How Glazes Melt

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NCECA · 2012

On the Edge

Seattle, Washington

Firing Temperatures?

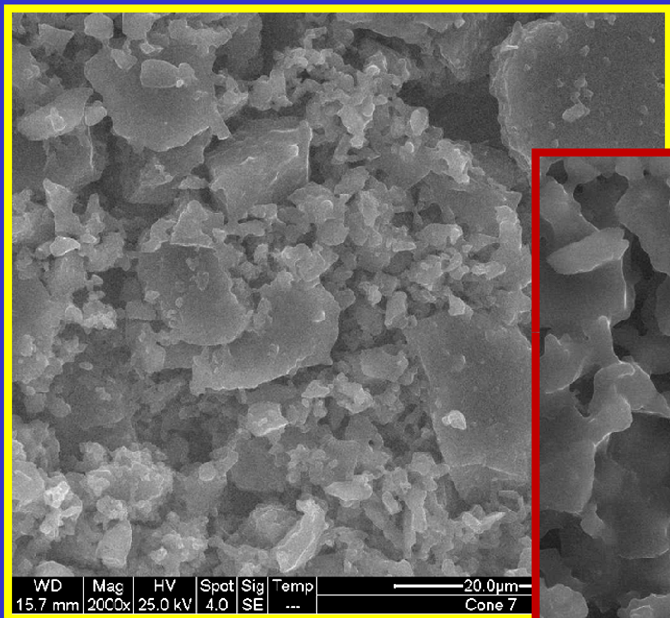
- Cone 10?
  - Broad range of melting compositions
- Low Fire?
  - Naturally occurring, contaminated clays (body considerations)
- Mid-range?
  - Energy savings
  - Body density
  - Glaze durability

How do Glazes Melt?

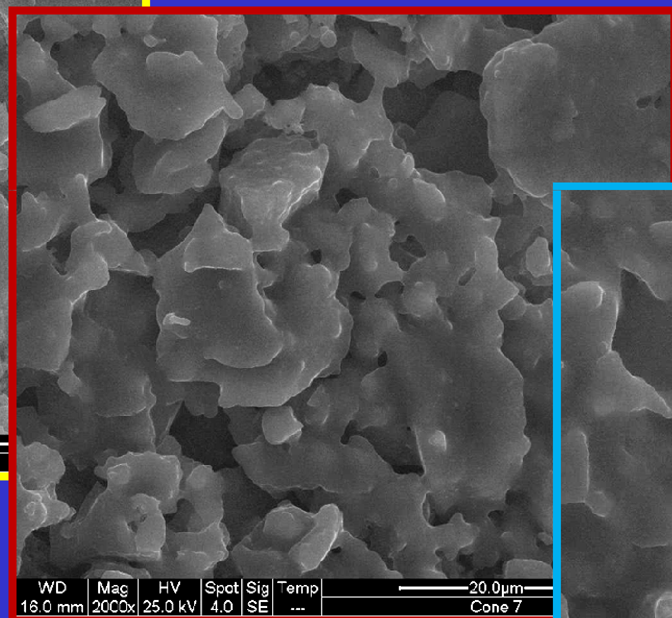
Pyrometric cones give us insight

Understanding melting reactions reveals a lot about glazes.

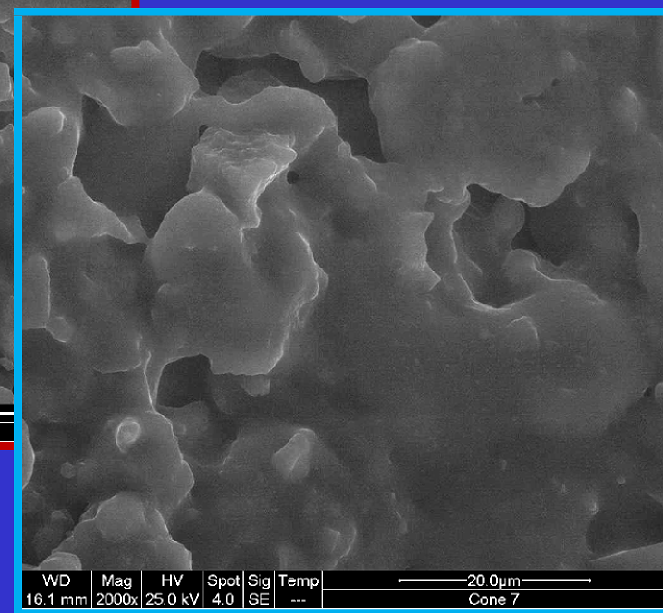
800°C



1200°C



1300°C



SEM images of *in situ* melting of a Δ7 pyrometric cone.
Courtesy: Dr. Tom Lam.

What is a Eutectic?

Eutectic temperature

The lowest temperature at which a given combination of elements will melt.

Heat = Melting

DETAILS: How Raw Glazes Melt

Melting takes time.

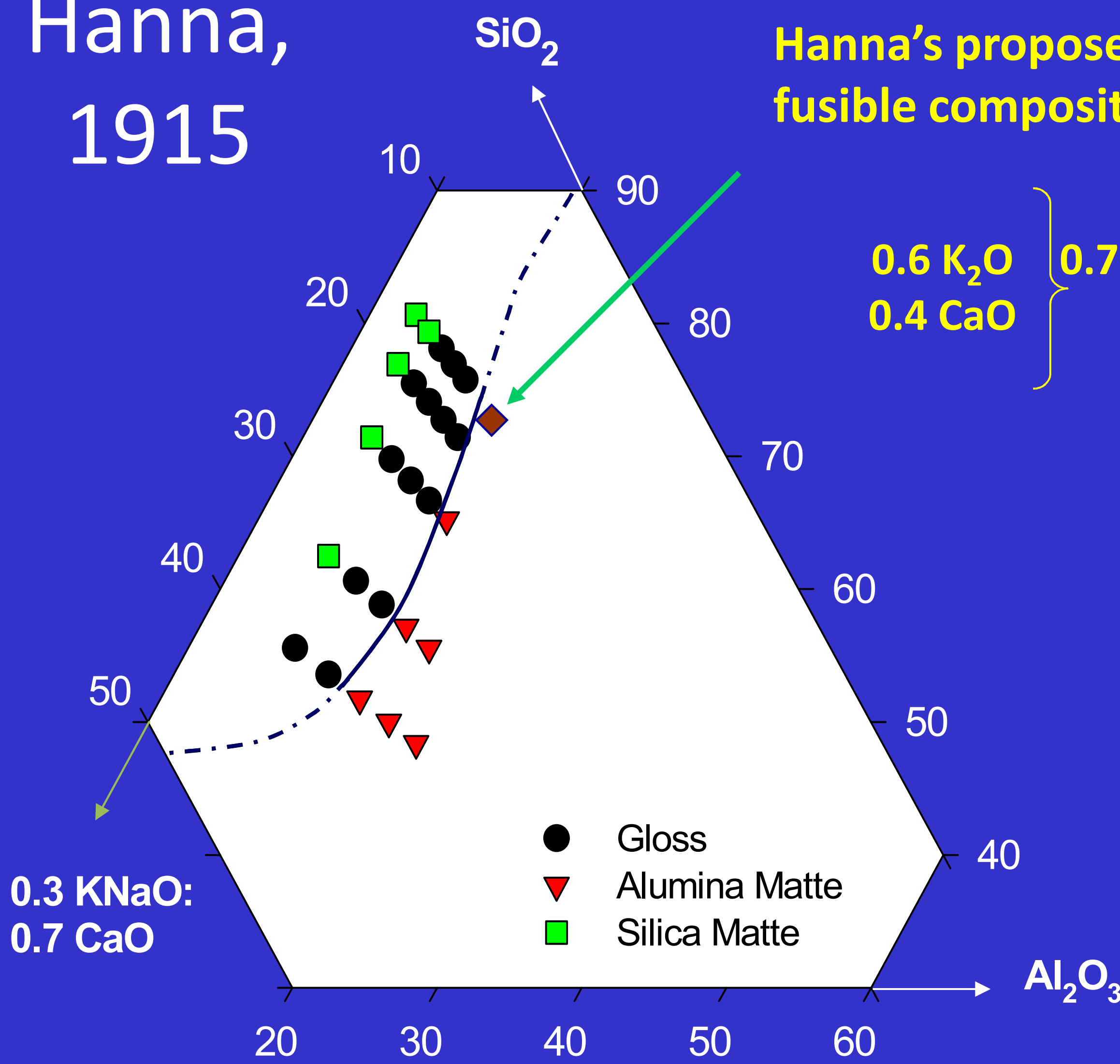
Liquid formation facilitates atomic mobility.

Diffusion of ions within the melt improves the uniformity.

Well melted glazes are chemically uniform (always true for glosses?).

Raw glaze melting starts at a eutectic composition *(proposed – Hanna).*

Hanna, 1915



Hanna's proposed composition of most fusible composition:

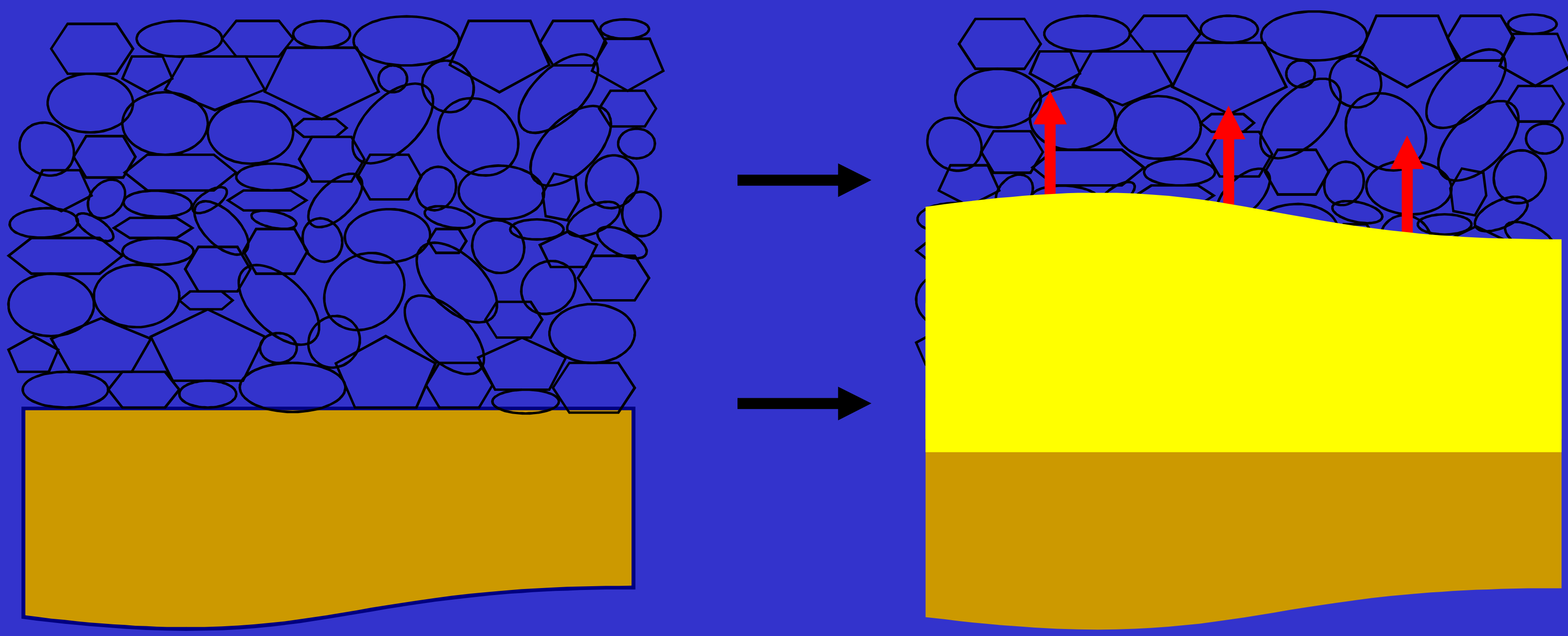
0.6 K_2O / 0.4 CaO } **0.739 Al_2O_3** } **4.829 Si_2O**

This composition "fuses" at Cone 3.

Proposal: Raw glazes melt from the body out to the surface

Localized melting in pockets at the glaze-body interface.

Pools of liquid form and particles "melt" into them to eventually form a continuous melt.



Why Does Melt Start at Body?

The body is rich in alumina

The body is rich in silica

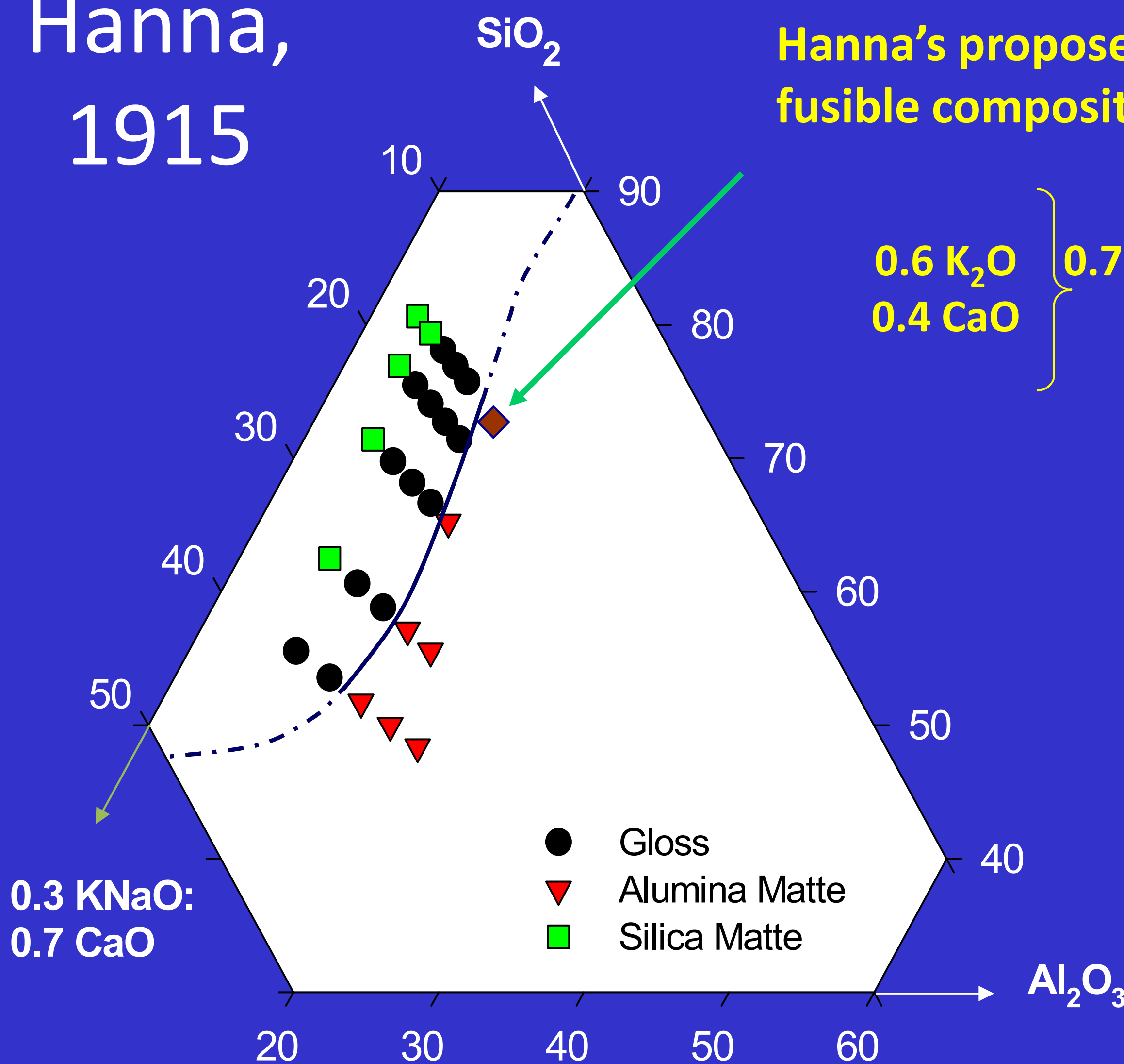
The glaze is rich in RO (CaO, etc.)

The level of R_2O is nearly equivalent between glaze and body (no movement).

A chemistry exchange at the glaze-body interface results in a eutectic melt: *“Hanna’s Eutectic”*

CaO moves into the body; silica and alumina move into the glaze.

Hanna, 1915



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Body Glaze Chemistry Exchange

Glaze Example	**0.3 K_2O** **0.7 CaO**	**0.35** **Al_2O_3**	**3.5** **Si_2O**
Glaze-Body Interface ***(Hanna's Eutectic)***	**0.6 K_2O** **0.4 CaO**	**0.739** **Al_2O_3**	**4.829** **Si_2O**
Typical Body Glass Phase Chemistry	**1.0 K_2O** **0.0 CaO**	**1.19** **Al_2O_3**	**17.0** **Si_2O**

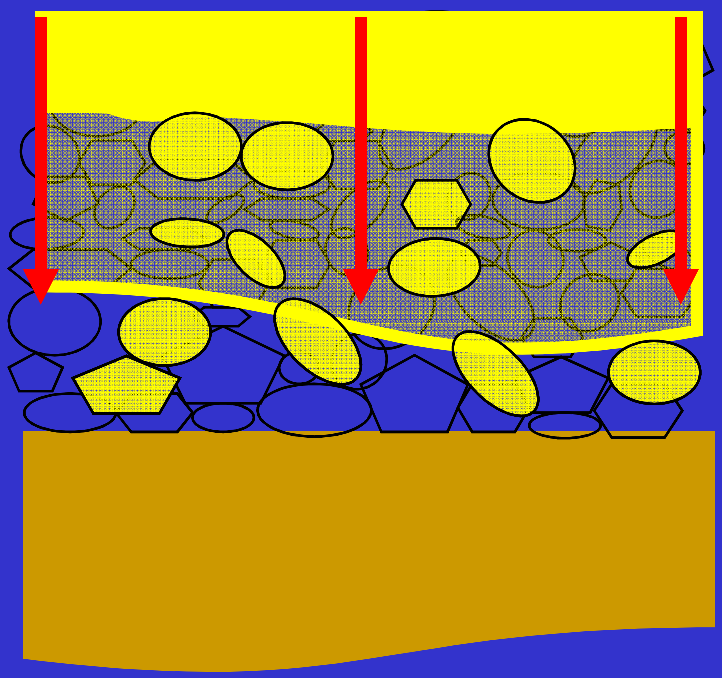
How Frits Melt: *A Proposal*

Frits are powdered glass

Melt similar to ice

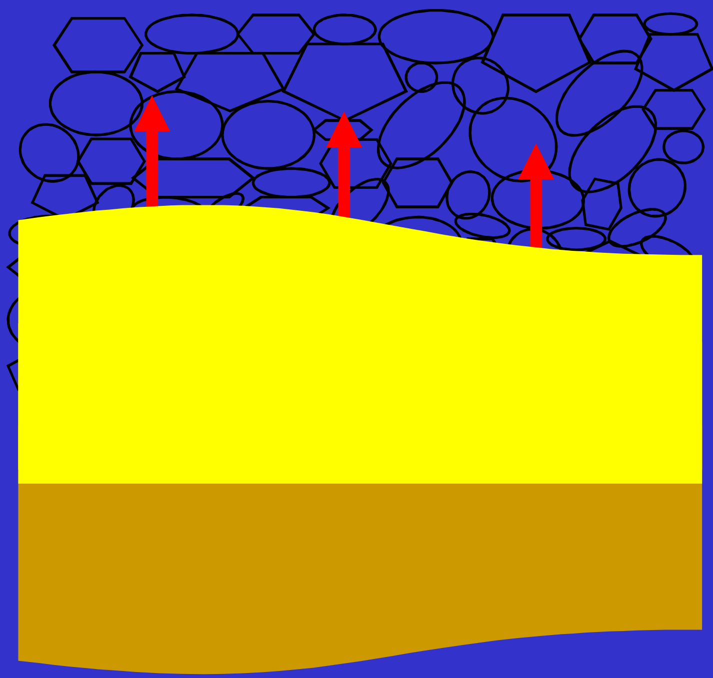
Particles melt uniformly, or "soften" rapidly upon reaching melting temperature

This is "re-melting" as the frit was previously melted when it was made (at the frit factory)

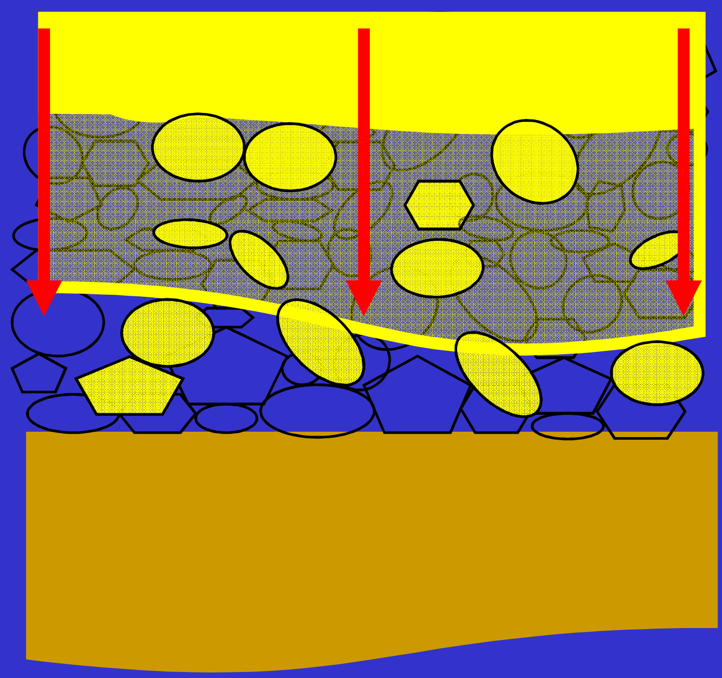


Comparison

Raw Glazes



Glazes with Frit

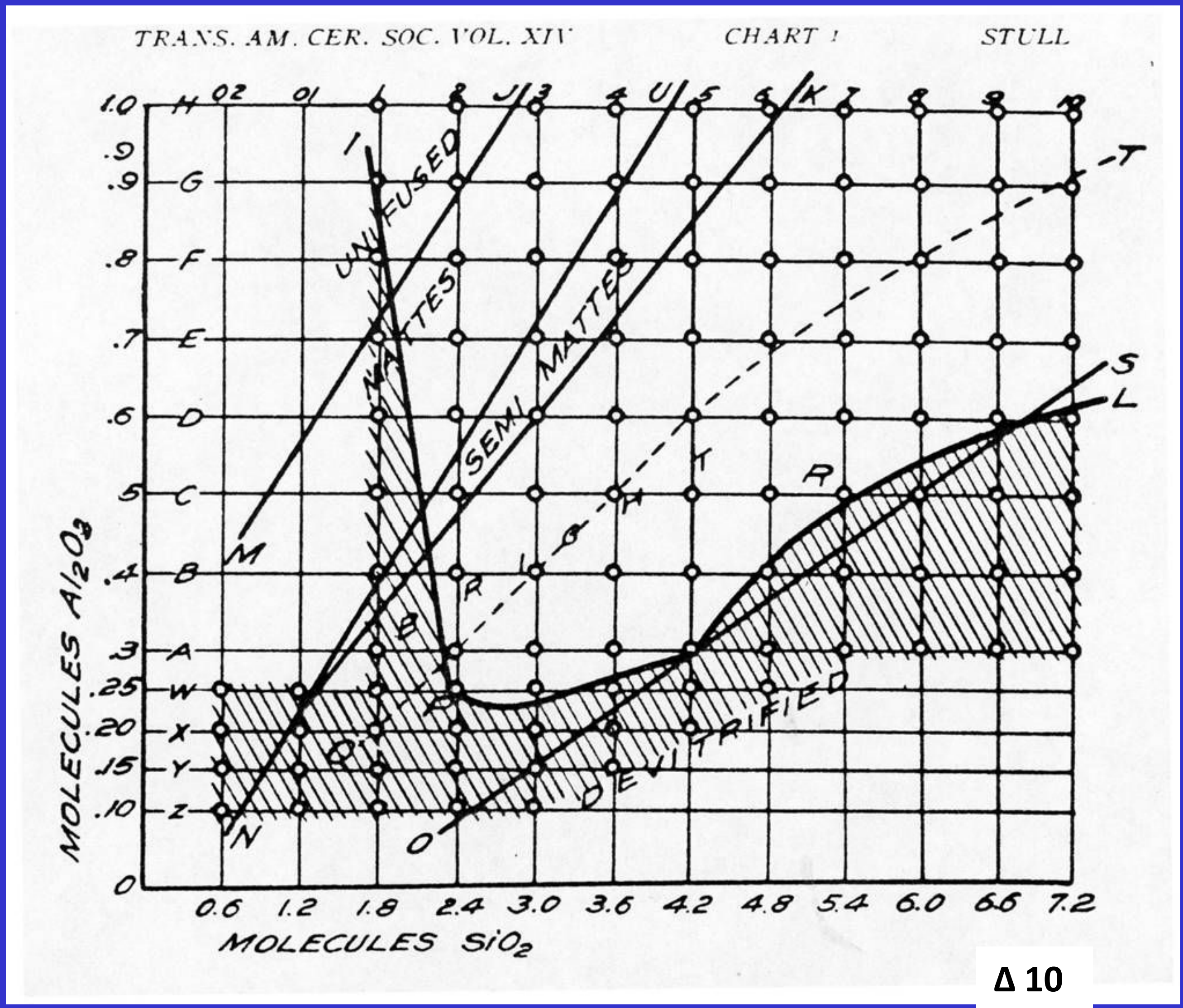


Science!

A map of glaze compositions & texture

Stull ·1912

0.3:0.7 $R_2O:RO$



Quick background

Silica is a glass former.

Alumina modifies a glass.

Fluxes reduce melting temperature.

The Unity Molecular Formula systematically relates these chemistries to each other.

- Useful glaze chemistry shorthand
- Shows ratio of glass formers to fluxes

UMF can be used to predict glaze behavior

UMF-Example

0.3 R_2O+0.7 RO : 0.35 Al_2O_3 : 3.5 SiO_2

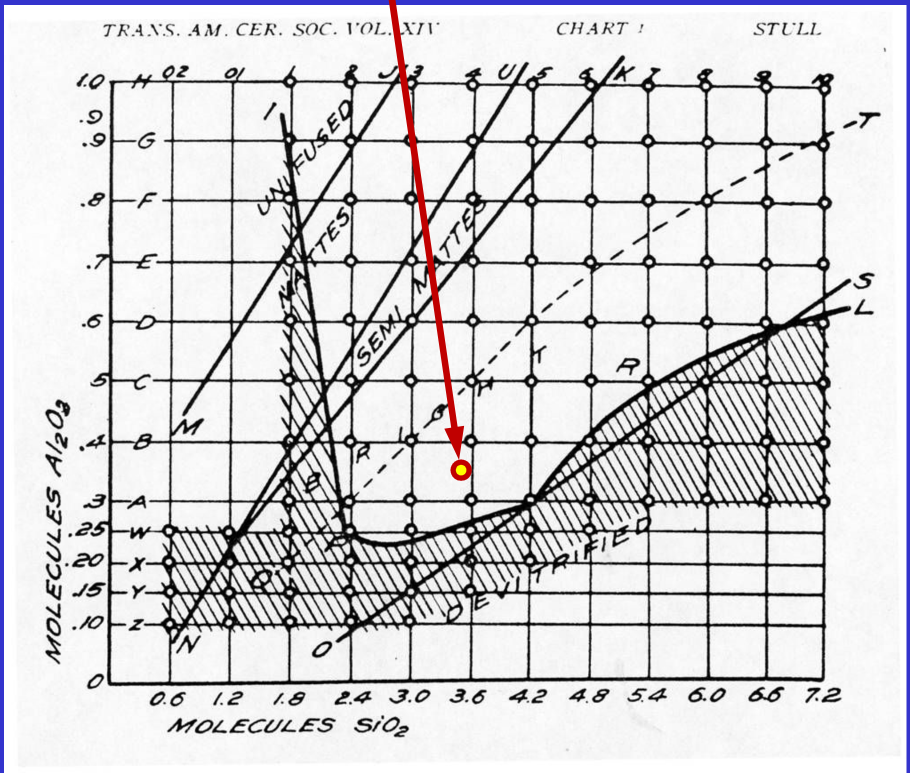
One mole of flux (combined):

- 0.3 alkali oxides (R_2O)
- 0.7 alkaline earth oxides (RO)

0.35 moles of alumina (Al_2O_3)

3.5 moles of silica (SiO_2)

10:1 SiO_2:Al_2O_3



UMF Prediction (via Stull)

0.3 R_2O*+0.7 RO : 0.35* Al_2O_3 *: 3.5* SiO_2

10:1 SiO_2:Al_2O_3

Melt between cone 5 and cone 10

Won't run off ware

Glossy (Actually, a good single-fire gloss glaze)

Chemically Durable

Mechanically Durable

This chemistry approach was invented by Hermann Seger

- Stull's work was based on that of Seger.
- Seger invented Cones (1895).
- Cone 4 was the first cone
- Incremental proportions of silica:alumina for each mole of flux.

Cone	R_2O:RO	Alumina	Silica
1	0.3:0.7	0.1	1
2	0.3:0.7	0.2	2
3	0.3:0.7	0.3	3
4	0.3:0.7	0.4	4
5	0.3:0.7	0.5	5
6	0.3:0.7	0.6	6
7	0.3:0.7	0.7	7
8	0.3:0.7	0.8	8
9	0.3:0.7	0.9	9
10	0.3:0.7	1.0	10
11	0.3:0.7	1.1	11
12	0.3:0.7	1.2	12

Important details

This 0.3 R_2O: 0.7 RO flux ratio is important.

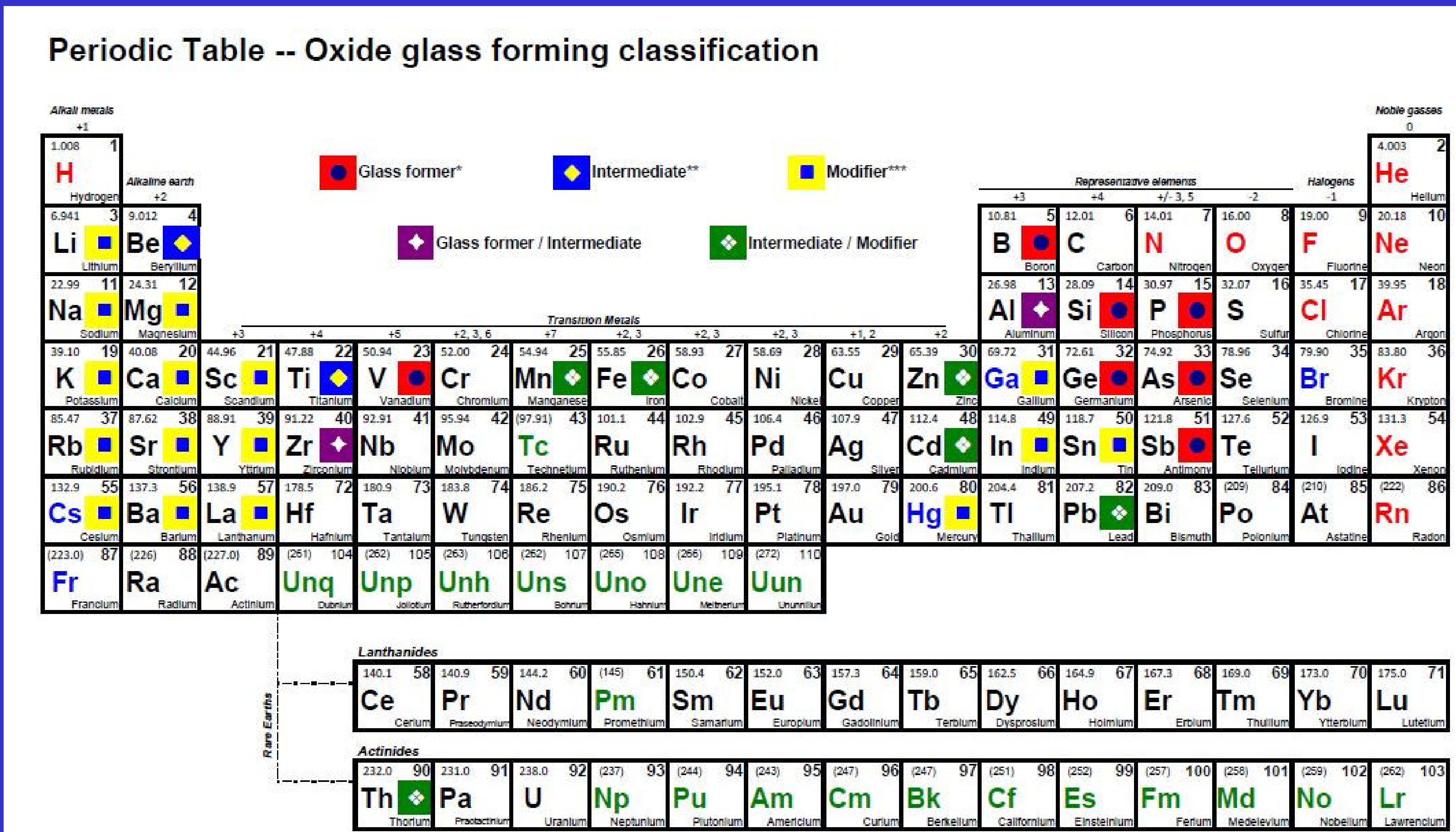
Specifies the ratio of the two different flux families used in glazes.

- More in a minute.

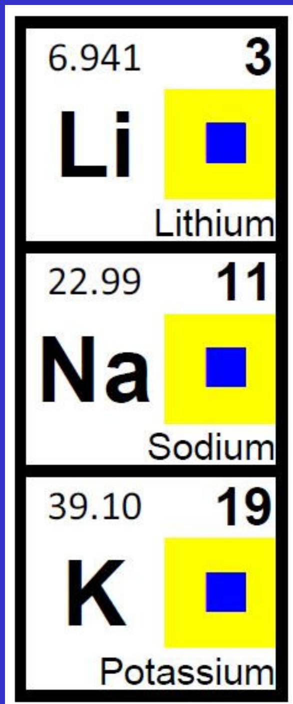
The ratio of the fluxes determines the durability of a glaze

- More from Matt.

Periodic Table of the Elements



Alkali Metals
(R_2O)



These flux families work together.

Activates melting.
Gets the melt started.
Too much softens, weakens glaze.

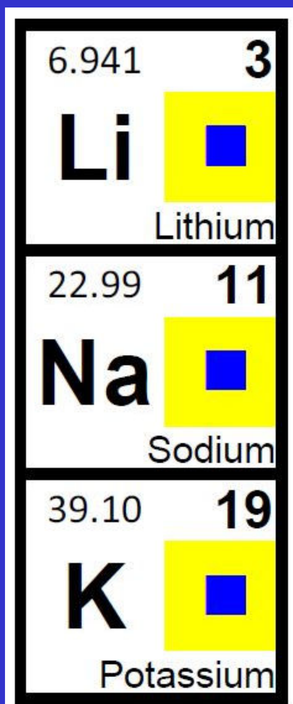
Alkaline Earths
(RO)

Complimentary flux.
Keeps glazes stable.
Too much melts poorly.

Why 0.3 R_2O : 0.7 RO flux ratio?
Because it works!

Some General Guidelines
for chemistry substitution

Alkali Oxides
(R_2O)



Alkali can substitute for alkali

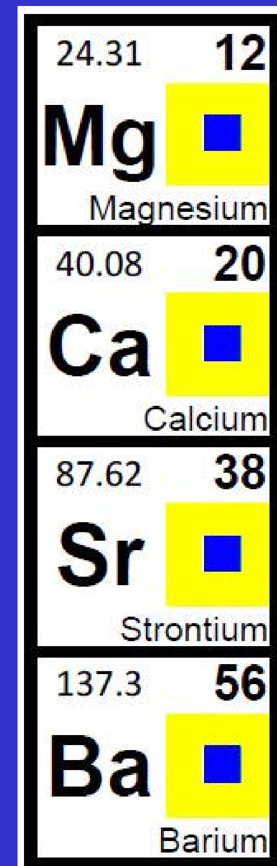
Alkaline earth can substitute for each other.

Provided the substitution is on a molar basis!

Texture is dictated by silica:alumina ratio

PbO, however, is a wildcard!

Alkaline Earths
(RO)



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We can also add Fe, Cu, Co, Ni, and other RO to this list.

Historic Chinese Glazes

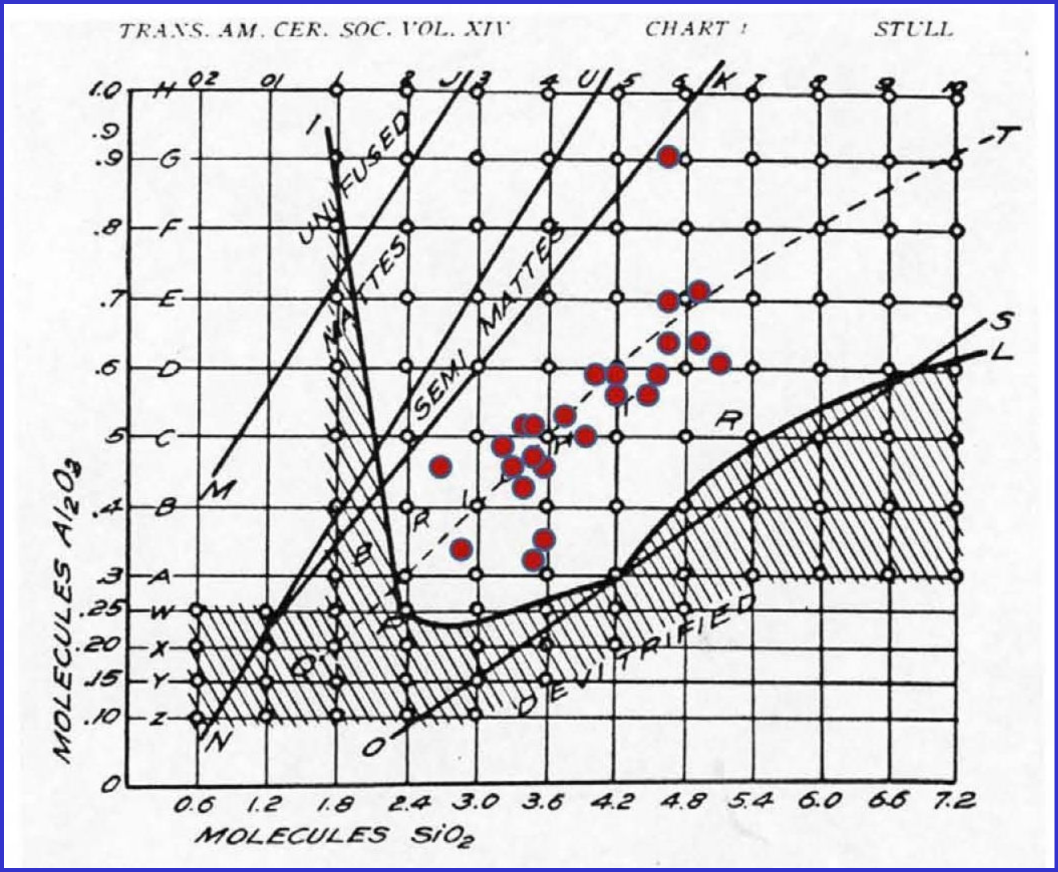
Nigel Wood analyzed ancient Chinese glazes (1999).

UMF format of the analyses is informative.

Most of the glazes fall within glaze limits in use today.

0.3 R_2O: 0.7 RO is the predominant flux ratio.

Glossy glazes fall in Stull's gloss region.



Why? Glaze chemistry determines glaze texture.

Summing Up

Modern Glazes & Ancient Glazes

SIMILAR CHEMISTRY!

It's all about the chemistry!

Now, onto to Mid-range glaze firing and the role of R_2O:RO on durability.