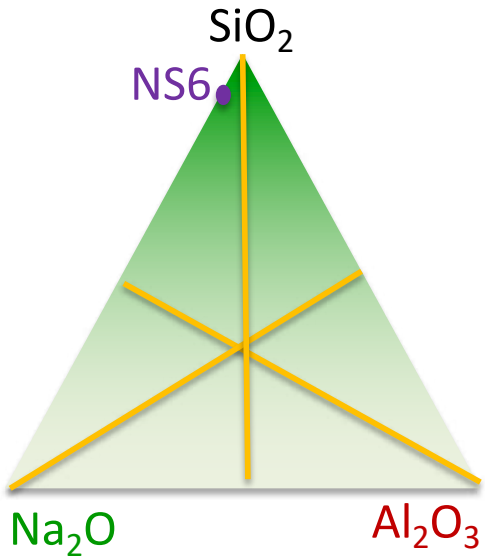

Viscosité, log Pa.s
T, °C
SiO_2
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

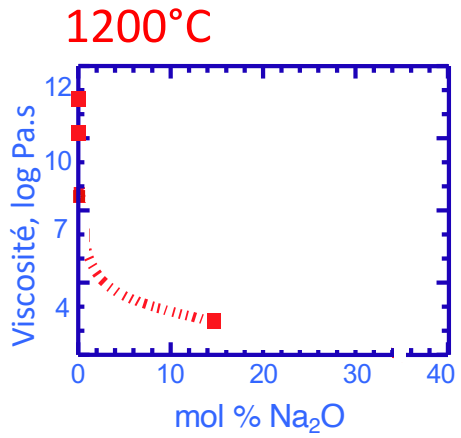

SiO_2
Na_2O
Al_2O_3

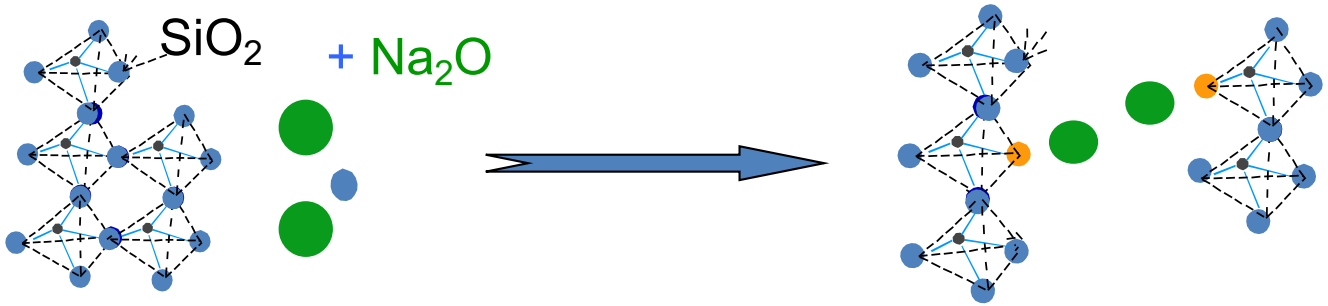

1200°C
Viscosité, log Pa.s
mol % Na_2O
4
7
10
12
0
10
20
30
40

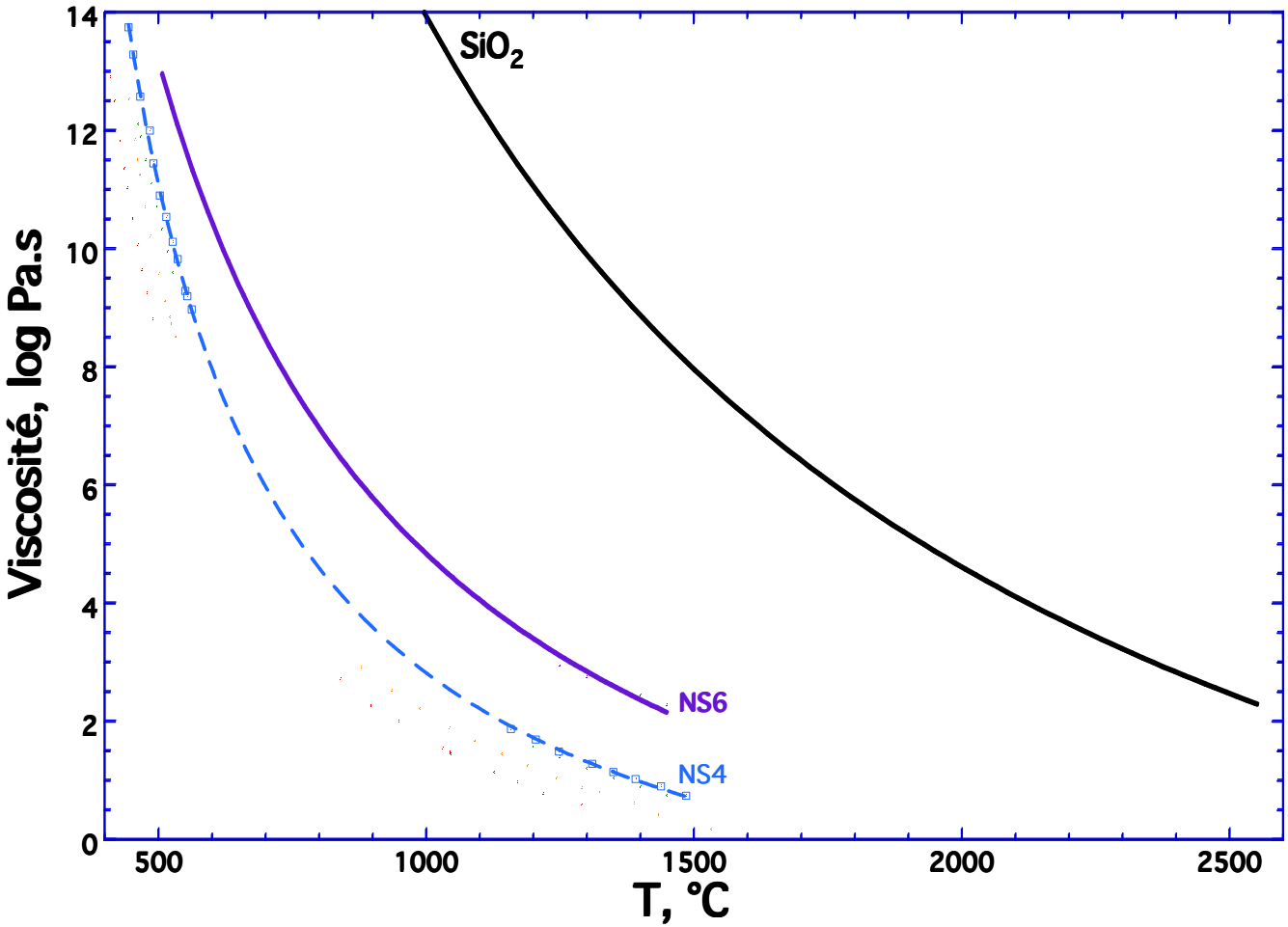

SiO_2
+ Na_2O

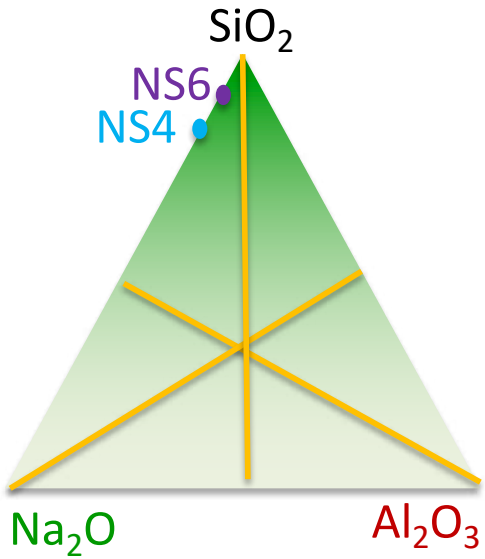

Viscosité, log Pa.s
T, °C
SiO_2
NS6
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

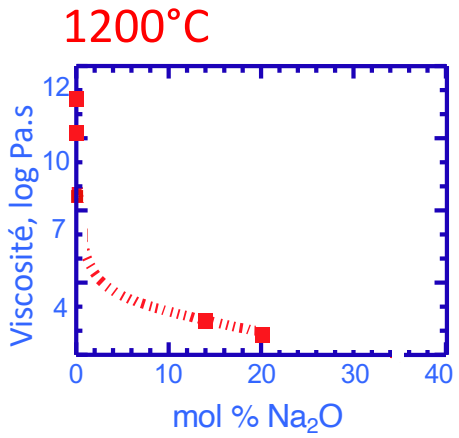

SiO_2
NS6
Na_2O
Al_2O_3

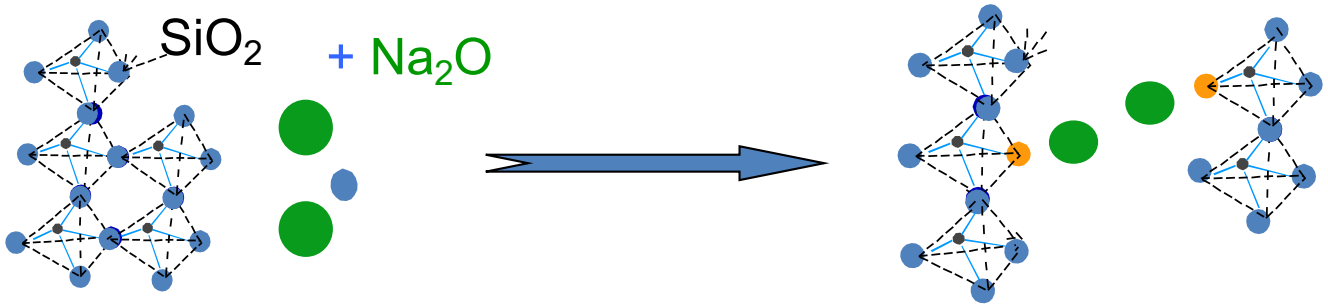

1200°C
Viscosité, log Pa.s
mol % Na_2O
4
7
10
12
0
10
20
30
40

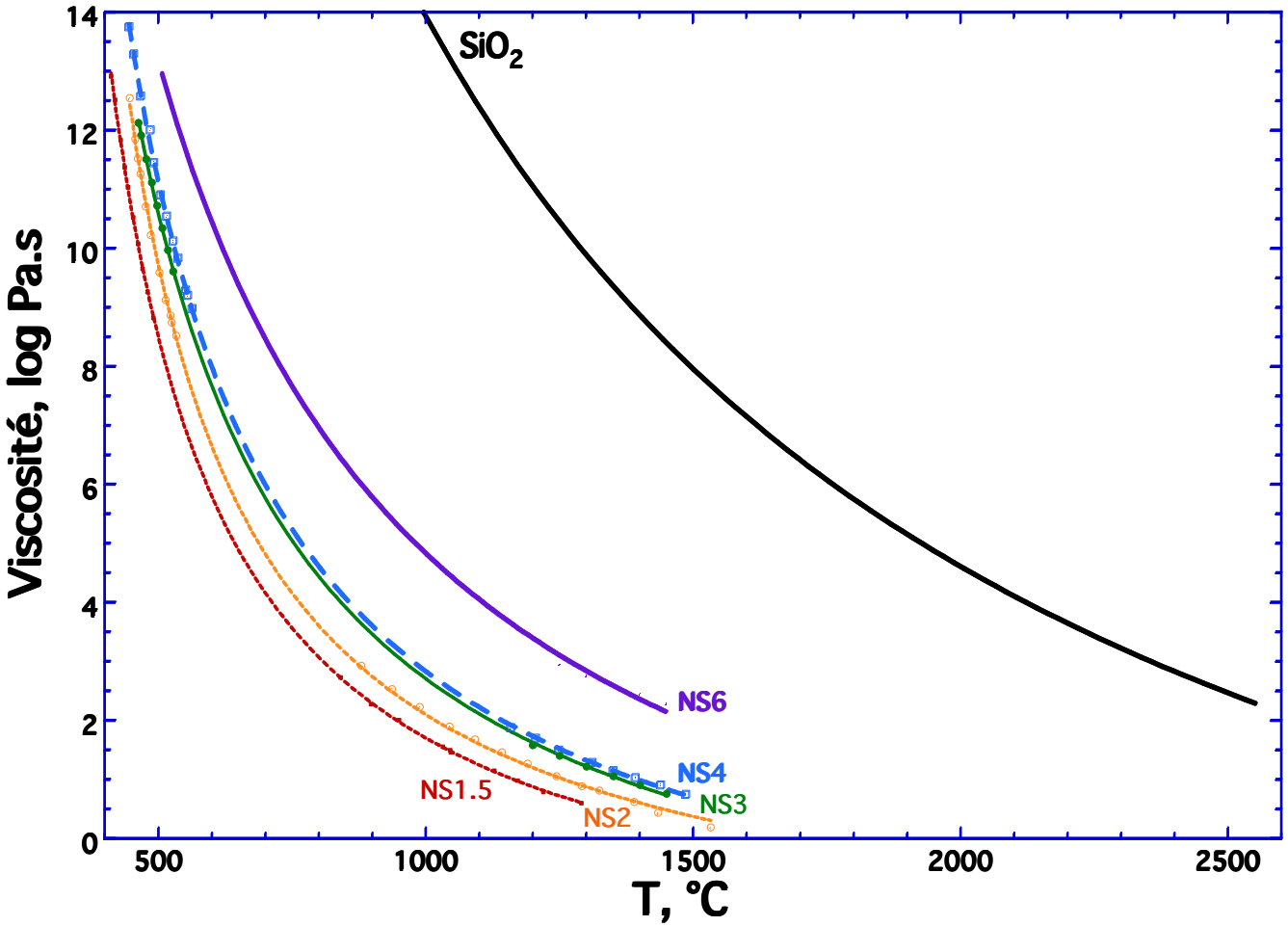

SiO_2
+ Na_2O

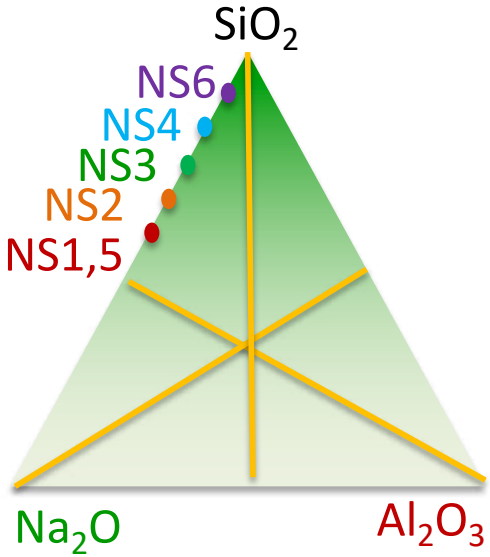

Viscosité, log Pa.s
T, °C
SiO_2
NS6
NS4
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

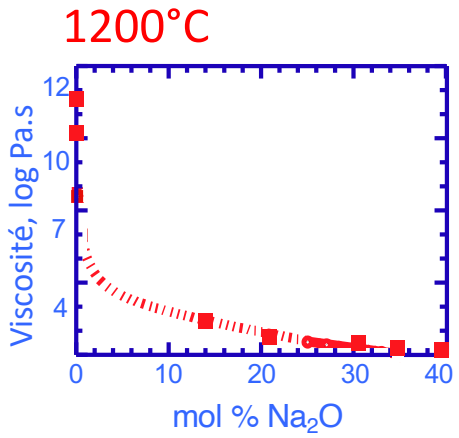

SiO_2
NS6
NS4
Na_2O
Al_2O_3

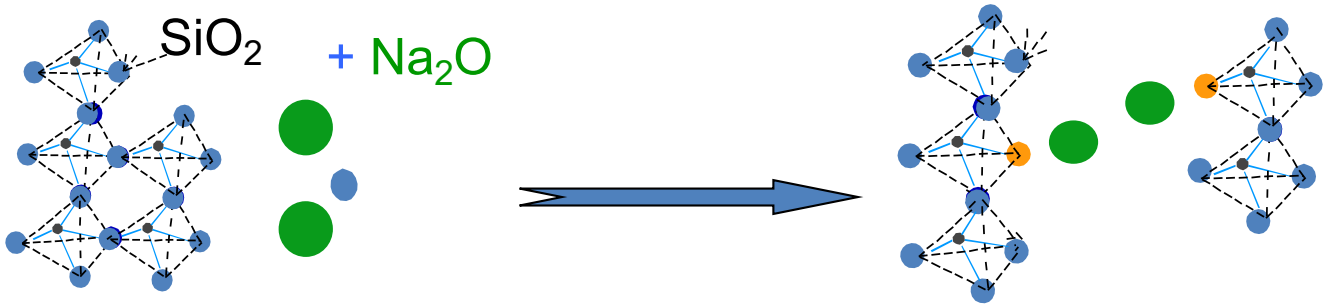

1200°C
Viscosité, log Pa.s
mol % Na_2O
4
7
10
12
0
10
20
30
40

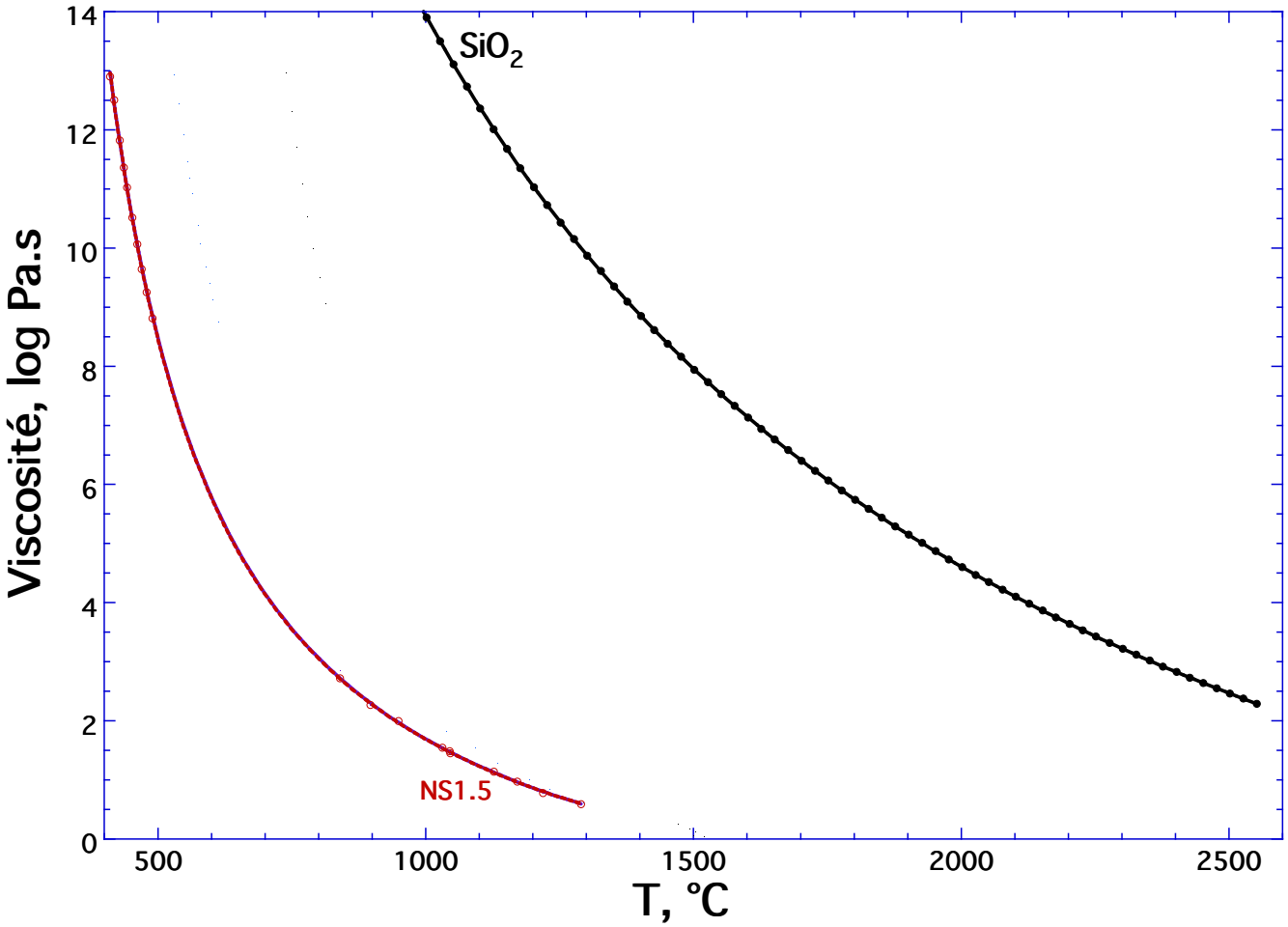

SiO_2
+ Na_2O

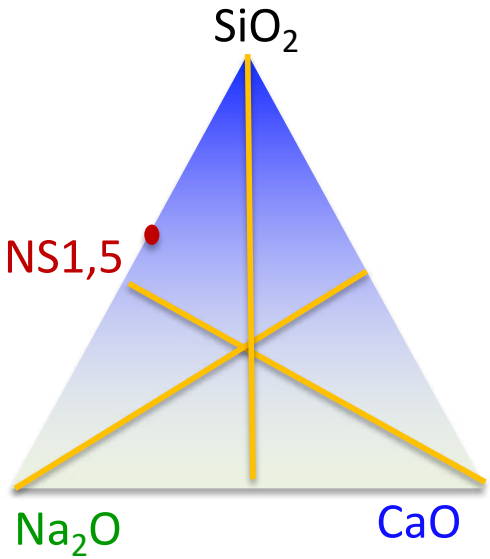

Viscosité, log Pa.s
T, °C
SiO_2
NS6
NS4
NS3
NS2
NS1.5


SiO_2
NS6
NS4
NS3
NS2
NS1,5
Na_2O
Al_2O_3

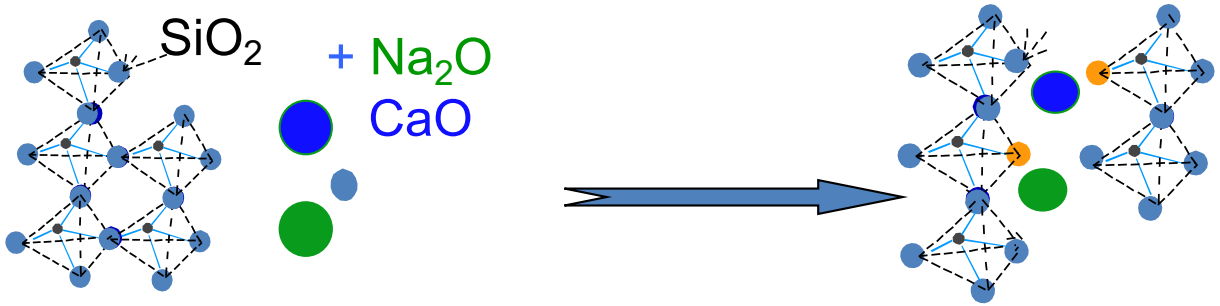

1200°C
Viscosité, log Pa.s
mol % Na_2O

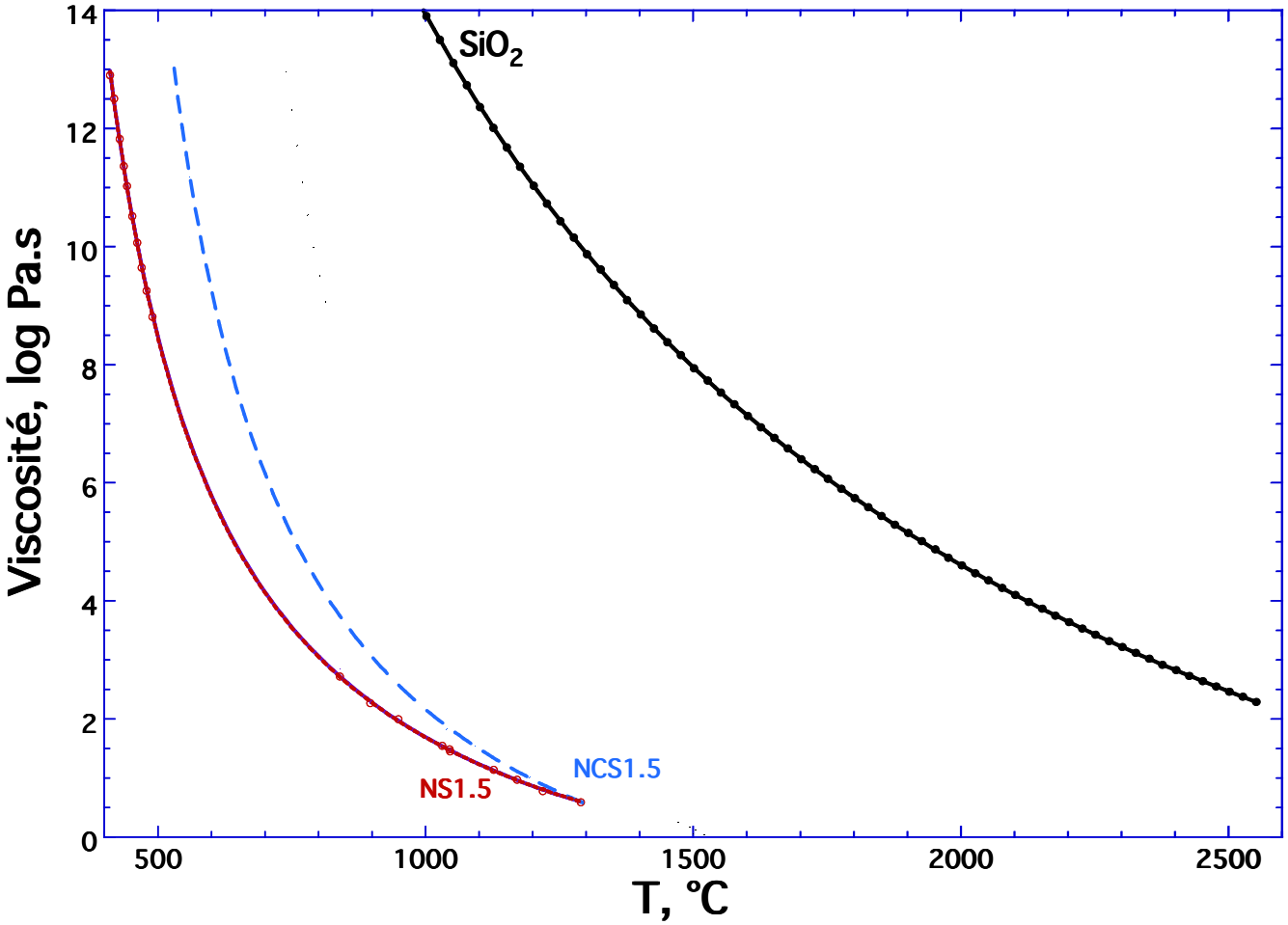

SiO_2
+ Na_2O

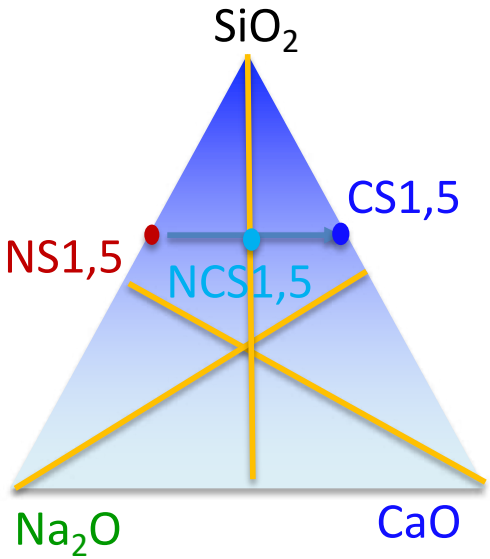

Viscosité, log Pa.s
T, °C
SiO_2
NS1.5
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500


SiO_2
NS1,5
Na_2O
CaO

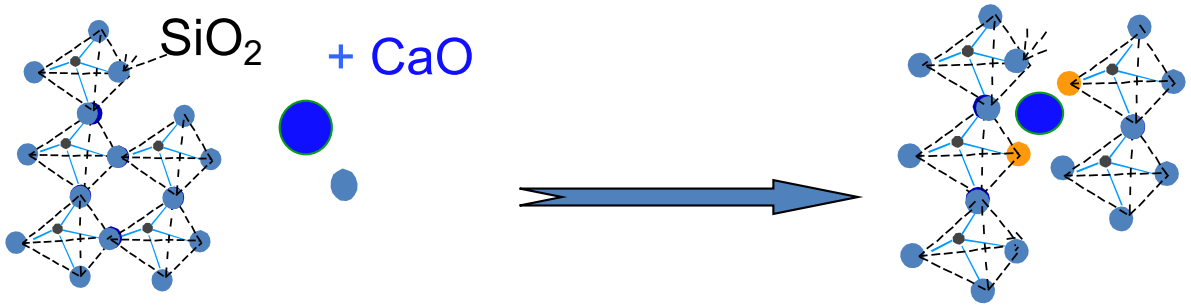
Silicate vitreux de calcium et sodium

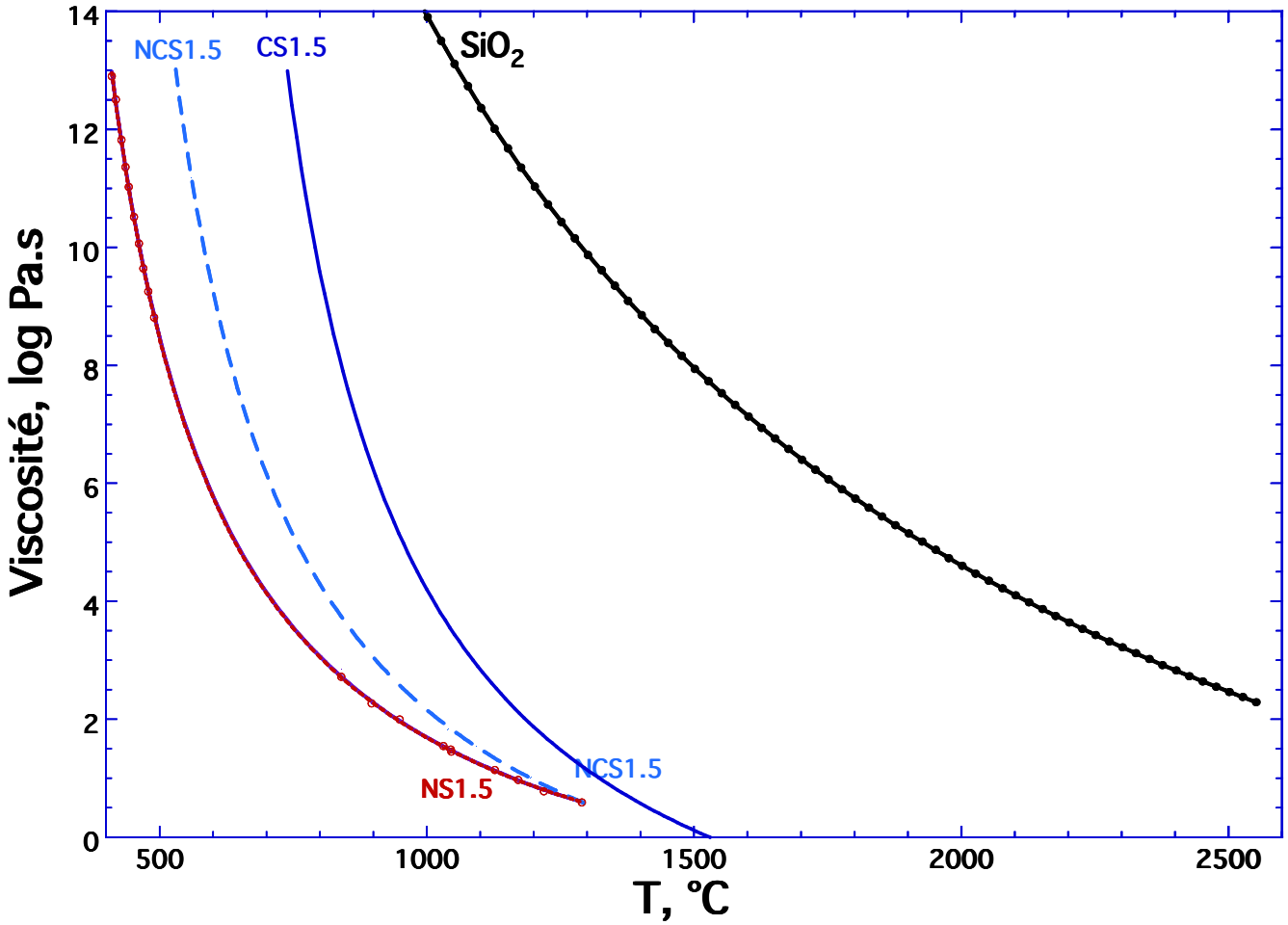


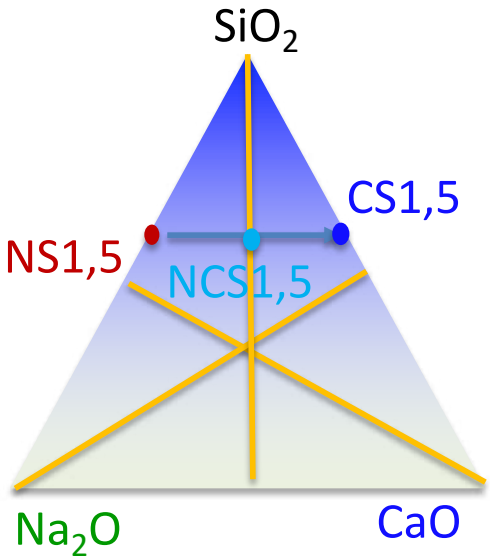


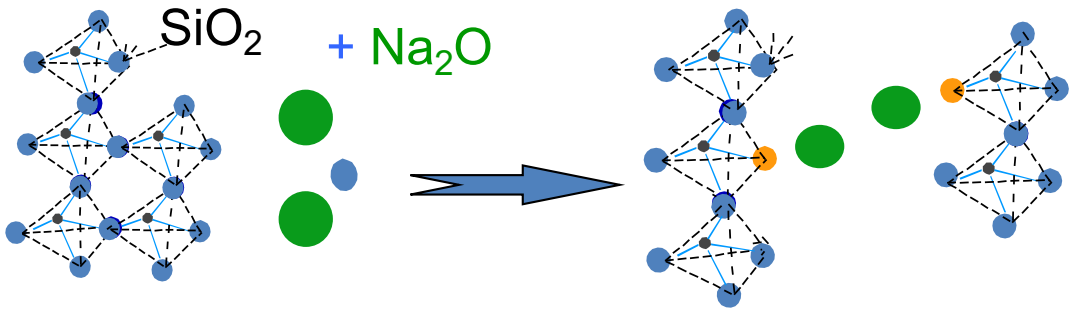


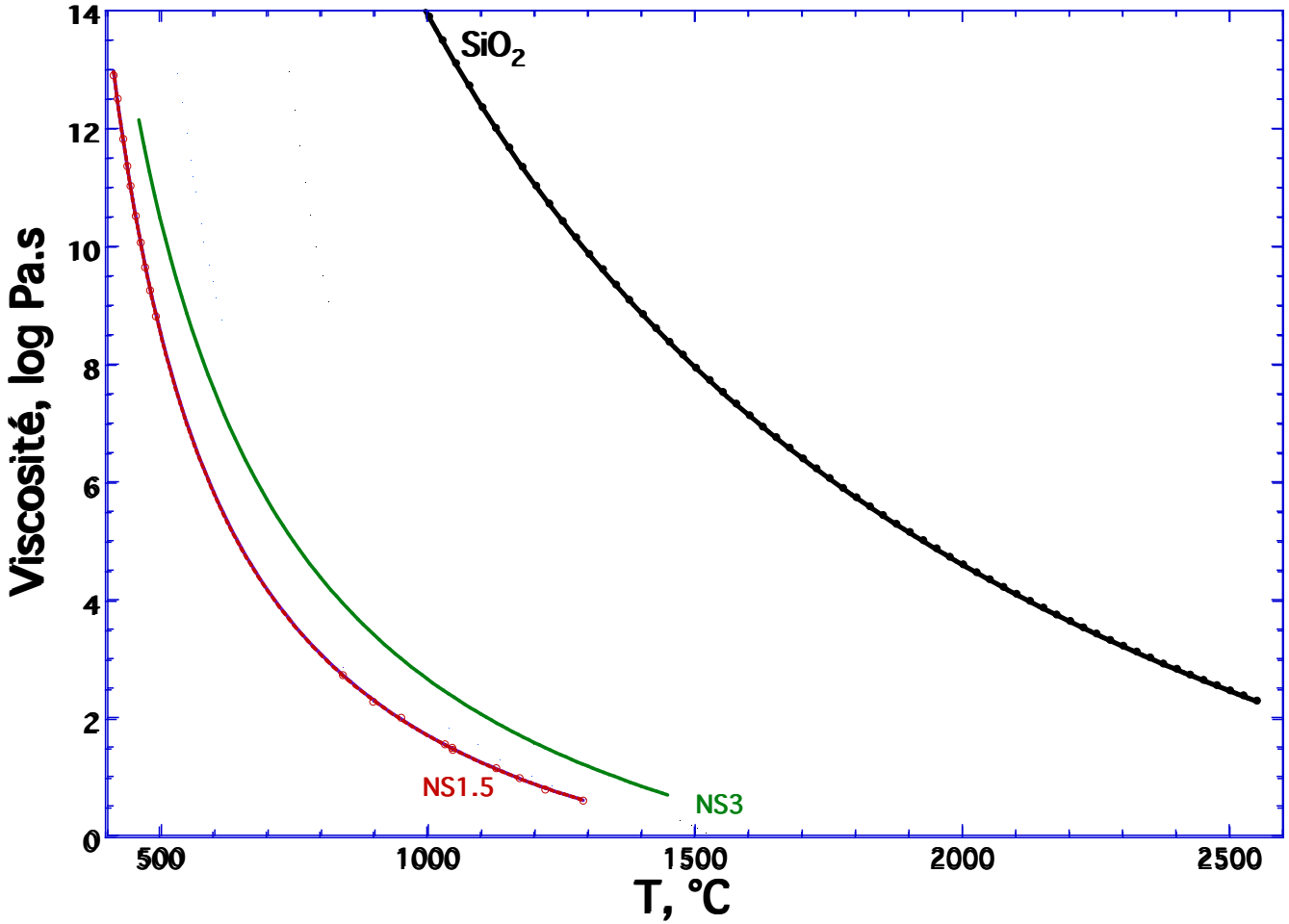
Silicate vitreux de calcium et sodium

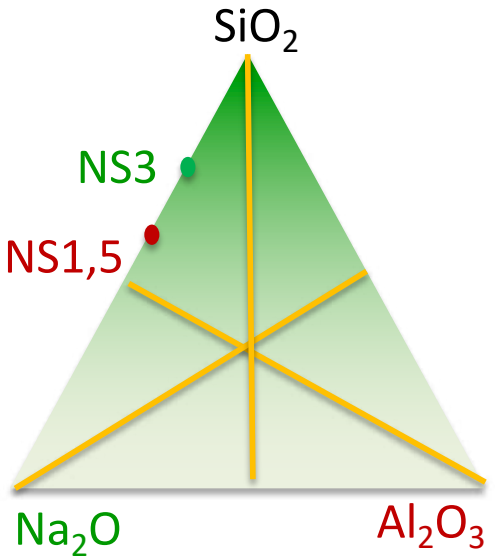


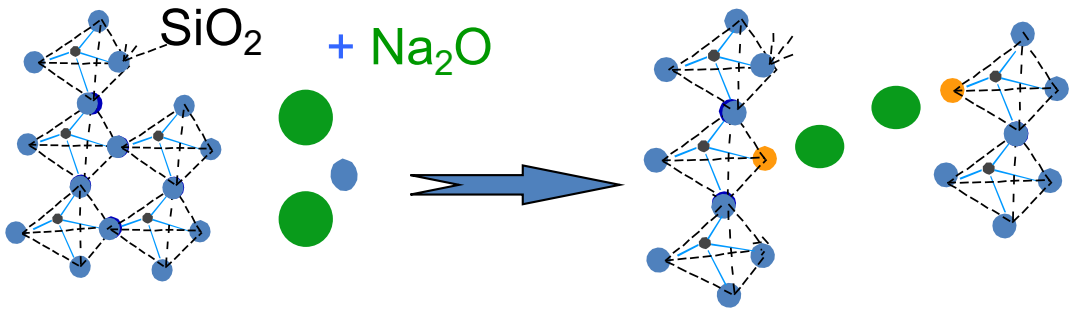


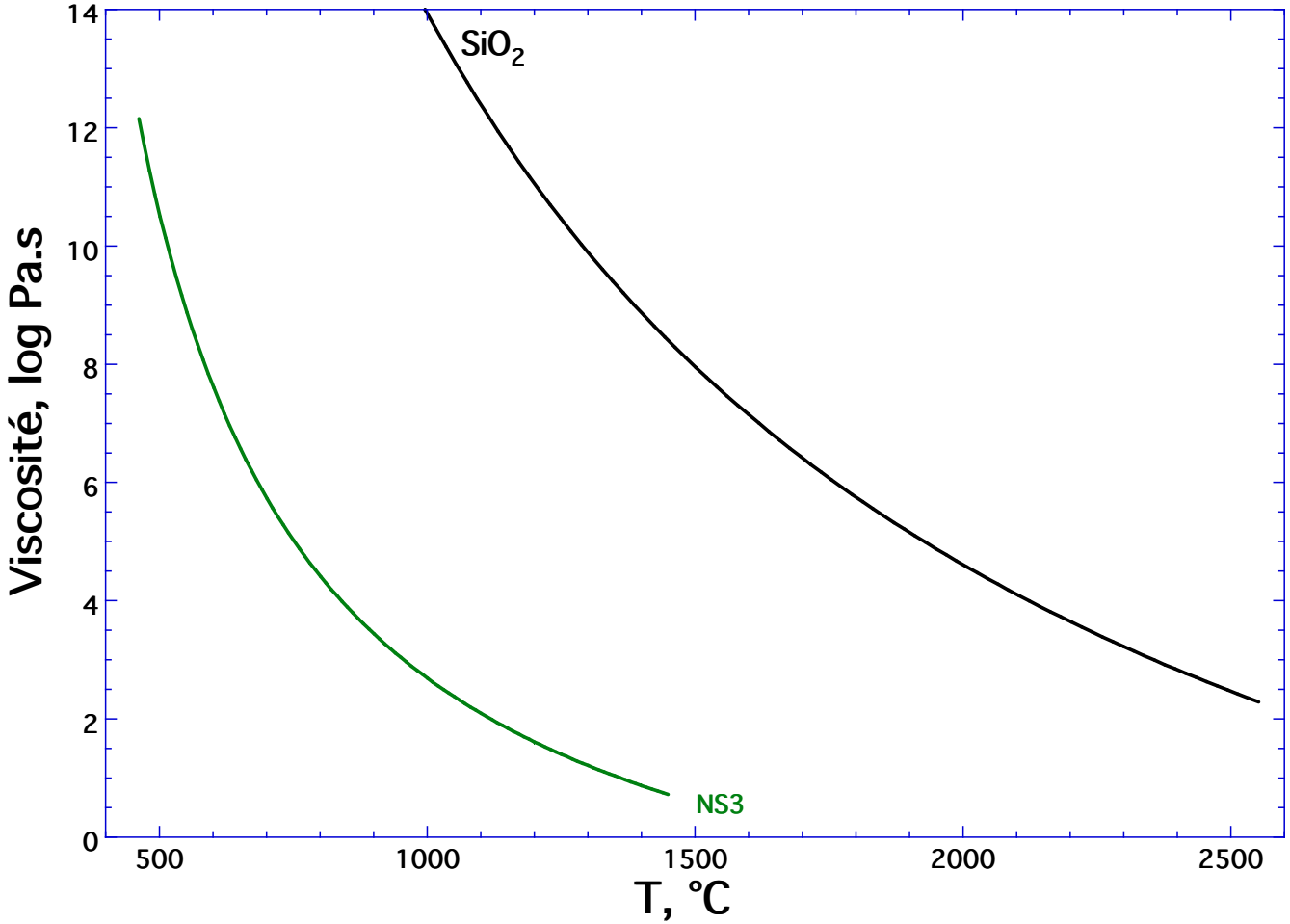


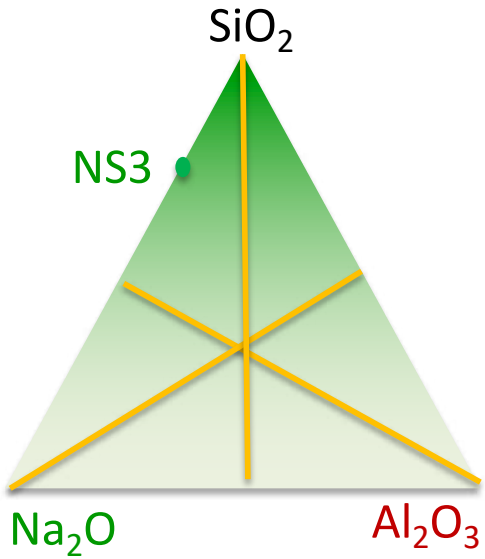

SiO_2
+ Na_2O

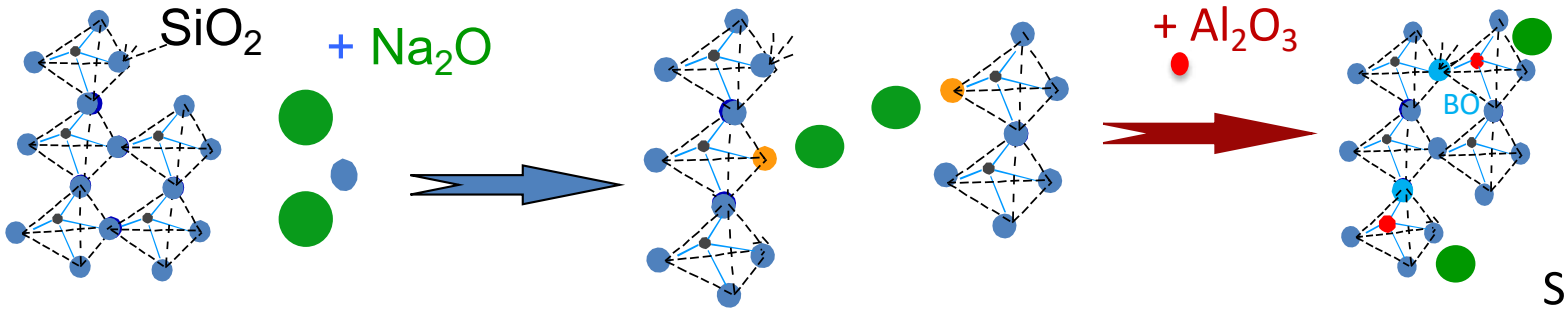

Viscosité, log Pa.s
T, °C
SiO_2
NS1.5
NS3
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

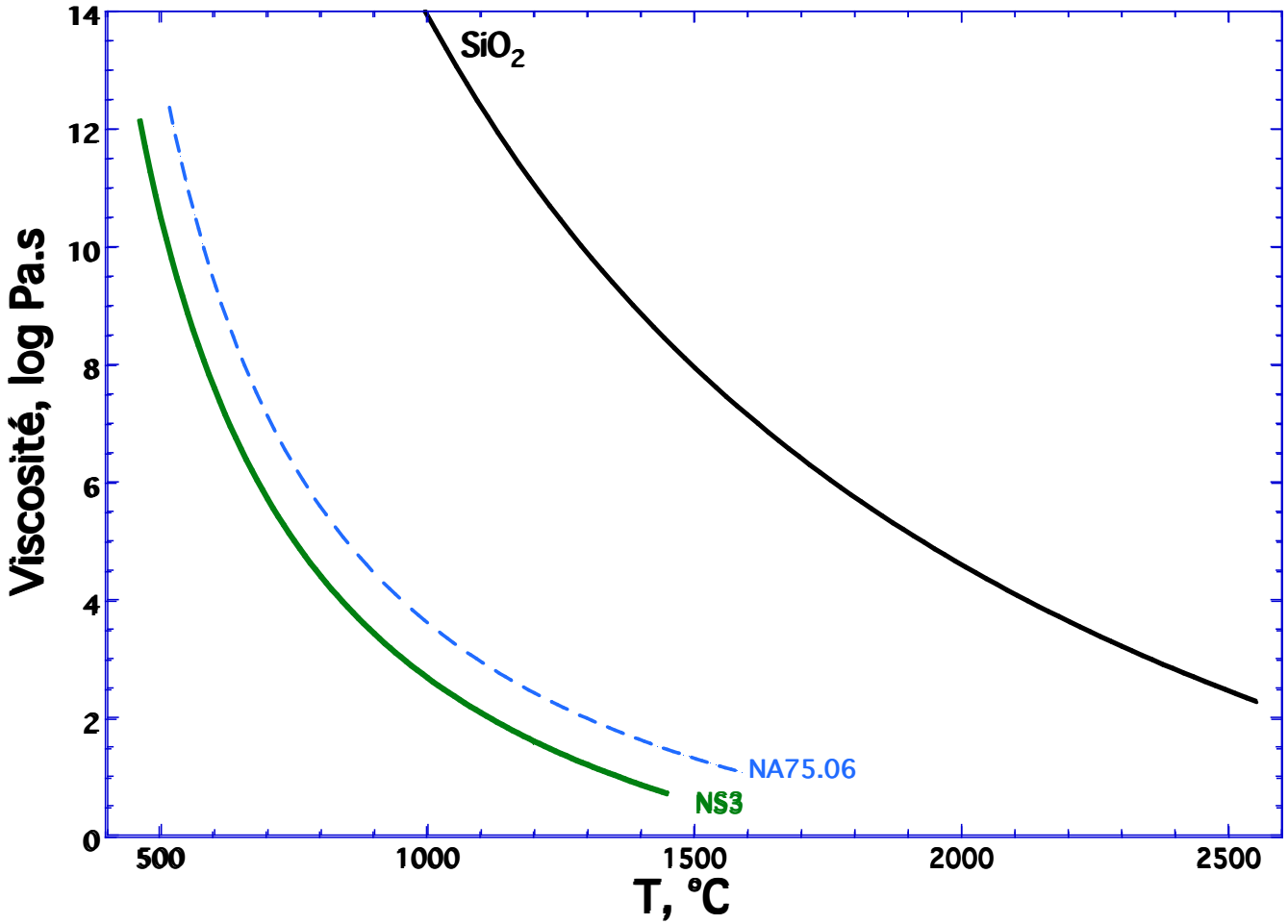

SiO_2
NS3
NS1,5
Na_2O
Al_2O_3

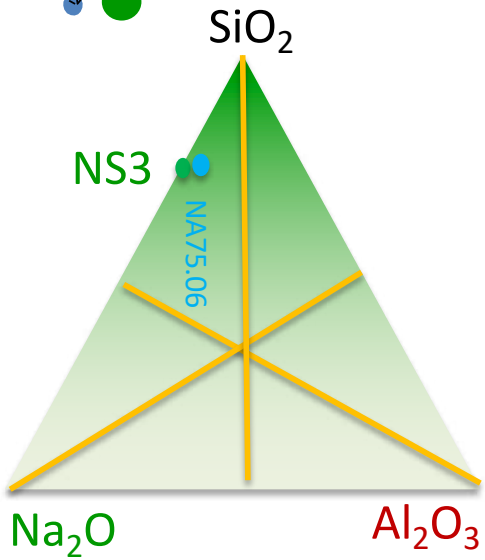

SiO_2
+ Na_2O

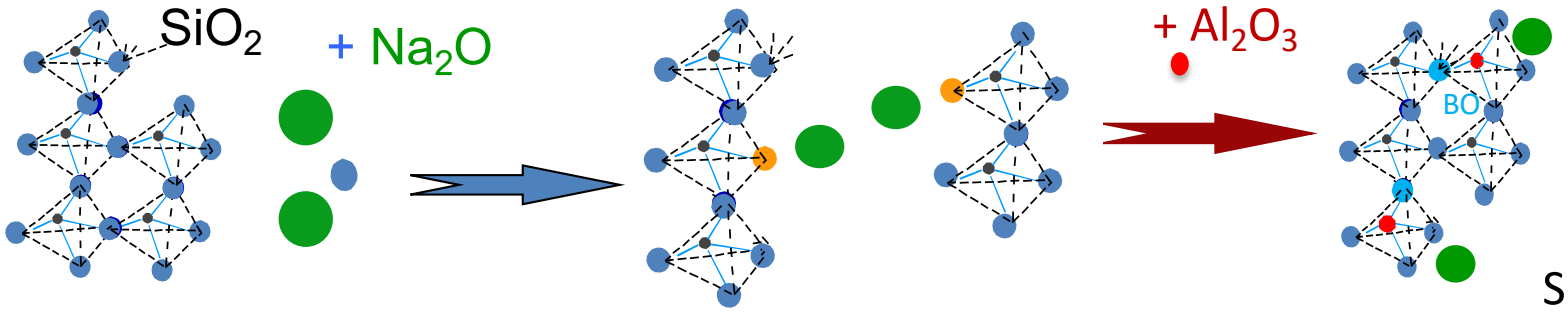

Viscosité, log Pa.s
T, °C
SiO_2
NS3
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

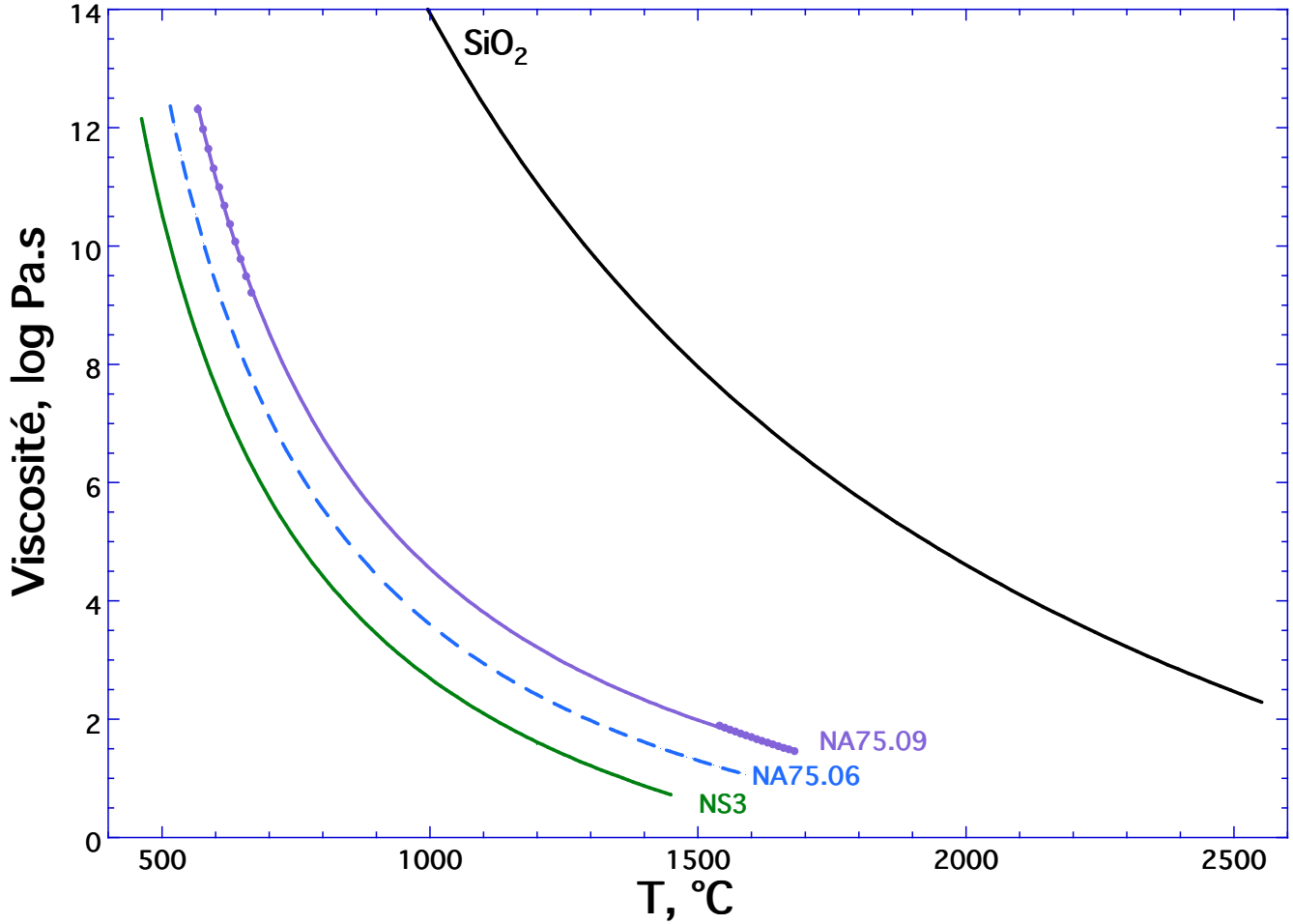

SiO_2
NS3
Na_2O
Al_2O_3

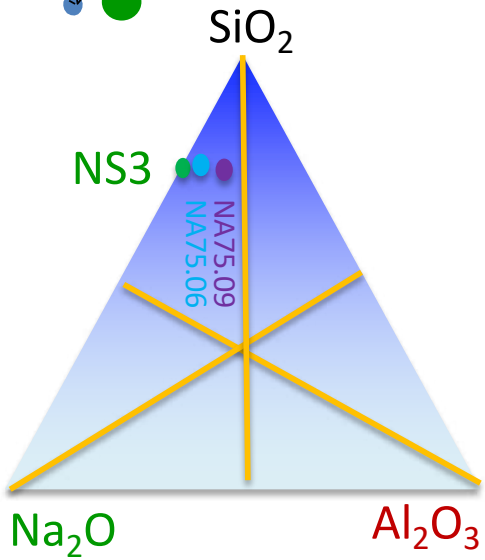

SiO_2
+ Na_2O
+ Al_2O_3
BO

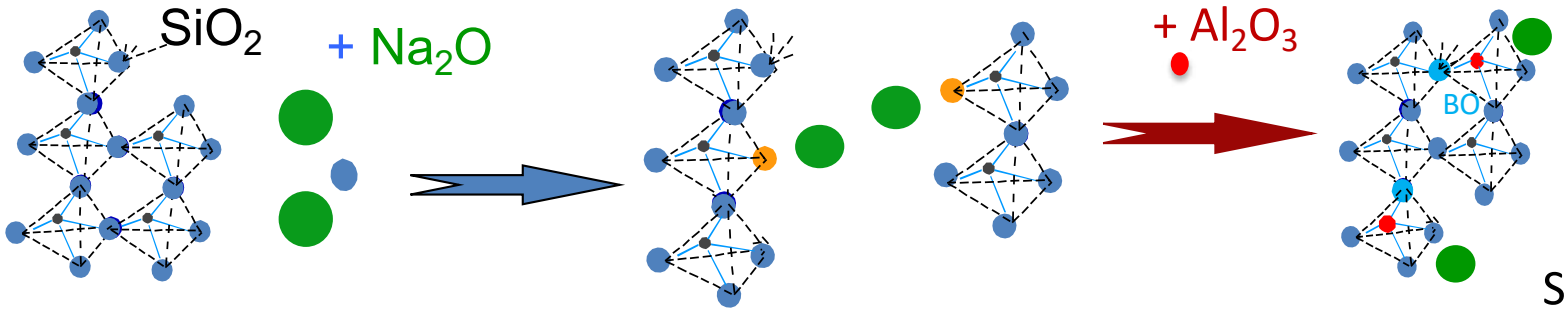

Viscosité, log Pa.s
T, °C
SiO_2
NA75.06
NS3
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

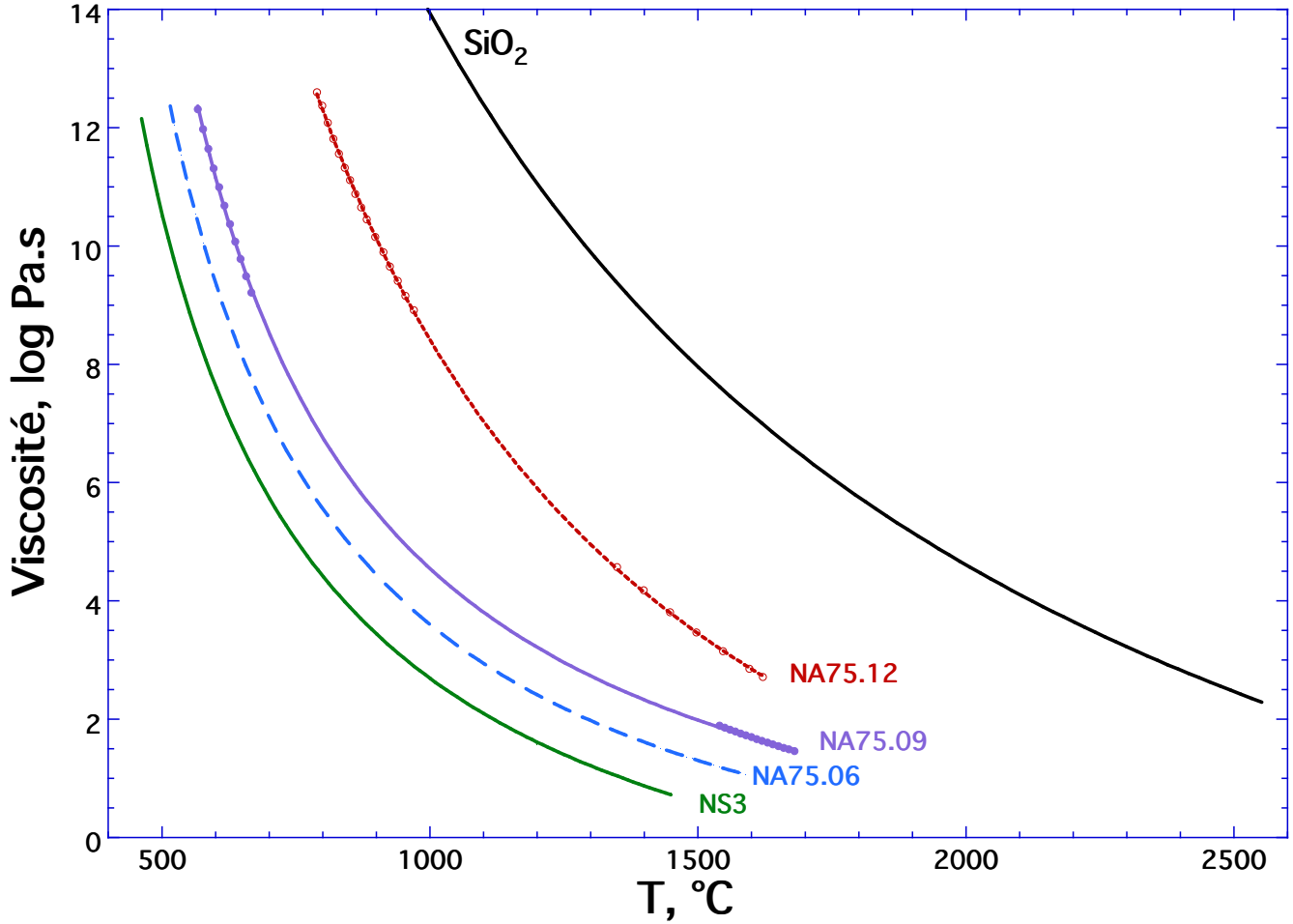

SiO_2
NS3
NA75.06
Na_2O
Al_2O_3

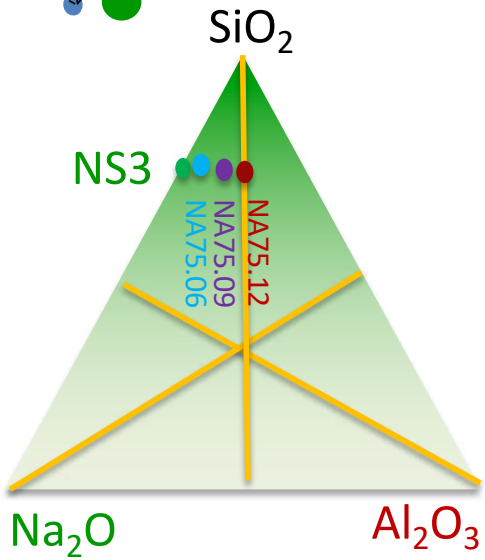

SiO_2
+ Na_2O
+ Al_2O_3
BO

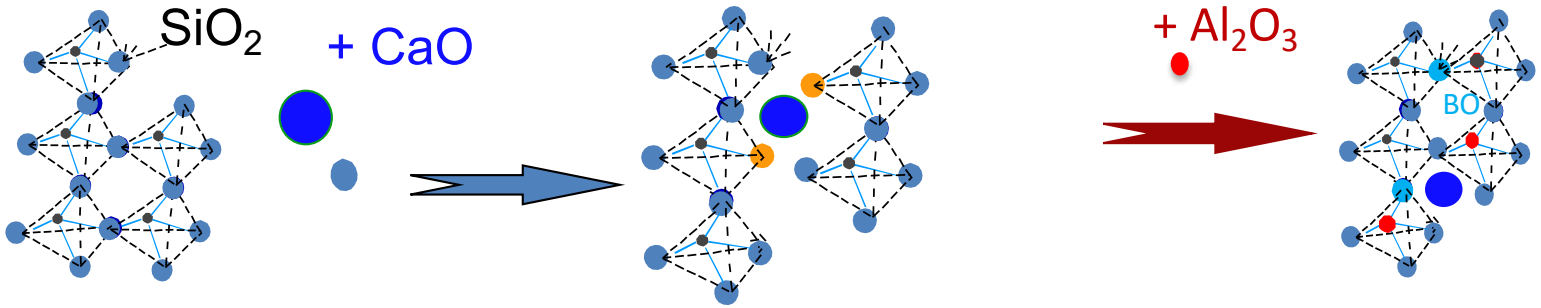

Viscosité, log Pa.s
T, °C
SiO_2
NA75.09
NA75.06
NS3
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

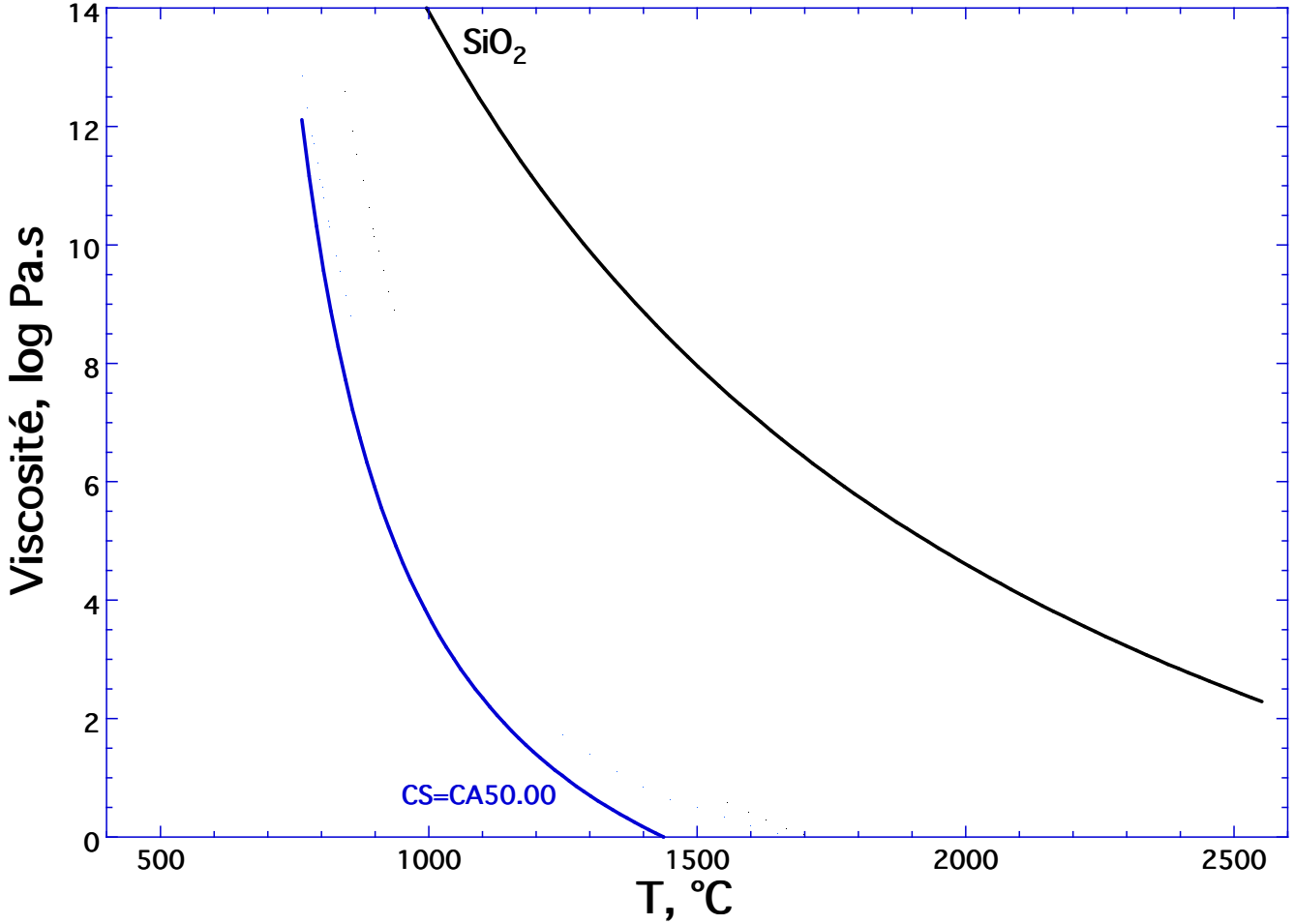

SiO_2
NS3
NA75.09
NA75.06
Na_2O
Al_2O_3

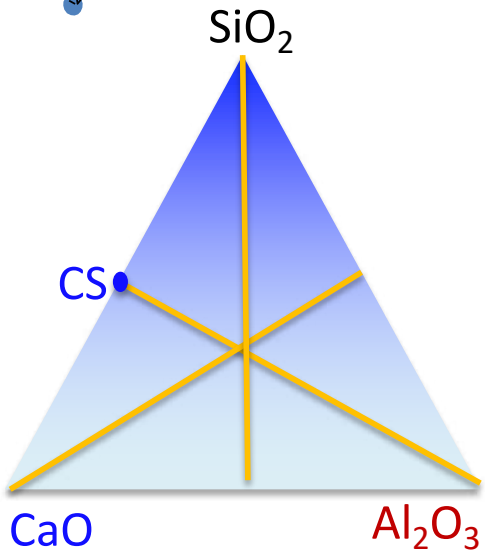

SiO_2
+ Na_2O
+ Al_2O_3
BO⁻

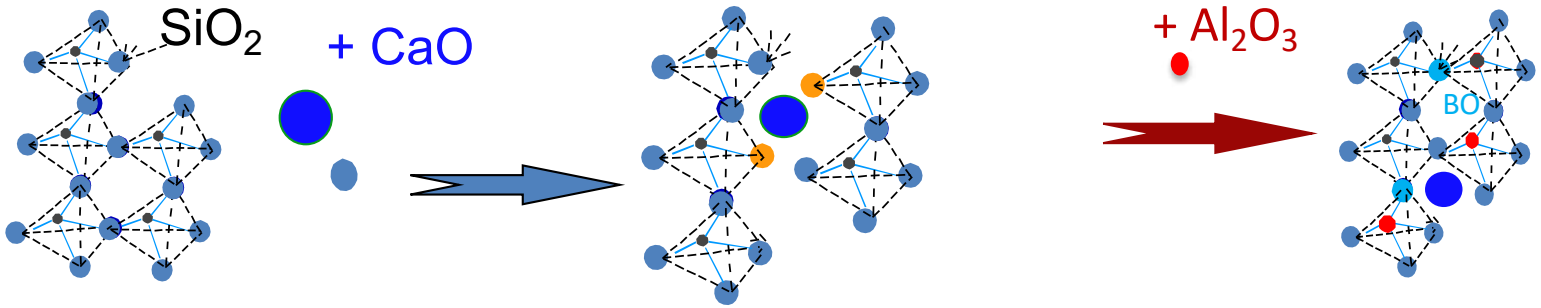

Viscosité, log Pa.s
T, °C
SiO_2
NA75.12
NA75.09
NA75.06
NS3
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

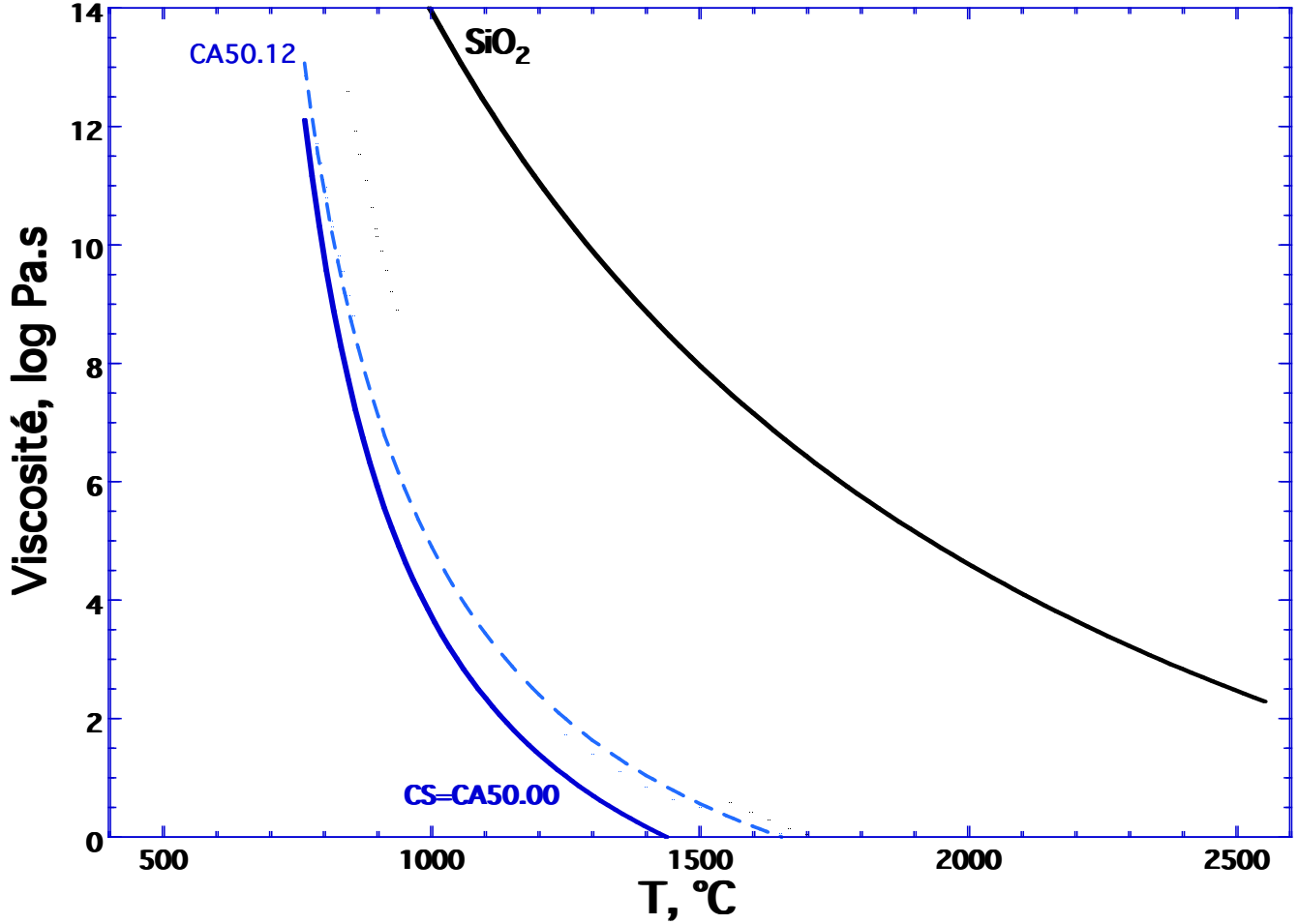

SiO_2
NS3
NA75.09
NA75.06
NA75.12
Na_2O
Al_2O_3

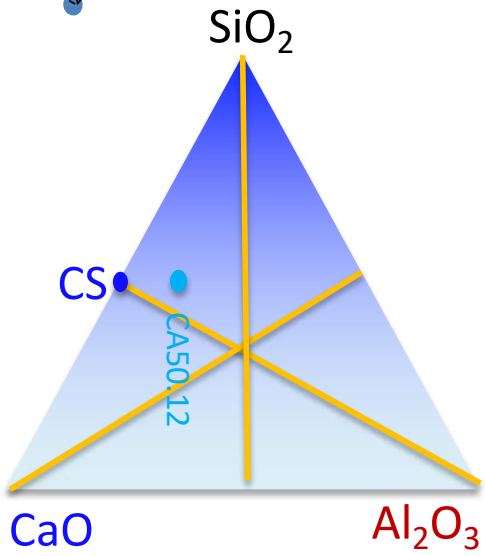

SiO_2
+ CaO
+ Al_2O_3
BO

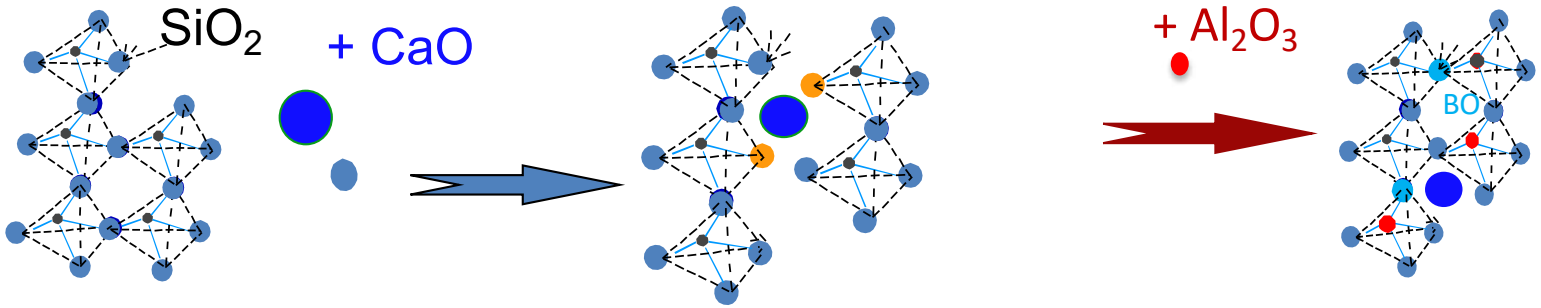

Viscosité, log Pa.s
T, °C
SiO_2
CS=CA50.00
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500

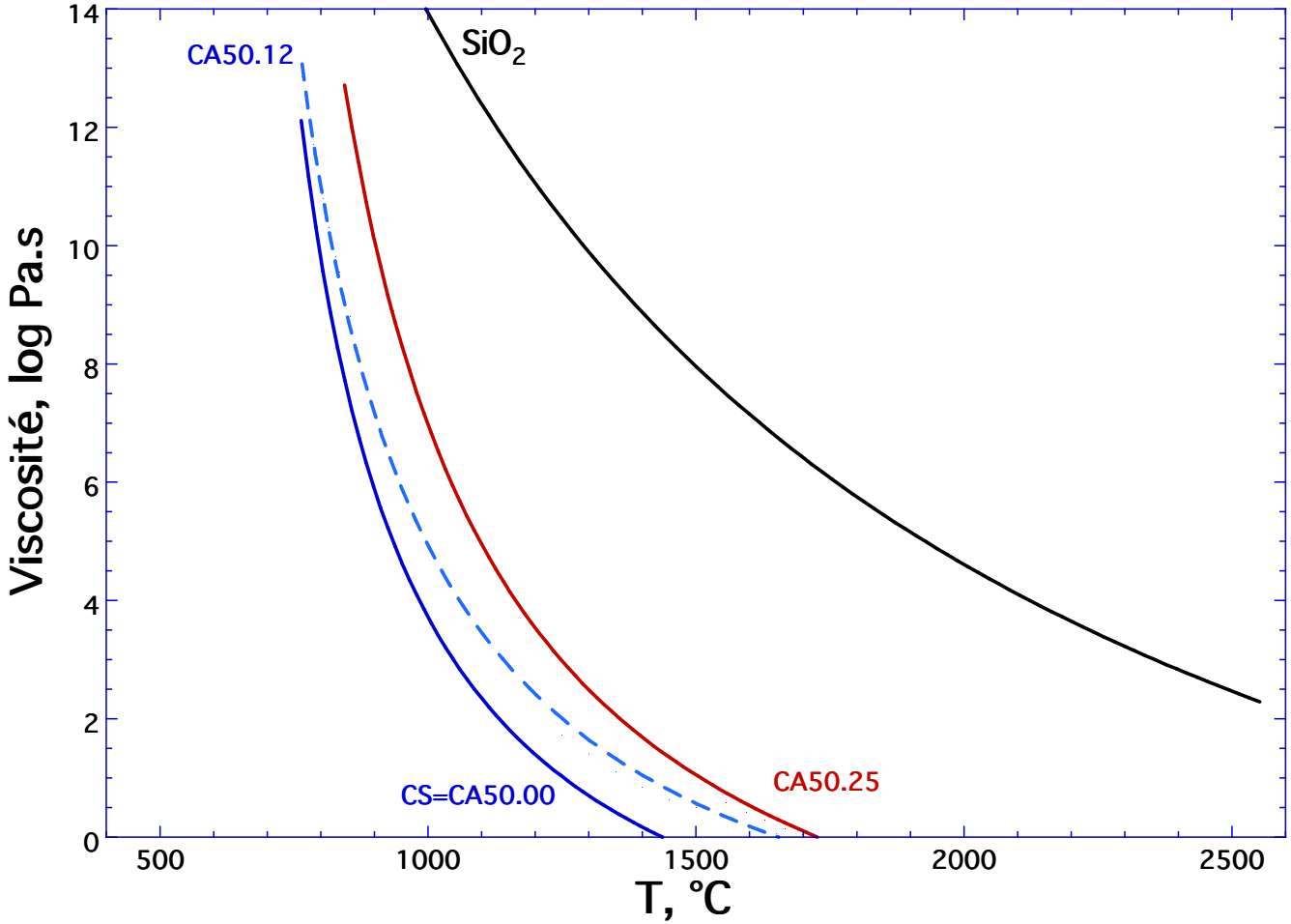

SiO_2
CS
CaO
Al_2O_3

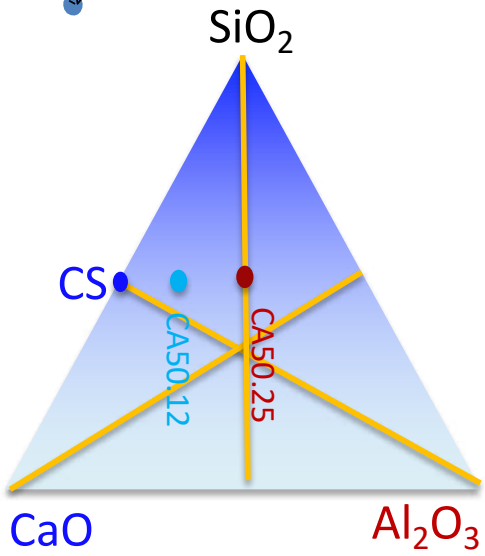

SiO_2
+ CaO
+ Al_2O_3
BO


Viscosité, log Pa.s
T, °C
CA50.12
SiO_2
CS=CA50.00
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500


SiO_2
CS
CA50.12
CaO
Al_2O_3


SiO2
+ CaO
+ Al2O3
BO


Viscosité, log Pa.s
T, °C
CA50.12
SiO2
CA50.25
CS=CA50.00
0
2
4
6
8
10
12
14
500
1000
1500
2000
2500


SiO2
CS
CA50.12
CA50.25
CaO
Al2O3

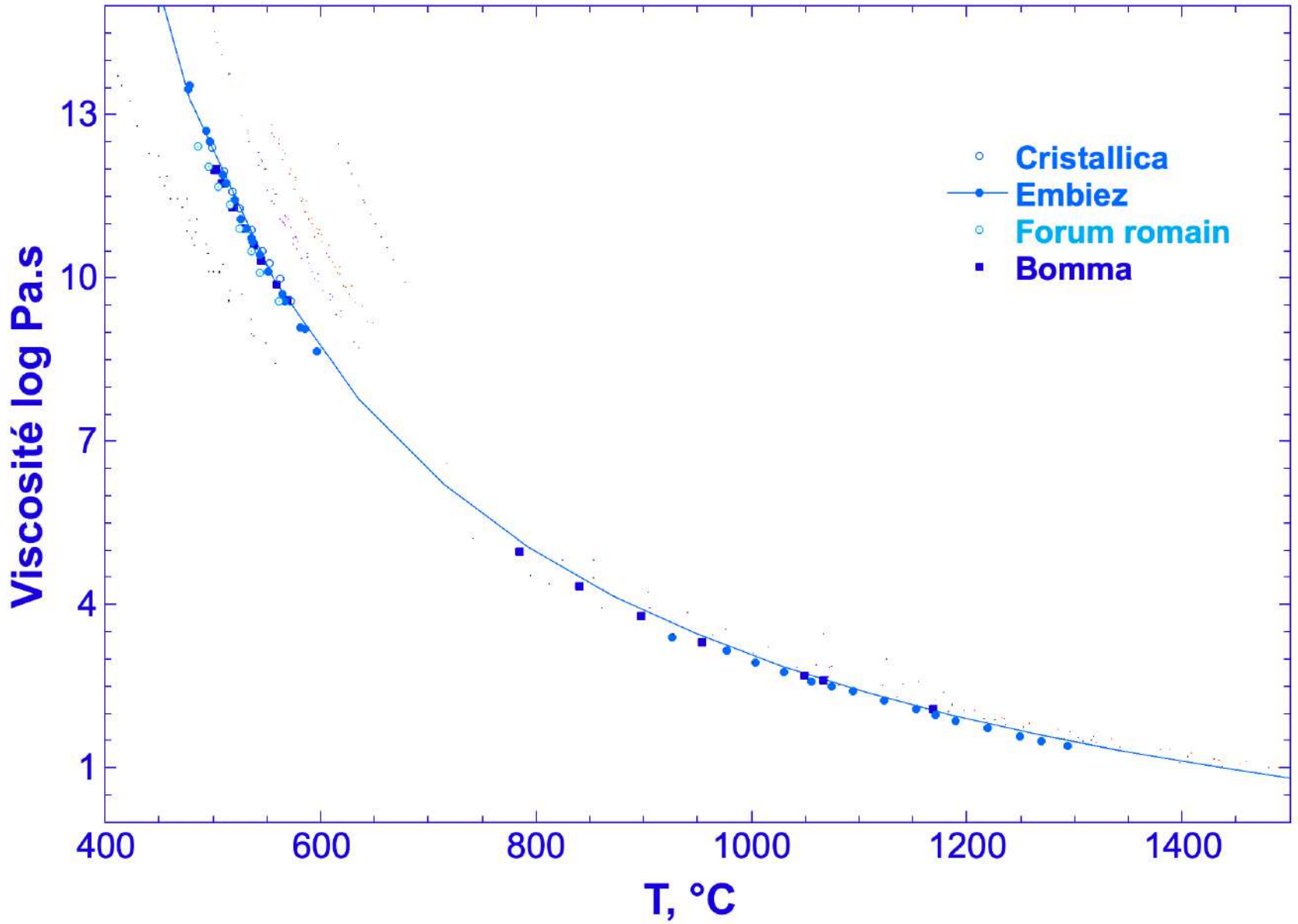
Si^{4+} : formateur de réseau : très forte viscosité.

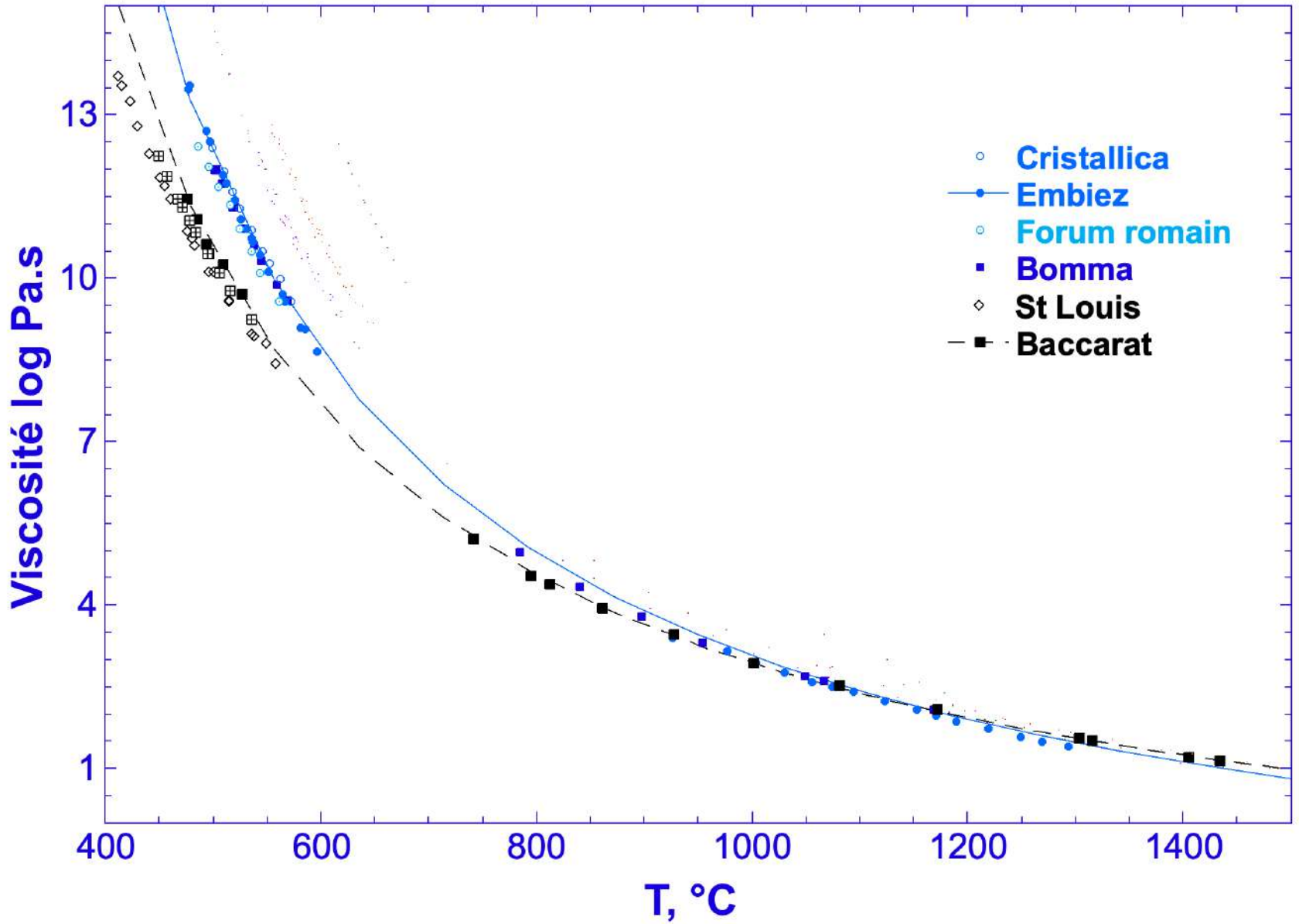
O : Oxygène : connection entre les Si en créant des oxygènes pontants.

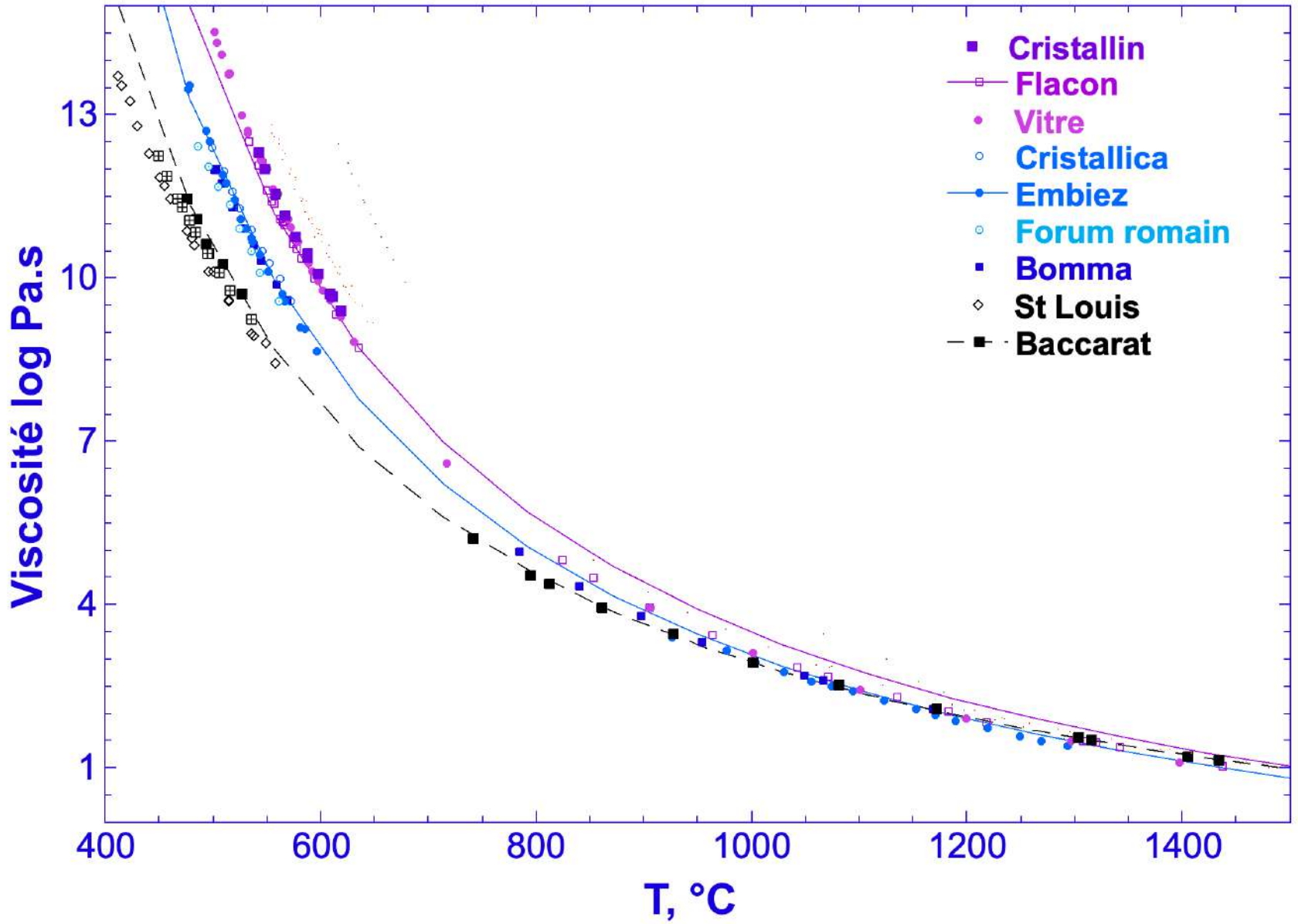
Na^{+} : casse les connections entre les Si : plus Na augmente et plus viscosité diminue.

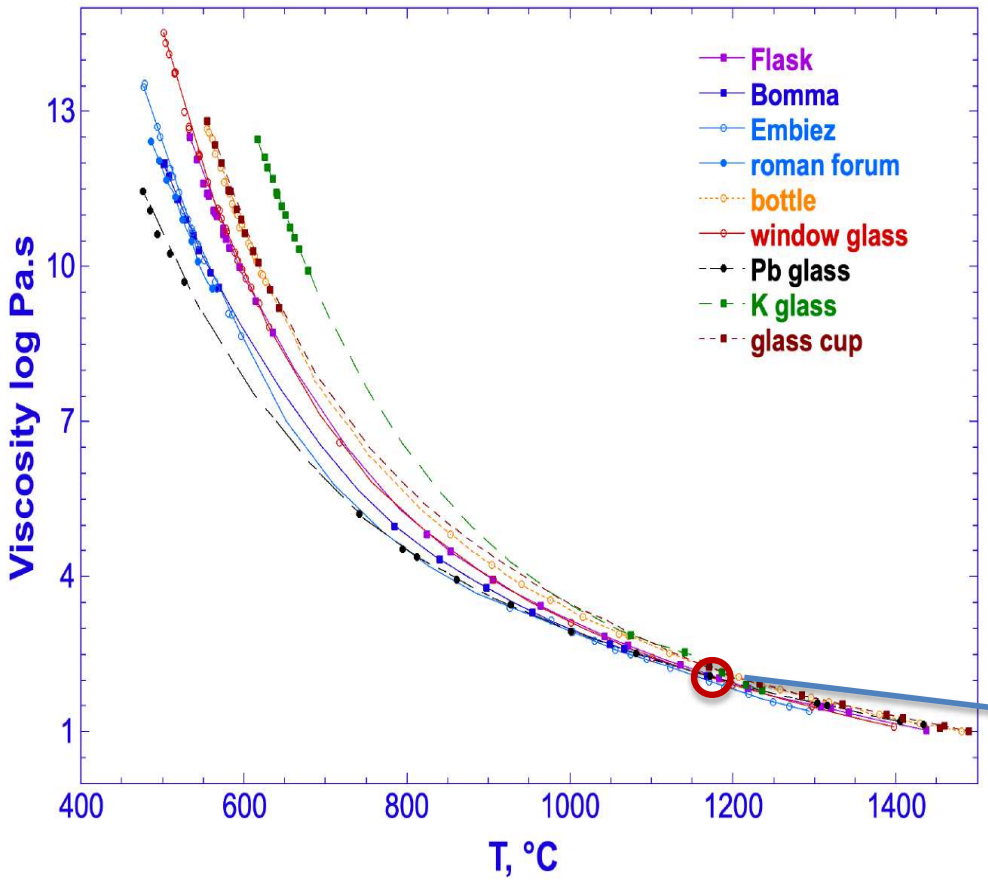
Ca^{2+} : stabilise le réseau, mais casse les connections entre Si, faible viscosité mais moins faible qu'avec Na.

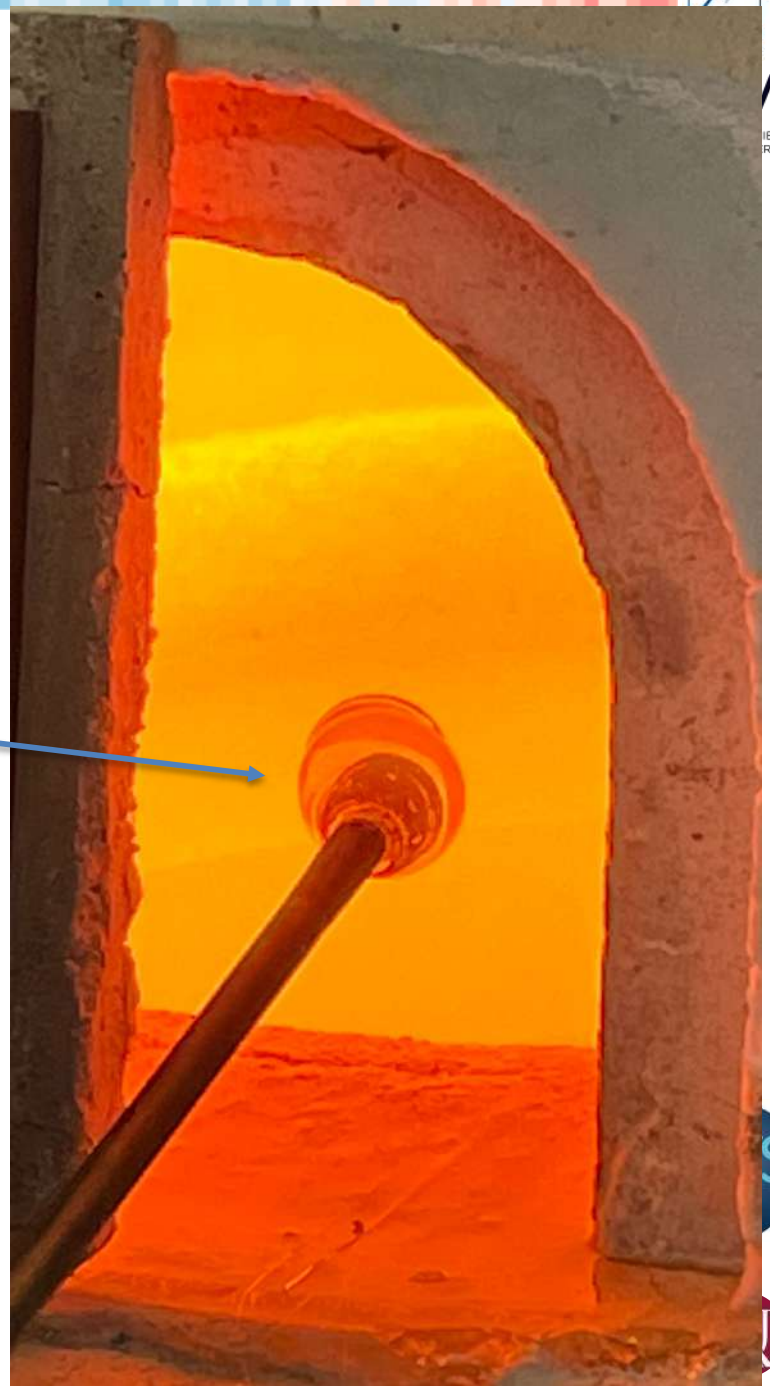
Al^{3+} : reconstruit le réseau car il prend la charge + de Na ou 2+ de Ca qui ne casse plus le réseau, la connection du réseau augmente et la viscosité aussi.


Viscosité log Pa.s
13
10
7
4
1
400
600
800
1000
1200
1400
T, °C
Cristallica
Embiez
Forum romain
Bomma

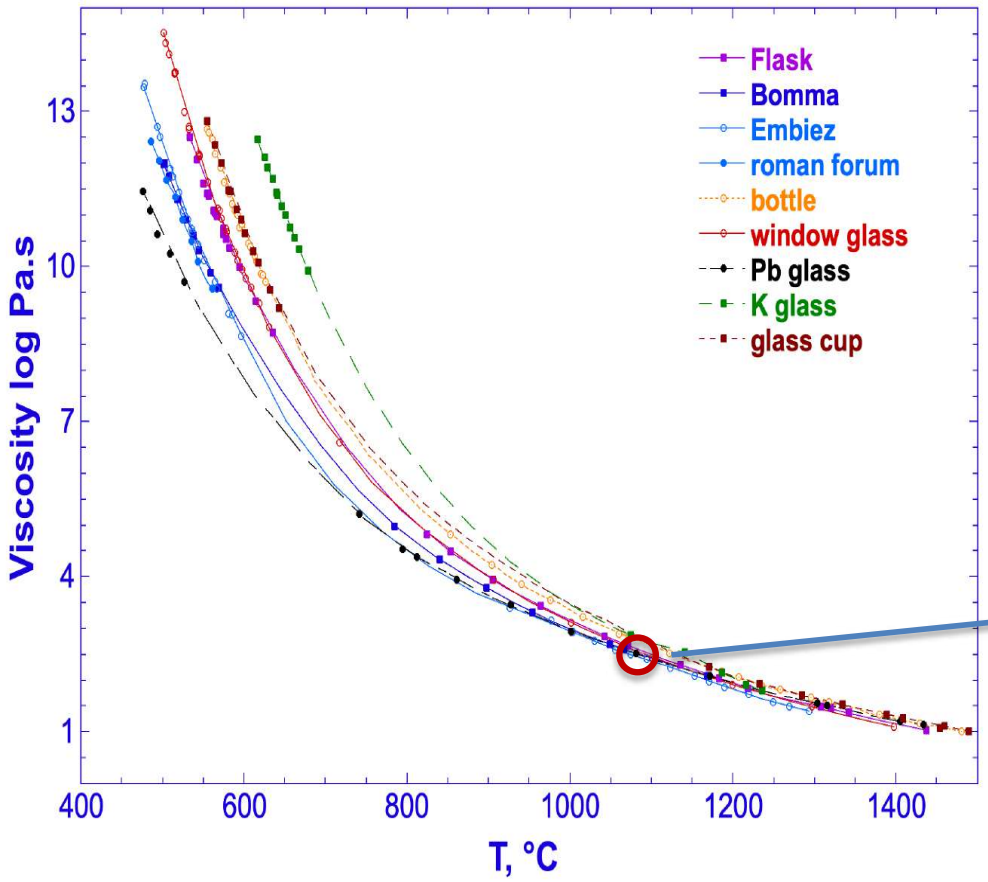

Viscosité log Pa.s
13
10
7
4
1
400
600
800
1000
1200
1400
T, °C
Cristallica
Embiez
Forum romain
Bomma
St Louis
Baccarat

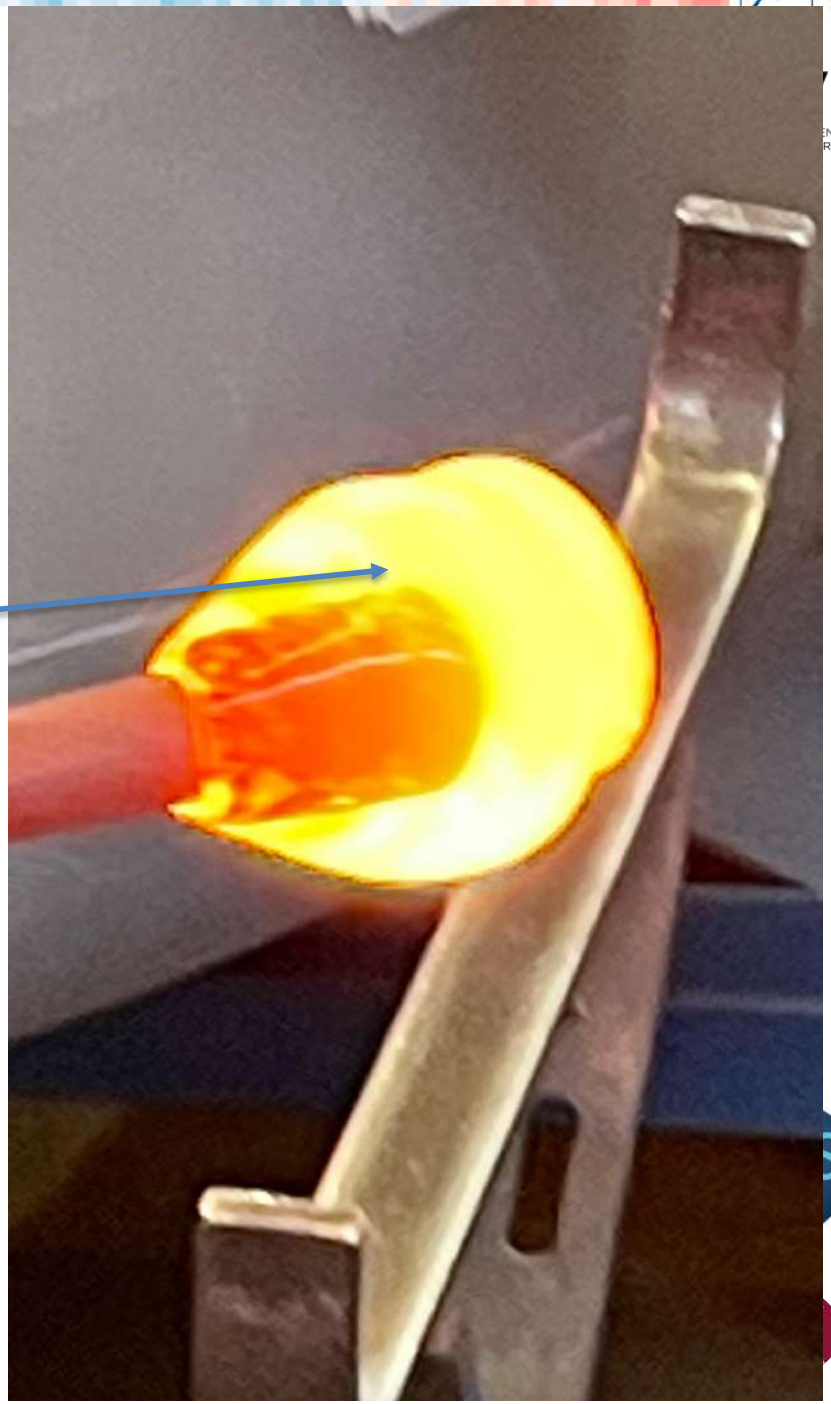

Viscosité log Pa.s
13
10
7
4
1
400
600
800
1000
1200
1400
T, °C
Cristallin
Flacon
Vitre
Cristallica
Embiez
Forum romain
Bomma
St Louis
Baccarat



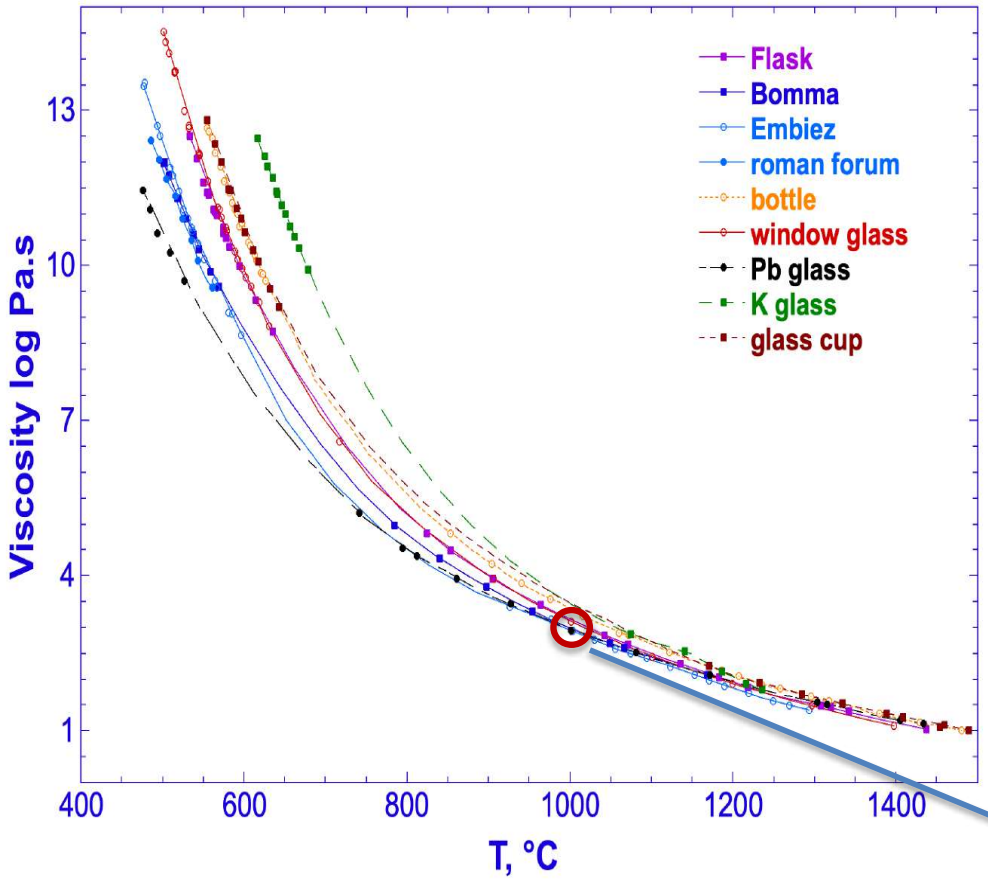


1150°C => ~2 log Pa.s

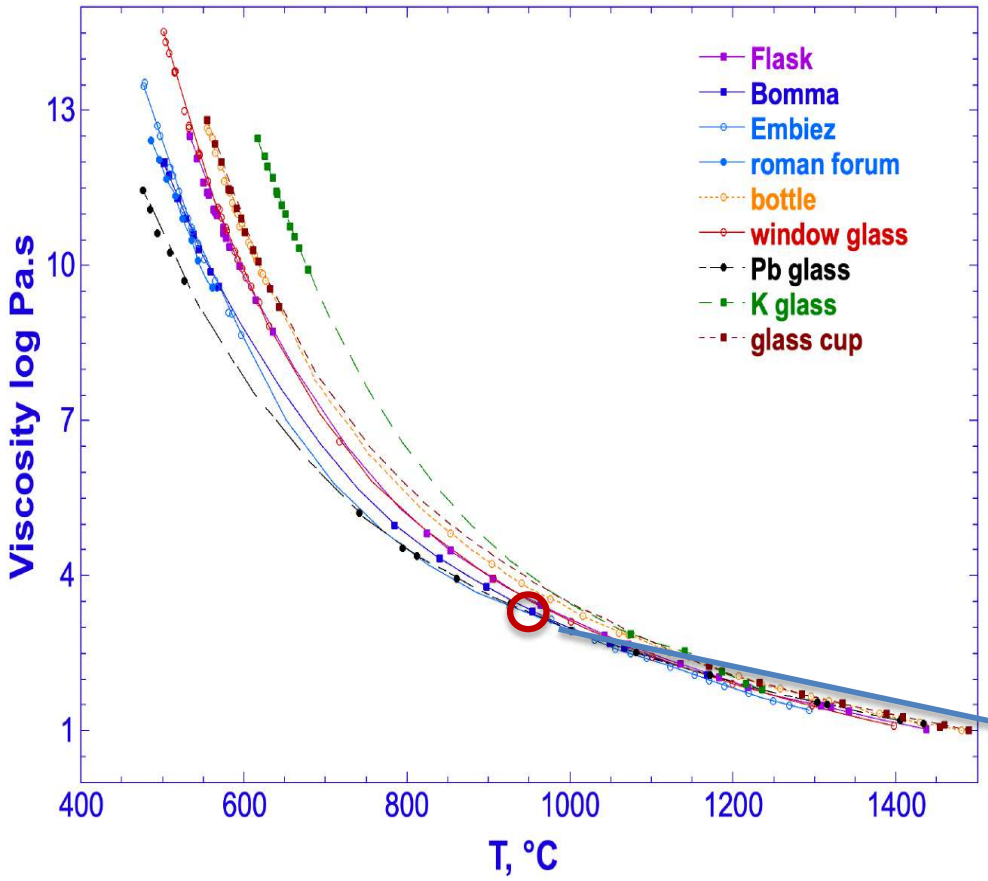




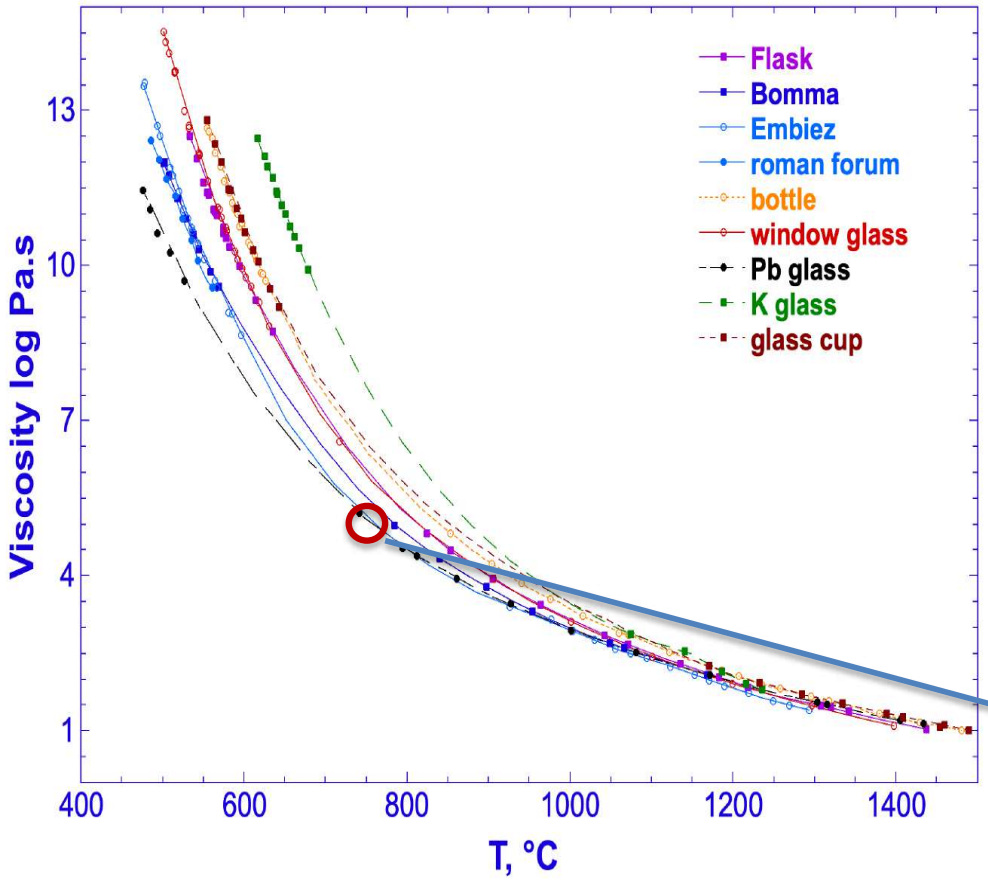
1060°C => ~2,6 log Pa.s



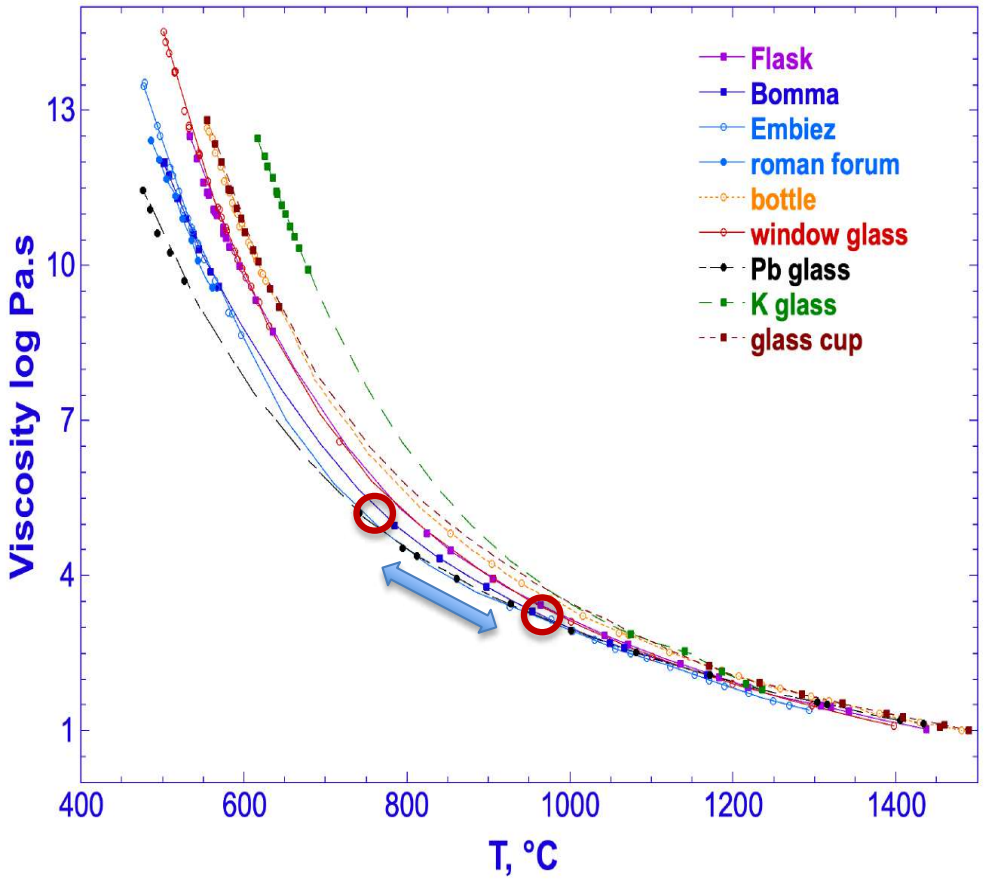
1060°C => ~3,2 log Pa.s



950°C => ~3,6 log Pa.s

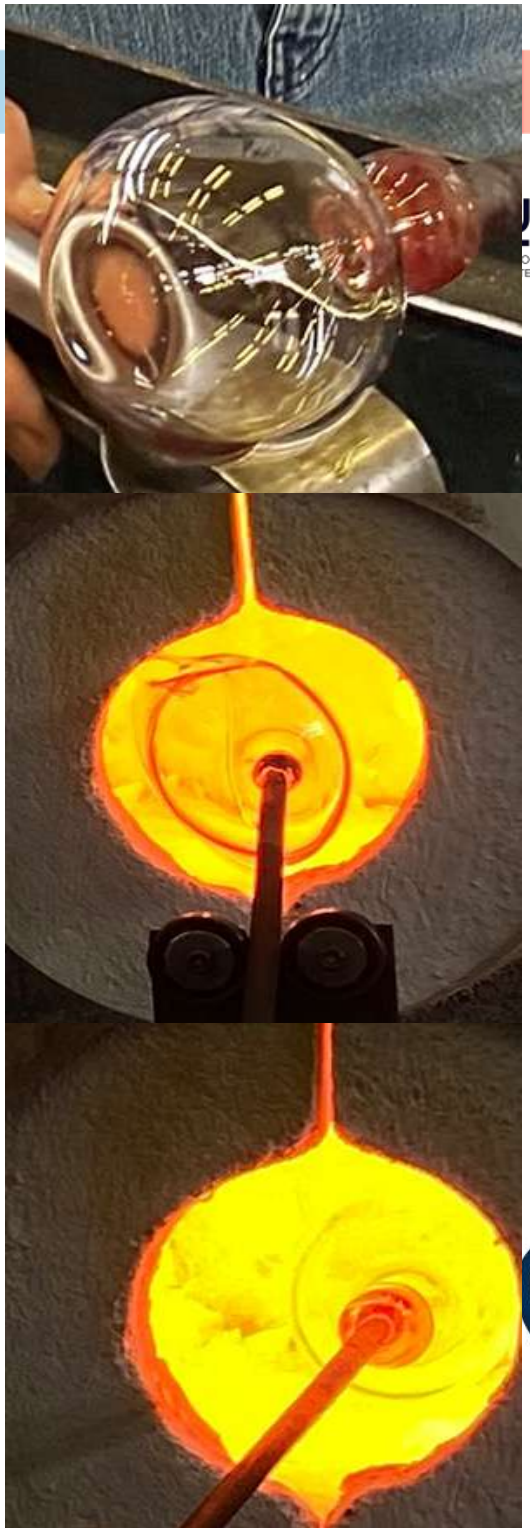


720°C => ~5,3 log Pa.s



950°C => ~3,6 log Pa.s

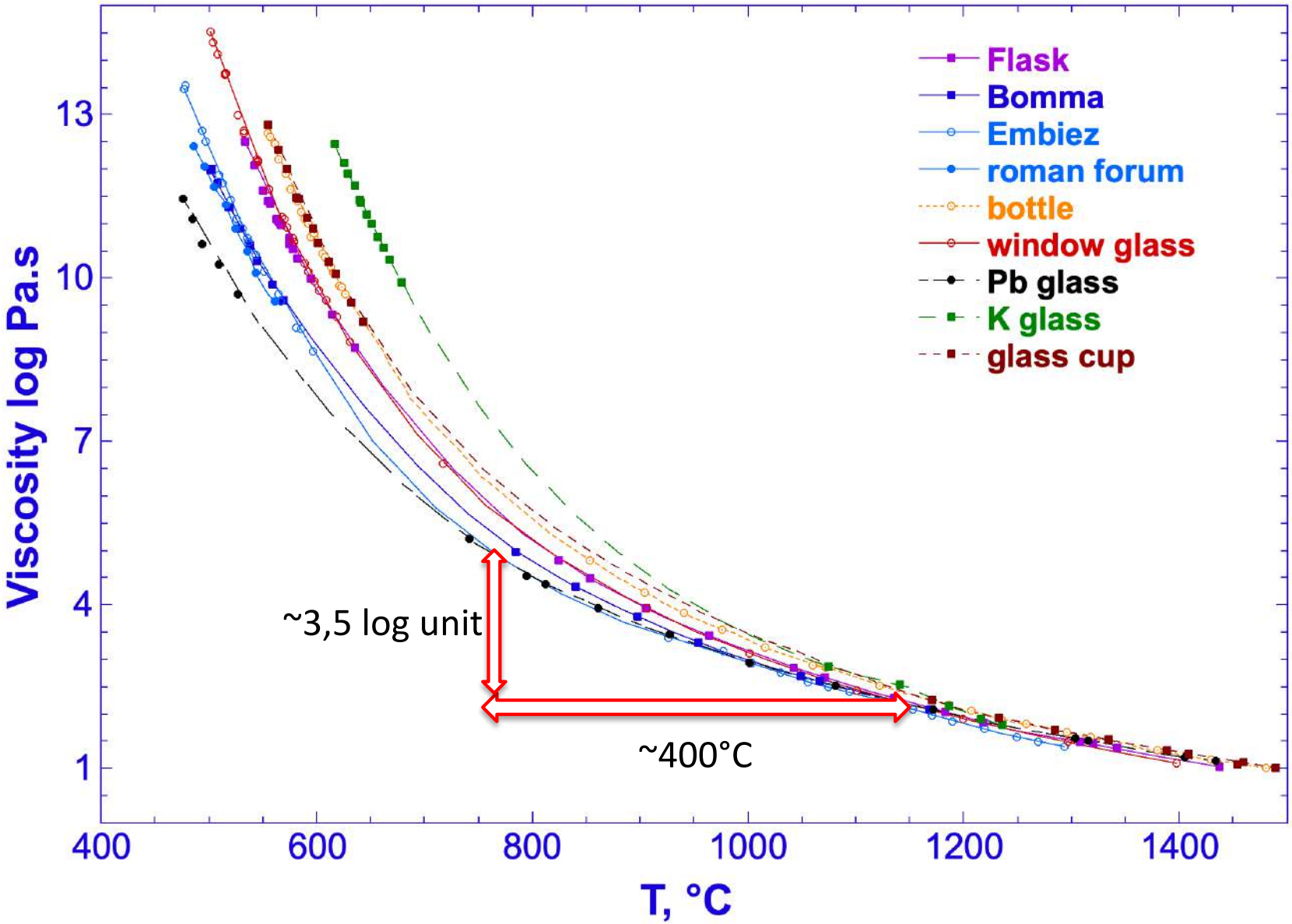
720°C => ~5,3 log Pa.s

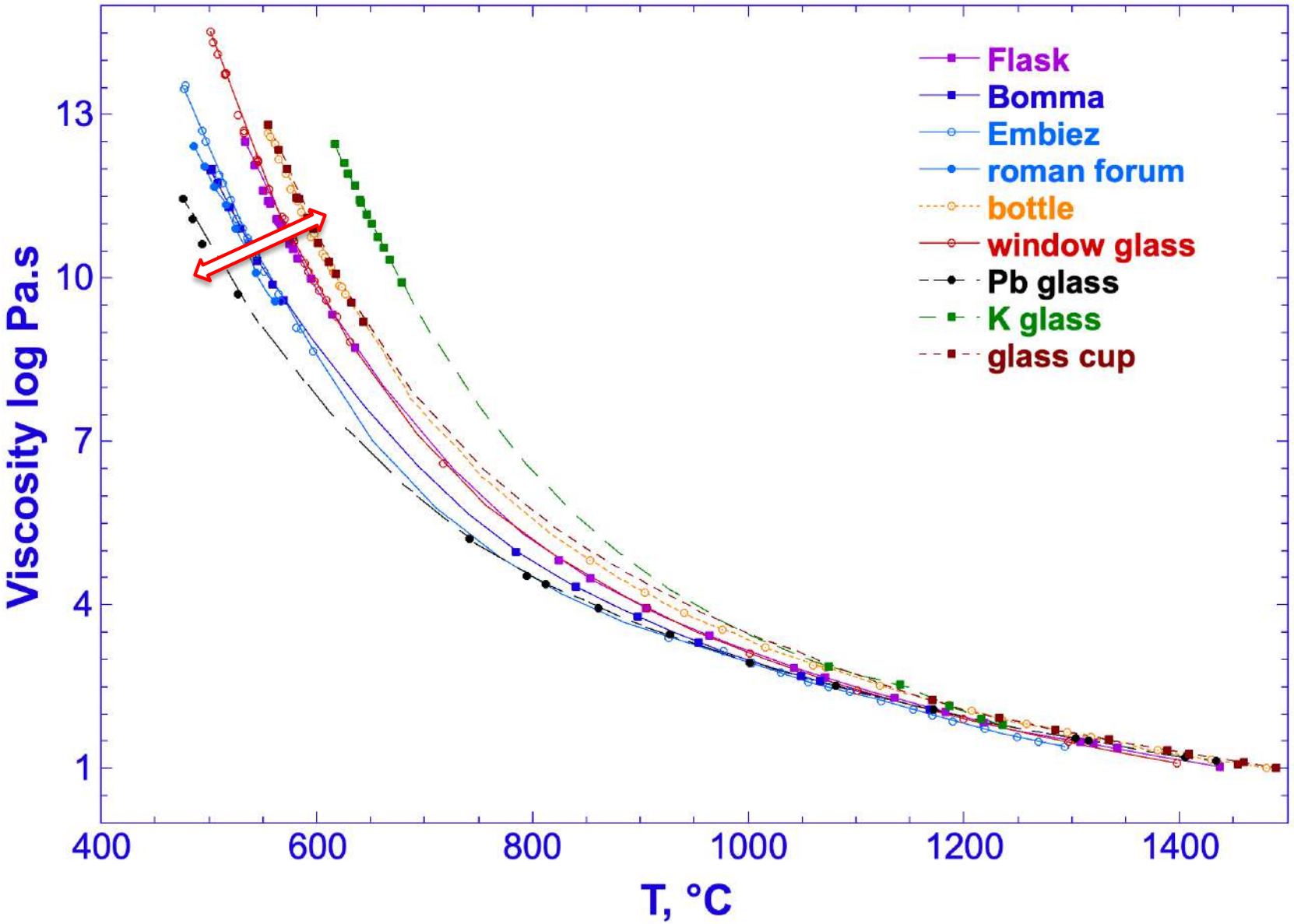



83 1.4


109.8

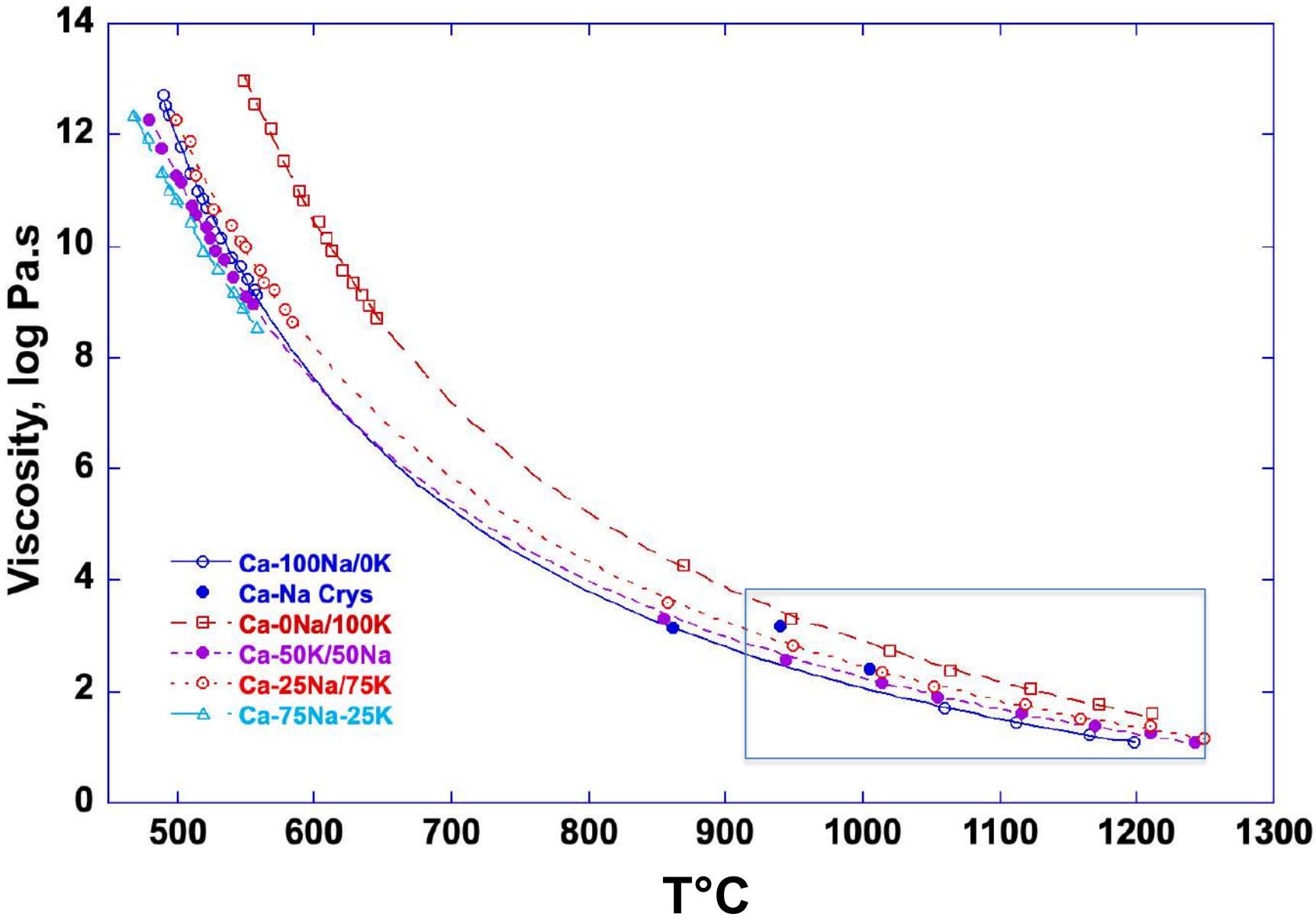

850.1
850.1
SET
DATA

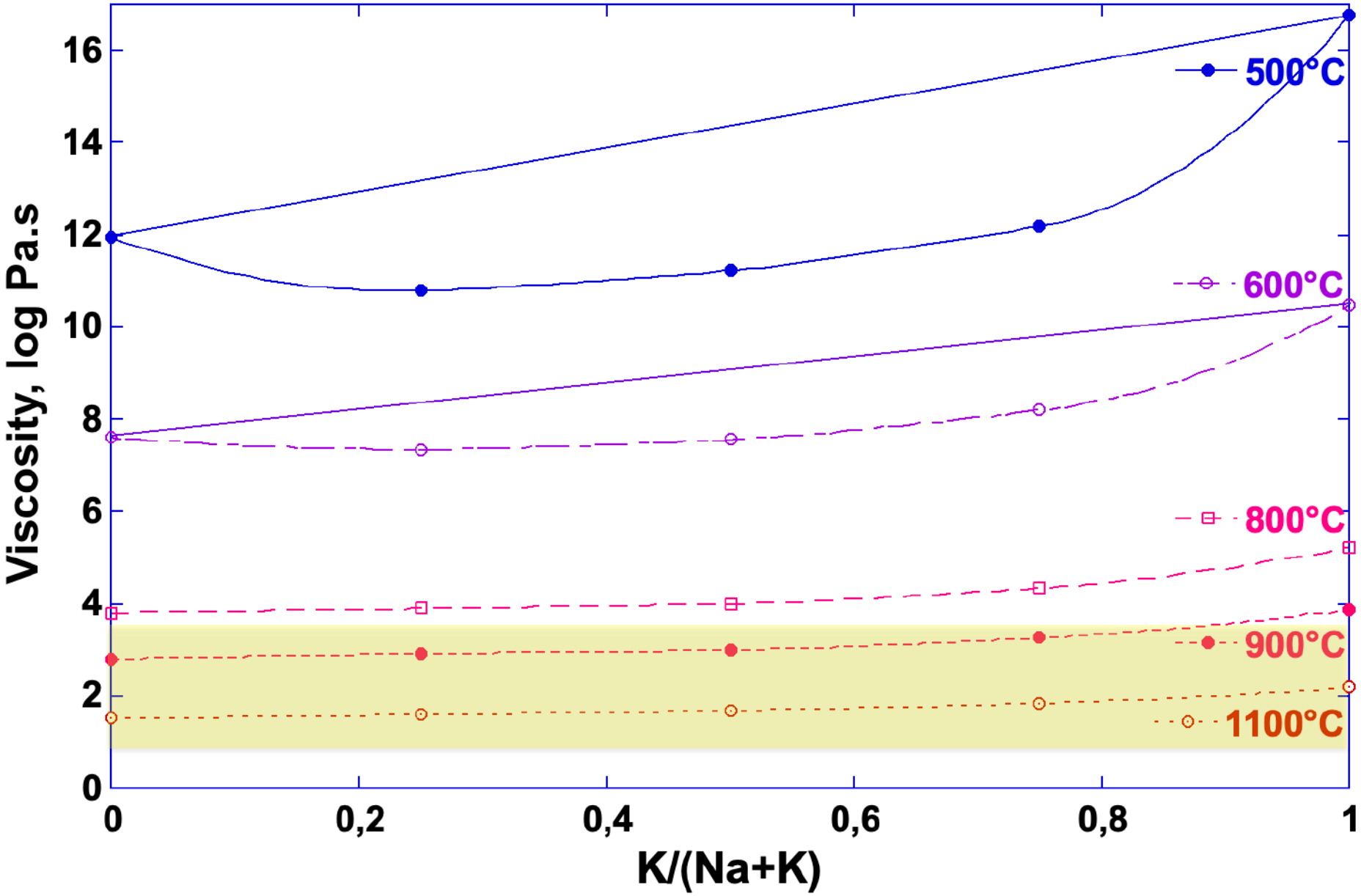

Viscosity log Pa.s
13
10
7
4
1
400
600
800
1000
1200
1400
T, °C
Flask
Bomma
Embiez
roman forum
bottle
window glass
Pb glass
K glass
glass cup
~3,5 log unit
~400°C


Viscosity log Pa.s
13
10
7
4
1
400
600
800
1000
1200
1400
T, °C
Flask
Bomma
Embiez
roman forum
bottle
window glass
Pb glass
K glass
glass cup

	SiO2	CaO	Na2O	K2O	K/(Na+K)	A	B	T1	Tg K	Tg°C
Ca-100Na/0K	65	11	24	0	0	-2,5658	3403,9	538,42	772,1	499,0
Ca-75Na/25K	65	11	18	6	0,25	-3,0085	4144,7	472,58	748,7	475,6
Ca-50Na/50K	65	11	12	12	0,5	-2,7799	3930,9	492,43	758,4	485,2
Ca-25Na/75K	65	11	6	18	0,75	-2,9839	4246,9	493,13	776,6	503,4
Ca-0Na/100K	65	11	0	24	1	-3,0338	4244,9	558,58	840,9	567,8

ALICIA VAN HAM-MEERT ET MAYA DAUSSIN

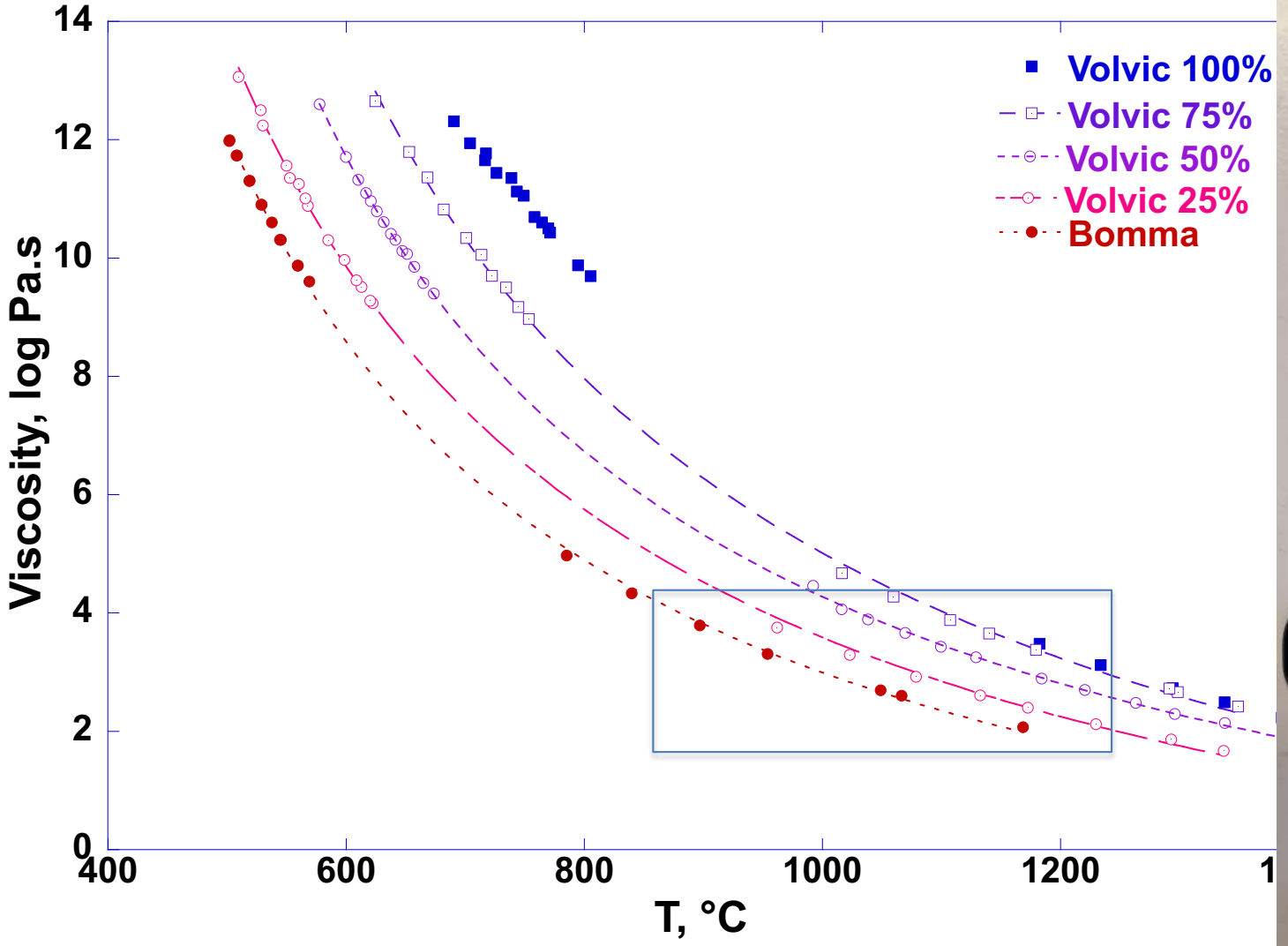

Viscosity, log Pa.s
T°C
14
12
10
8
6
4
2
0
500
600
700
800
900
1000
1100
1200
1300
Ca-100Na/0K
Ca-Na Crys
Ca-0Na/100K
Ca-50K/50Na
Ca-25Na/75K
Ca-75Na-25K


Viscosity, log Pa.s
K/(Na+K)
0
2
4
6
8
10
12
14
16
0
0,2
0,4
0,6
0,8
1
500°C
600°C
800°C
900°C
1100°C

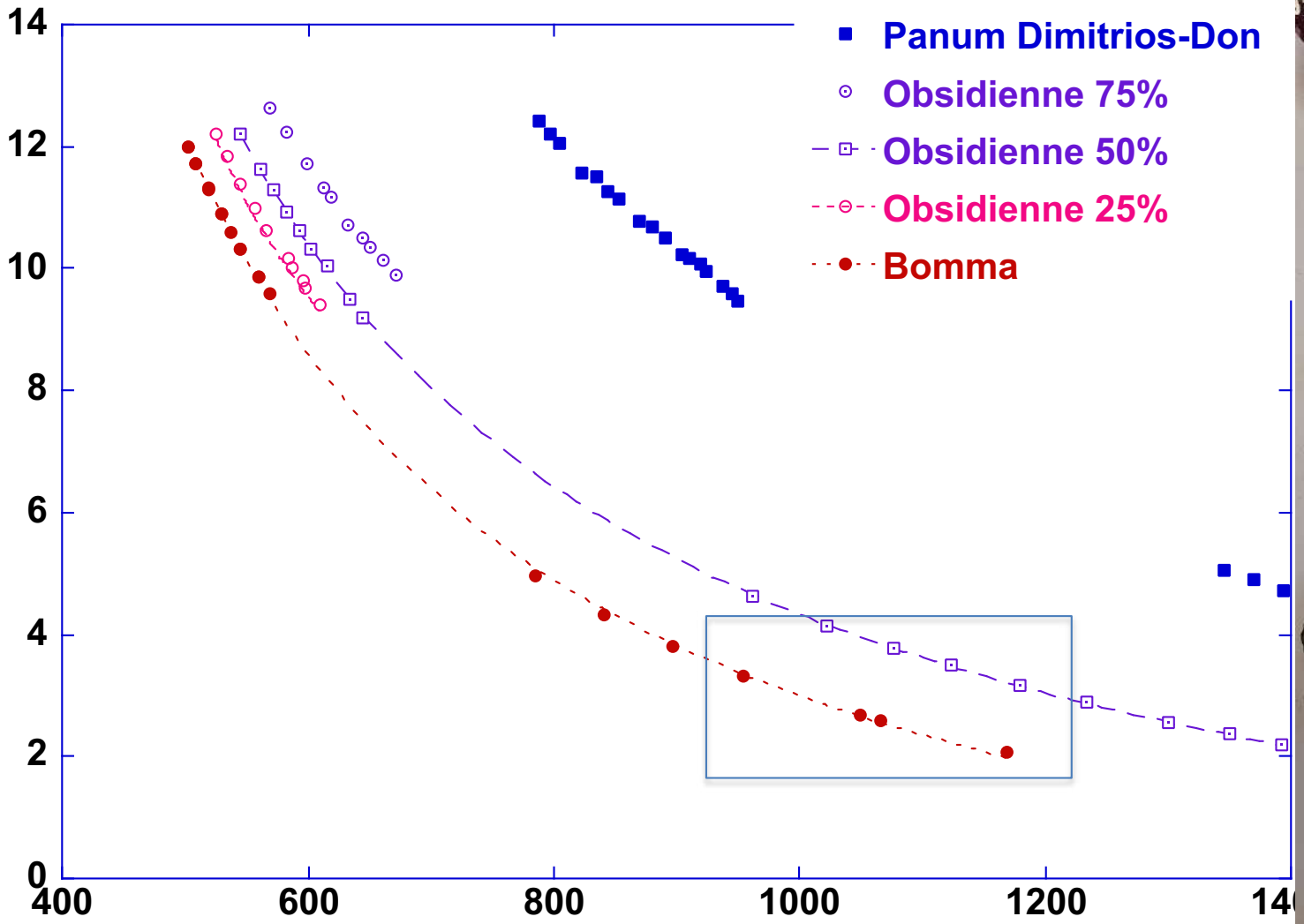
Que faut-il faire pour développer de nouvelles compositions de verre?

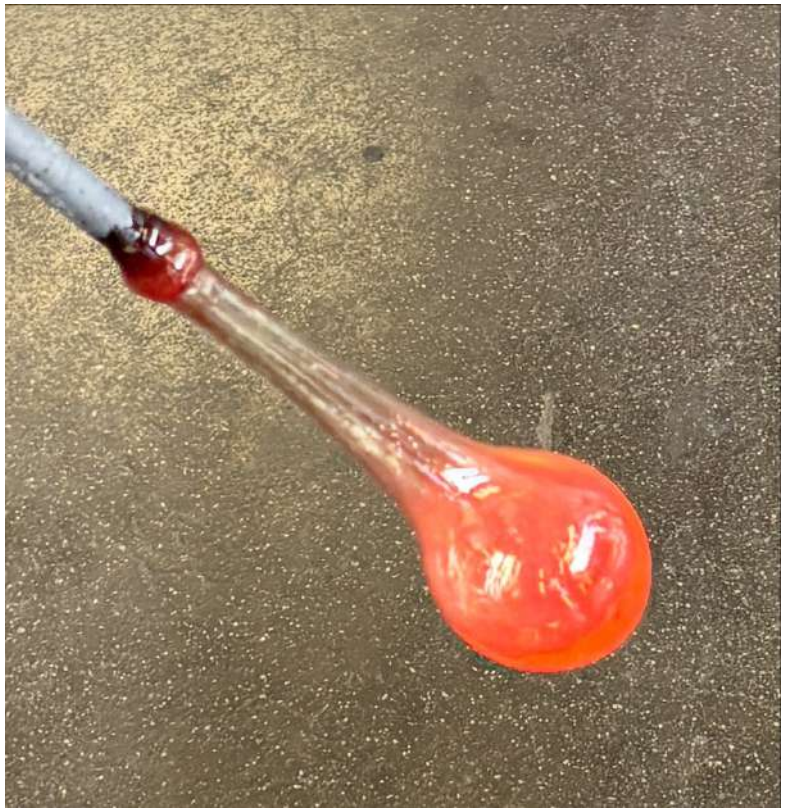
=> Trouver une composition qui présente un palier de travail comparable compositions précédentes !

	SiO2	Al2O3	Na2O	K2O	MgO	CaO	BaO	ZnO	Ce2O3	Sb2O3	SO2	P2O5	TiO2	FeO
Bomma	**71,79**	**0,68**	**9,68**	**5,18**	**0,23**	**4,54**	3,6	1,04	0,28	0,66	0,05	0,01	0	**0**
basalte	**44,73**	**13,74**	**2,85**	**1,77**	**11,23**	**8,92**	0,05	0	0,02	0,14	0,01	0,61	2,02	**10,37**
andesite-Volvic	**55,73**	**18,35**	**3,26**	**3,53**	**1,88**	**4,57**	0,11	0	0,04	0,02	0,02	0,15	1,16	**5,92**
obsidienne	**71,57**	**14,43**	**4,06**	**3,9**	**0**	**0,06**	0,02	0,07	0,03	0,02	0,01	0	0,02	**0,93**

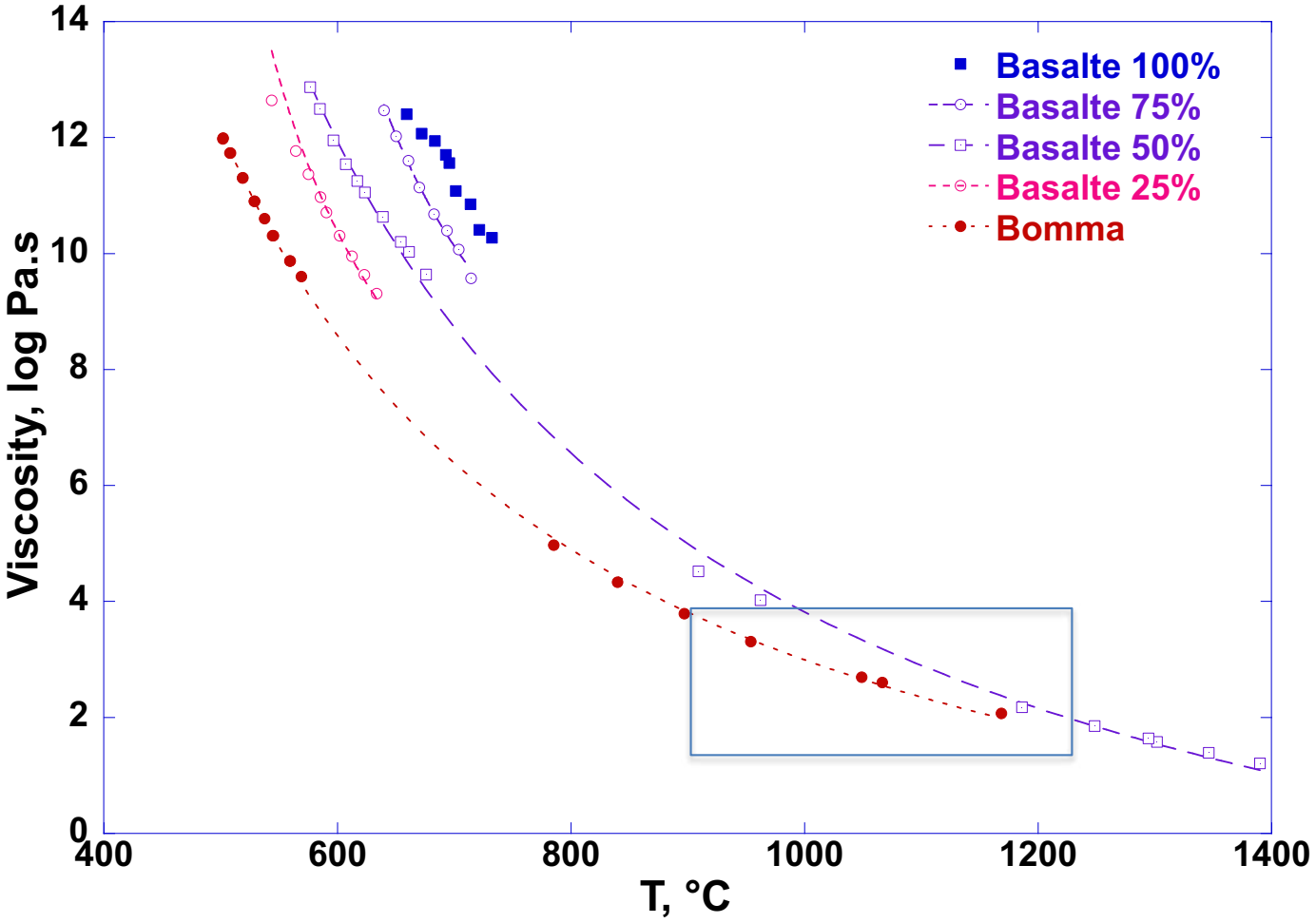

Volvic 100%
Volvic 75%
Volvic 50%
Volvic 25%
Bomma
Viscosity, log Pa.s
T, °C
0
2
4
6
8
10
12
14
400
600
800
1000
1200

50%Volvic-50%Bomma


14
12
10
8
6
4
2
0
400
600
800
1000
1200
Panum Dimitrios-Don
Obsidienne 75%
Obsidienne 50%
Obsidienne 25%
Bomma



25%obsidienne-75%Bomma


Viscosity, log Pa.s
T, °C
Basalte 100%
Basalte 75%
Basalte 50%
Basalte 25%
Bomma
0
2
4
6
8
10
12
14
400
600
800
1000
1200
1400


BASALTE 25%
19/12/24
BASALTE/50 BOMMA
26/11/24
BASALTE 75%
20/12/24
BASALTE 100%
22/01/25

1) Geste verrier : palier de travail long ~ 3,5 log pour 400°C

2) Nouvelles compositions = possible si répondes aux gestes verriers

Merci