Scanning Electron Microscopy (SEM) Analysis of FTCSG Stoneware

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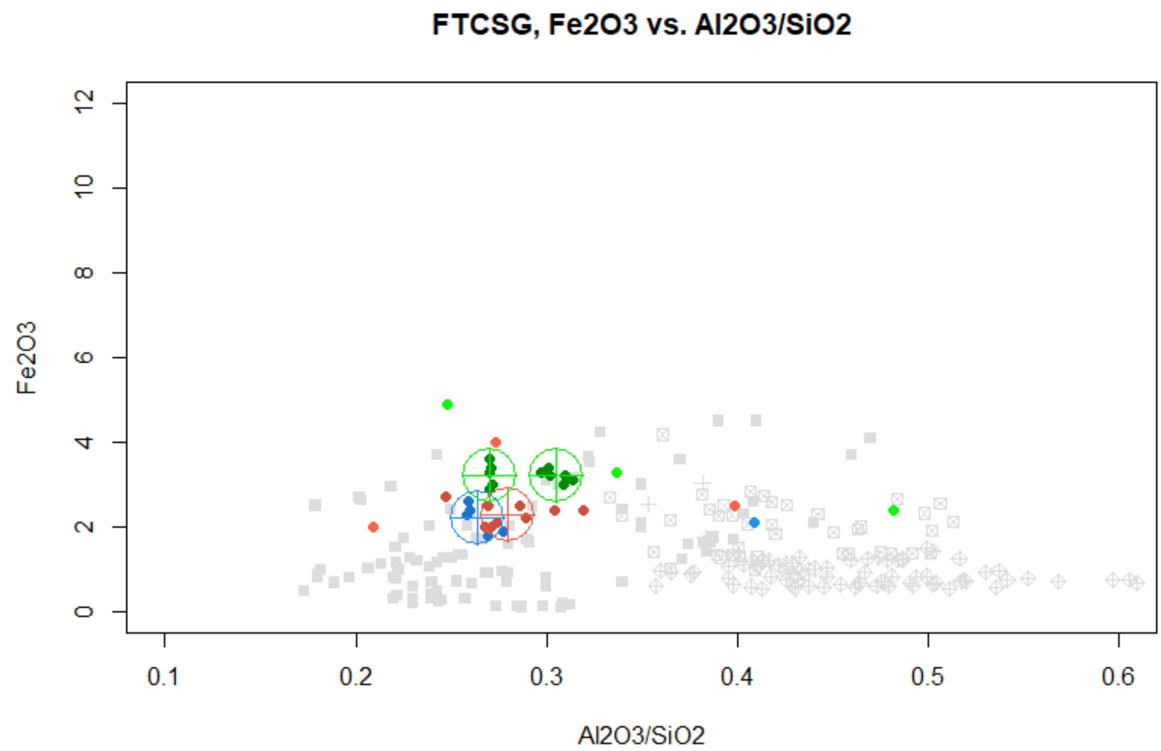
Bodies

Iron oxide (Fe_2O_3) vs. Al_2O_3/SiO_2



	Main body	Outliers	Means
Buff ware	●	●	⊕
Brittle ware	●	●	⊕
Mercury jars	●	●	⊕
Chinese ceramics	■	◇⊠	n/a

Iron oxide (Fe_2O_3) is generally seen as possessing a negative effect on the clay in the kiln during firing, whilst aluminium oxide (Al_2O_3) improves the quality of the clay, especially for stoneware and porcelain.

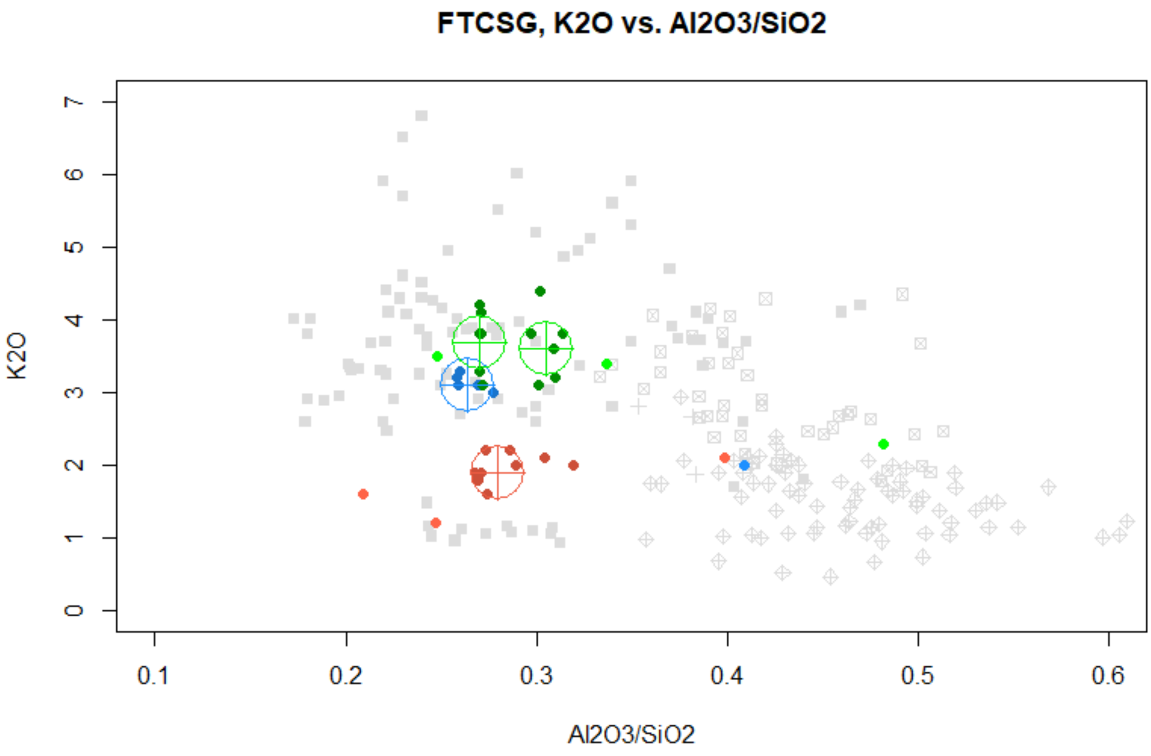
The Al_2O_3/SiO_2 ratio (no units) is representative of the bulk properties of the clay and serves as a useful baseline / x-axis to compare the other minor-proportion characteristic elements.

In terms of the Al_2O_3 content, the FTCSG corpus shows unsurprising values for stoneware similar to known Singapore and Kota Cina samples, nevertheless with notable high-Al_2O_3 outliers in all three categories. Buff wares again display the same broad variability relative to the other categories seen in the other sites, while the brittle wares uniquely converge in a bimodal pattern, with a distinct low- Al_2O_3 and high-Al_2O_3 group which bracket the mean Al_2O_3 among buff wares.

Like the CCT corpus, the FTCSG sherds with regard to Fe_2O_3% vs. Al_2O_3/SiO_2, do not seem to have separate high-iron and low-iron groups in any of its categories. The mercury jars tending to display low Fe_2O_3% values, the brittle ware having the most iron-rich sherds (regardless of Al_2O_3 content), and the buff wares are much closer to mercury jars on average than at CCT.

As with CCT, the Fe_2O_3% vs. Al_2O_3/SiO_2 means are most compatible with Hangzhou and Longquan ware, with some outliers tending towards Longquan Guan ware, with Al_2O_3/SiO_2 ratios and Fe_2O_3 fairly distant from those observed in Jingdezhen. It is very clear that there is practically no commonality with high-Fe_2O_3% Chinese stonewares.

Potassium oxide (K_2O) vs. Al_2O_3/SiO_2



	Main body	Outliers	Means
Buff ware	●	●	⊕
Brittle ware	●	●	⊕
Mercury jars	●	●	⊕
Chinese ceramics	■	◇⊠	n/a

Potassium oxide (K_2O) is generally seen as possessing a positive effect on the clay in the kiln during firing, permitting tolerance to higher temperatures and longer firing durations.

The FTCSG stoneware demonstrates similar patterns to the CCT results, with a similarly large gap between the high-K_2O brittle ware and the low-K_2O buff ware, but this time mercury jars do not group relatively closely to brittle ware, not forming a distinct cluster like at CCT.

The hypothesis that mercury jars can be meaningfully distinguished from the other two main categories and that brittle and buff wares can be distinguished from each other, especially via K_2O%) continues to be vindicated, even if it takes on a different nature to the CCT patterns.

	Mercury jars	**Brittle**	**Buff**
Al_2O_3	Low	**Both**	High
Fe_2O_3	Low	High	Low
K_2O	High	High	Low

The FTCSG values are highly similar to the CCT ones and both samples group closer to Jingdezhen and Hangzhou wares (especially the buff ware) than Longquan porcelains despite their Fe_2O_3% affinity; Longquan ware K_2O% being much higher than anything in the corpus, tending towards 6% as opposed to the ~2-4% values seen here.

This however is insufficient evidence to reject a production sequence more similar to Longquan kilns than the Jingdezhen *chaine operatoire* base on the presence of less K_2O, as adding potassium is less intensive than removing iron during the formation of these stoneware clays. Interestingly, unlike the samples from other sites, the FTCSG buff ware falls entirely outside of the ranges of known kilns due to their very low K_2O%.

Aluminium oxide

Category	Al_2O_3%	Category	Al_2O_3%	Category	Al_2O_3%
Mercury jars	19.5 ± 0.5	**Brittle High**	21.3 ± 0.3	**Buff ware**	20.4 ± 1.1
		Brittle Low	19.3 ± 0.2		
FTC-MER-UA	19.1 ± 0.5	FTC-BRI-GA	20.3 ± 1.2	FTC-BUF-GA	20.9 ± 0.9
		FTC-BRI-03	*17.7*		
FTC-MER-UB	20.1 ± 0.4	FTC-BRI-UB	20.2 ± 1.4	FTC-BUF-GB	21.0 ± 1.3
		FTC-BRI-02	*30.2*		
FTC-MER-UC	*27.2*	FTC-BRI-UC	21.0 ± 0.1	*FTC-BUF-UC*	*16.3*
		FTC-BRI-10	*23.1*		
		FTC-BRI-UD	19.1	FTC-BUF-UD	18.7
				FTC-BUF-UE	20.3
				FTC-BUF-09	*26.4*

				FTC-BUF-UF	20.1
				FTC-BUF-UG	19.6

Fabric Groups

```
> summary(aov(Al ~ Type, data= FTCdataAlTrimmed))
            Df Sum Sq Mean Sq F value   Pr(>F)
Type         3  15.15   5.049   9.286 0.000328 ***
Residuals   23  12.50   0.544
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
> with(FTCdataAlTrimmed, pairwise.t.test(x=Al, g=Type, p.adjust="holm"))

        Pairwise comparisons using t tests with pooled SD

data:  Al and Type

              Brittle-HighAl Brittle-LowAl Buff
Brittle-LowAl 0.00059        -             -
Buff          0.08728        0.02592       -
MercuryJar    0.00260        0.65838       0.08728

P value adjustment method: holm
```

There appears to exist both a high and a low-Al_2O_3 distribution within the brittle wares, with the high group slightly overlapping with the buff ware and the low group with the mercury jars. Even given its division into these groups there are a low outlier (GA-03, 17.7%) and two high outliers (UB-02, 30.2%; UC-10, 23.1%). Other outliers include MER-UC-07 (27.2%) as well as BUF-UE-09 (26.4%).

Iron oxide

Category	Fe_2O_3%	Category	Fe_2O_3%	Category	Fe_2O_3%
Mercury jars	2.2 ± 1.0	**Brittle ware**	3.2 ± 0.2	**Buff ware**	2.3 ± 0.2
FTC-MER-UA	2.4 ± 0.2	FTC-BRI-GA	2.9 ± 0.7	FTC-BUF-GA	2.2 ± 0.2
		FTC-BRI-03	*4.9*		
FTC-MER-UB	1.9 ± 0.1	FTC-BRI-UB	3.4 ± 0.0	FTC-BUF-GB	2.5 ± 0.1
		FTC-BRI-02	*2.4*		
FTC-MER-UC	*2.1*	FTC-BRI-UC	3.3 ± 0.1	FTC-BUF-GC	*2.0*
		FTC-BRI-10	3.3		
		FTC-BRI-UD	*3.6*	FTC-BUF-GD	2.7
				FTC-BUF-UE	2.5
				FTC-BUF-09	

				FTC-BUF-UF	2.0
				FTC-BUF-UG	*4.0*

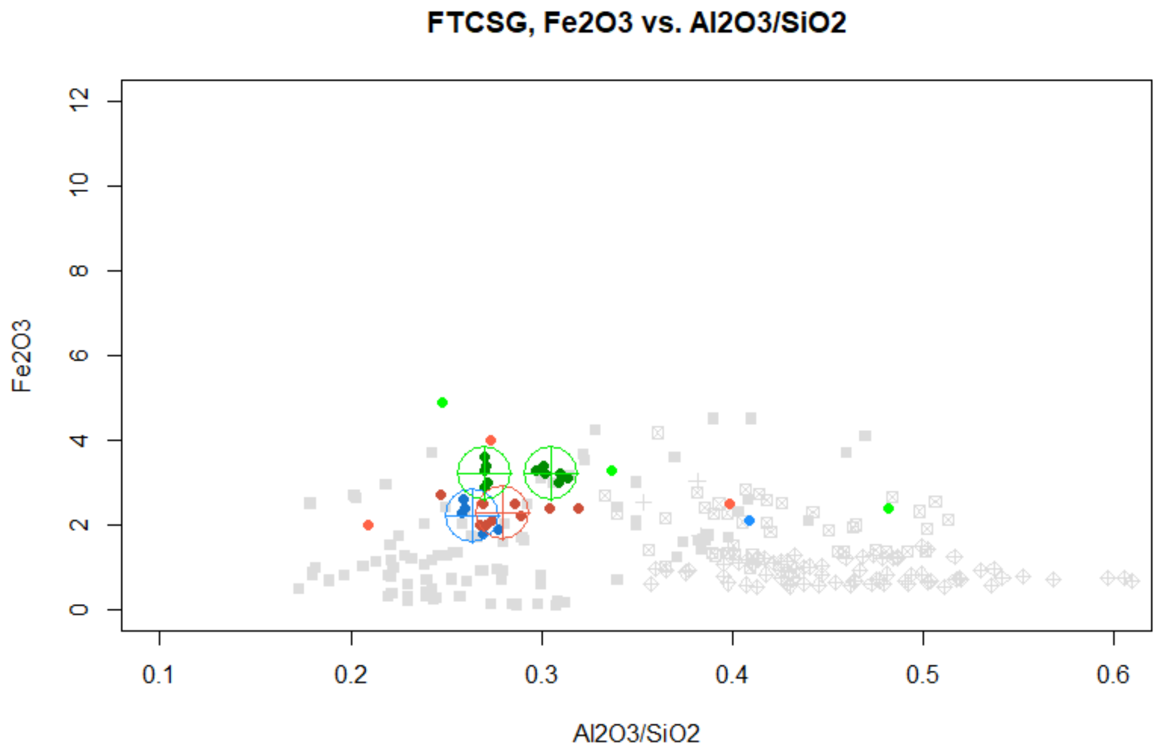
Fabric Groups

```
> summary(aov(Fe ~ Type, data= FTCdataFeTrimmed))
            Df Sum Sq Mean Sq F value   Pr(>F)    
Type         2  6.018  3.0091   48.89 5.21e-09 ***
Residuals   23  1.416  0.0615                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
> with(FTCdataFeTrimmed, pairwise.t.test(x=Fe, g=Type, p.adjust="holm"))

        Pairwise comparisons using t tests with pooled SD 

data:  Fe and Type 

           Brittle Buff
Buff       5.2e-08 -   
MercuryJar 1.3e-07 0.43

P value adjustment method: holm
```

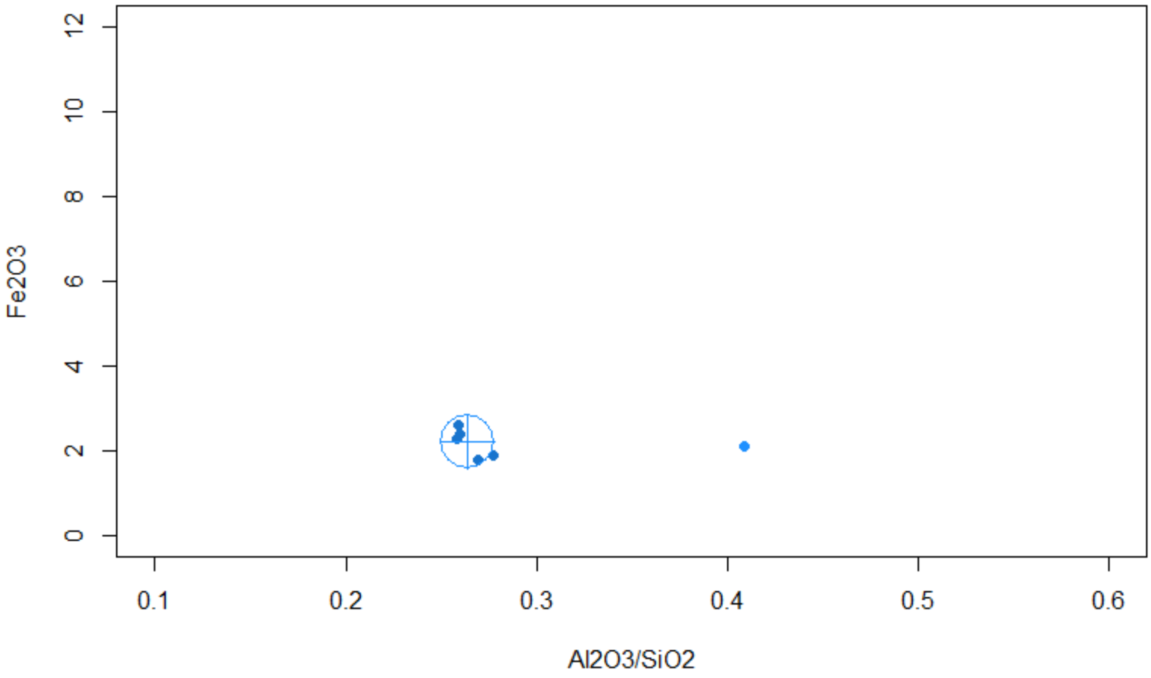
Despite the existence of low-Al_2O_3 and high-Al_2O_3 brittle wares, there is no statistically significant difference between them in terms of Fe_2O_3 (or K_2O) and their values are hence tested as a whole category.

The main pattern seems to be brittle wares being considerably enriched in Fe_2O_3 relative to the other two categories, which are statistically indistinguishable in terms of Fe_2O_3 content.

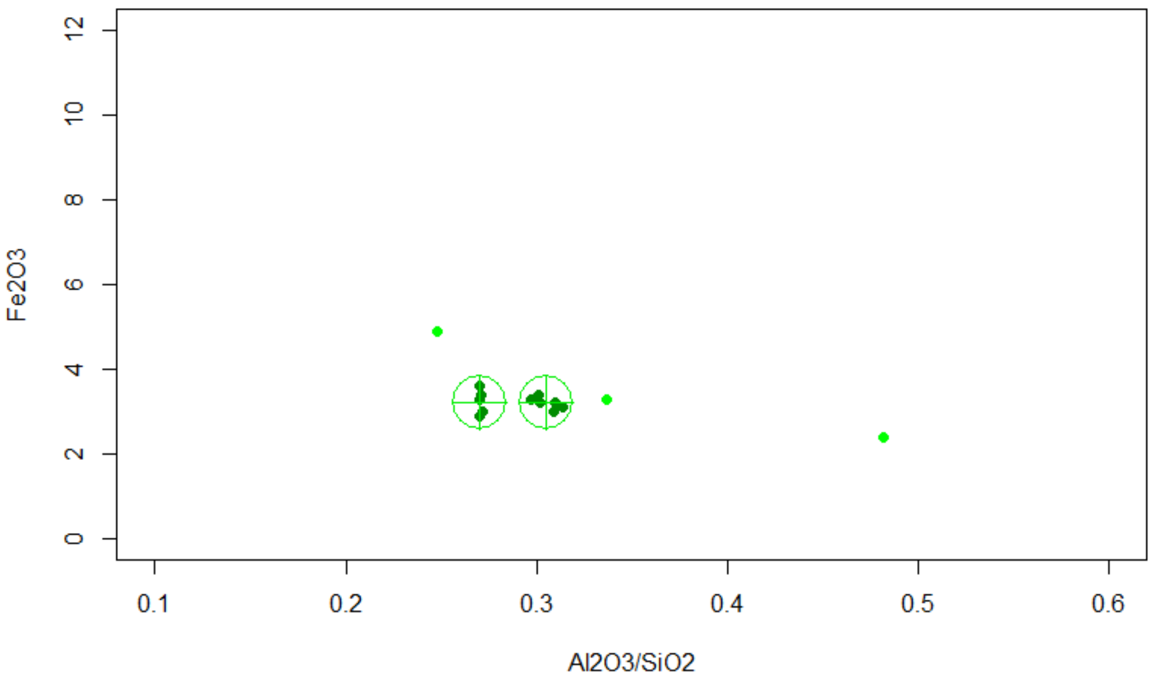


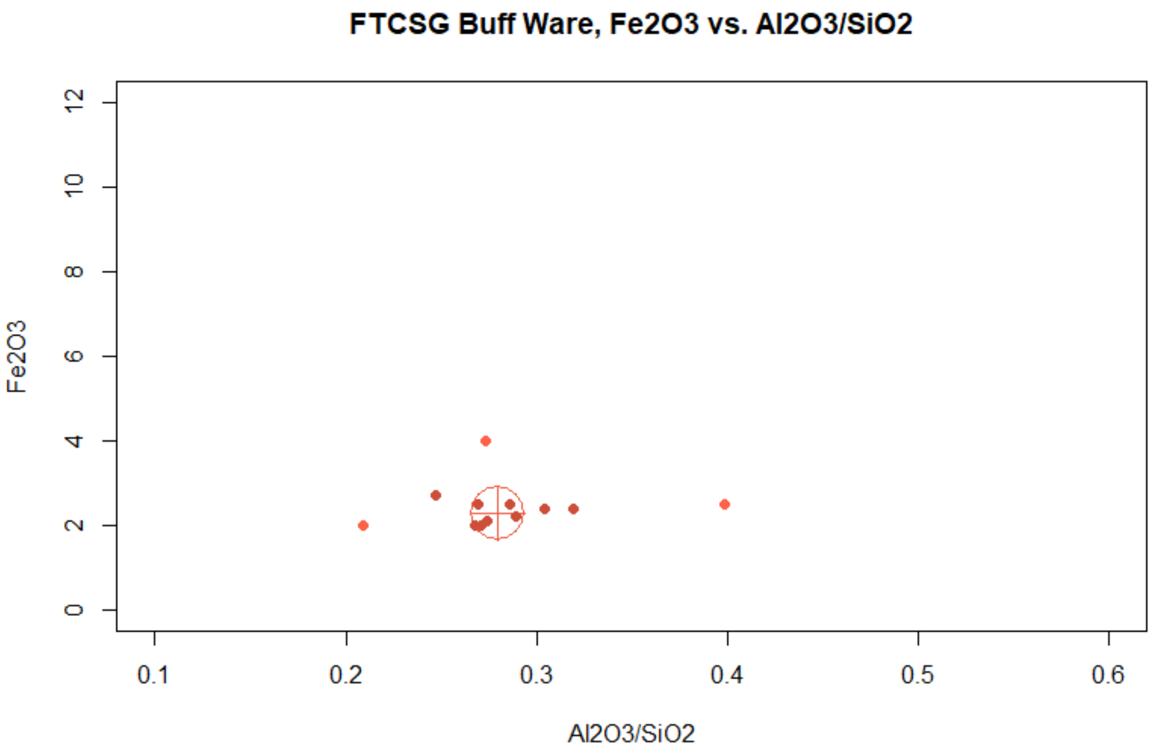
	Main body	Outliers	Means
Buff ware	●	●	⊕
Brittle ware	●	●	⊕
Mercury jars	●	●	⊕
Chinese ceramics	■	◇⊠	n/a

FTCSG Mercury Jars, Fe2O3 vs. Al2O3/SiO2



FTCSG Brittle Ware, Fe2O3 vs. Al2O3/SiO2





Potassium oxide

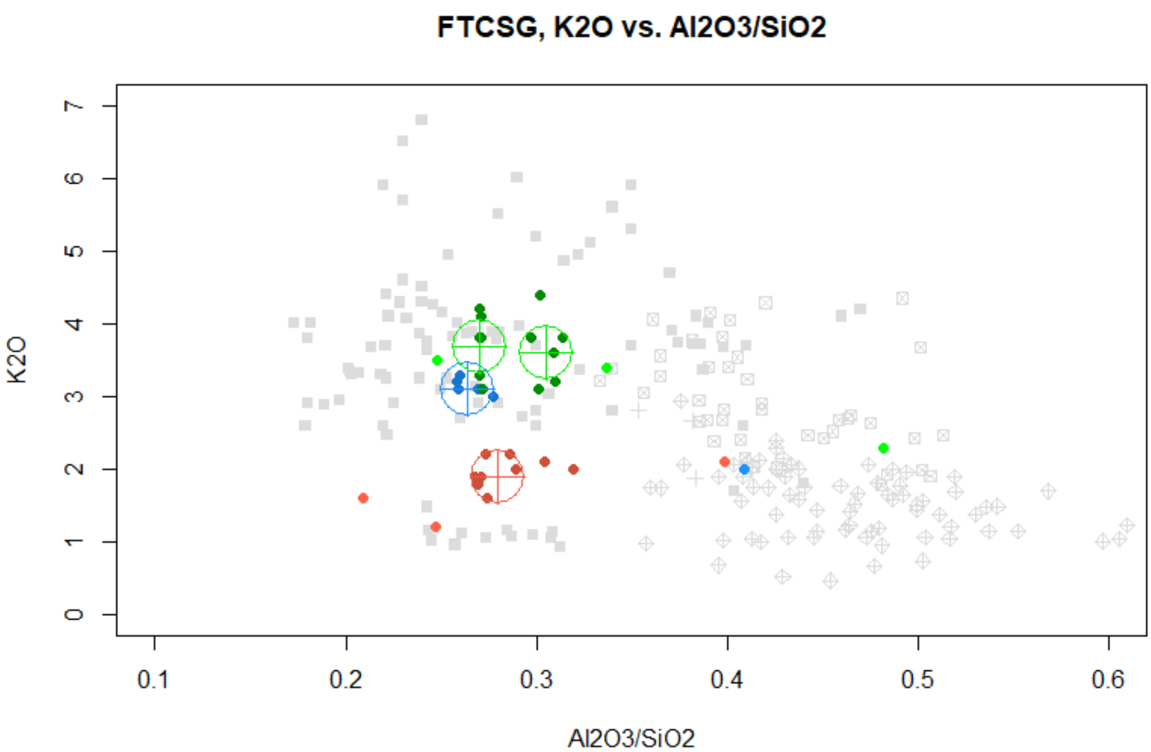
Category	K_2O%	Category	K_2O%	Category	K_2O%
Mercury jars	3.1 ± 0.1	**Brittle ware**	3.7 ± 0.4	**Buff ware**	1.9 ± 0.5
FTC-MER-UA	3.2 ± 0.2	FTC-BRI-GA	3.5 ± 0.7	FTC-BUF-GA	2.2 ± 0.2
		FTC-BRI-03	*3.5*		
FTC-MER-UB	3.1 ± 0.1	FTC-BRI-UB	3.2 ± 0.7	FTC-BUF-GB	2.5 ± 0.1
		FTC-BRI-02	*2.3*		
FTC-MER-UC	*2.0*	FTC-BRI-UC	4.1 ± 0.4	FTC-BUF-GC	1.6
		FTC-BRI-10	*3.4*		
		FTC-BRI-UD	4.2	*FTC-BUF-GD*	*1.2*
				FTC-BUF-UE	1.9 ± 0.3
				FTC-BUF-UF	1.9
				FTC-BUF-UG	*2.2*

Fabric Groups

```
> summary(aov(K ~ Type, data= FTCdataKTrimmed))
            Df Sum Sq Mean Sq F value    Pr(>F)
```

```
Type          2 18.138   9.069   91.56 9.33e-13 ***
Residuals    27  2.674   0.099
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

> with(FTCdataKTrimmed, pairwise.t.test(x=K, g=Type, p.adjust="holm"))

        Pairwise comparisons using t tests with pooled SD

data:  K and Type

           Brittle Buff
Buff       5.3e-13 -
MercuryJar 0.0044  2.9e-07

P value adjustment method: holm
```

There is no statistically significant overlap between the three types—they are all distinct, with buff ware having the least K_2O, brittle ware containing the most, and mercury jars falling in between. All groups have anomalously low-K_2O sherds in them, namely MER-UC (2.0%), BRI-UB-02 (2.3%), and BUF-GD (1.2%).



	Main body	Outliers	Means
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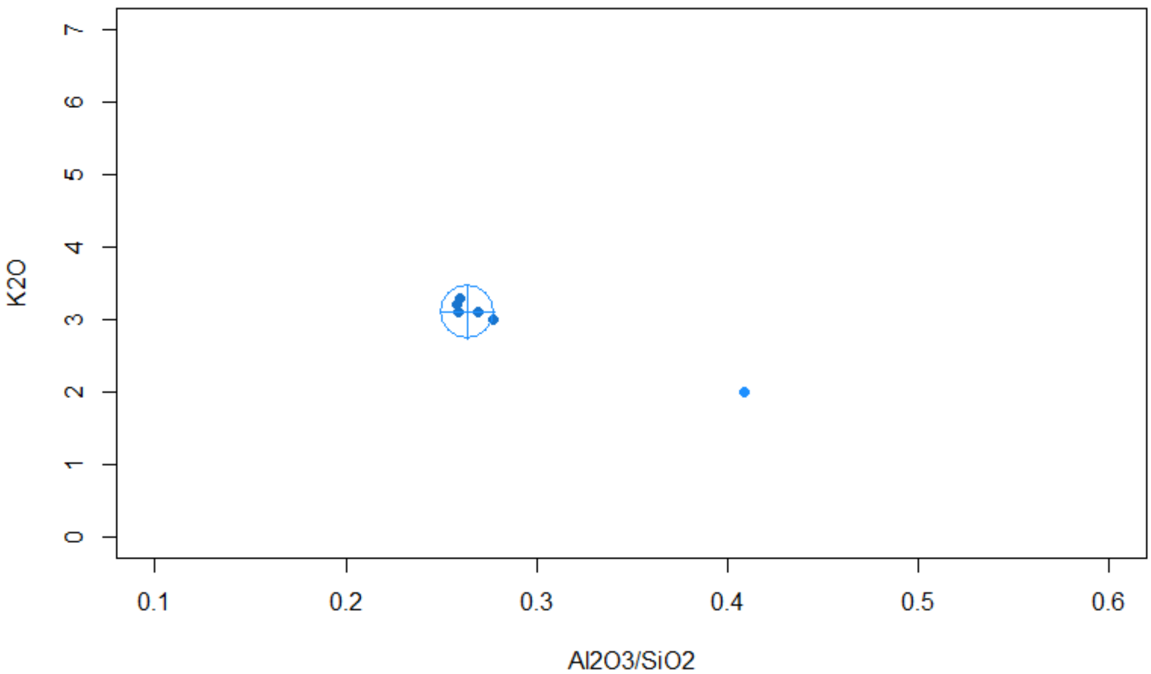
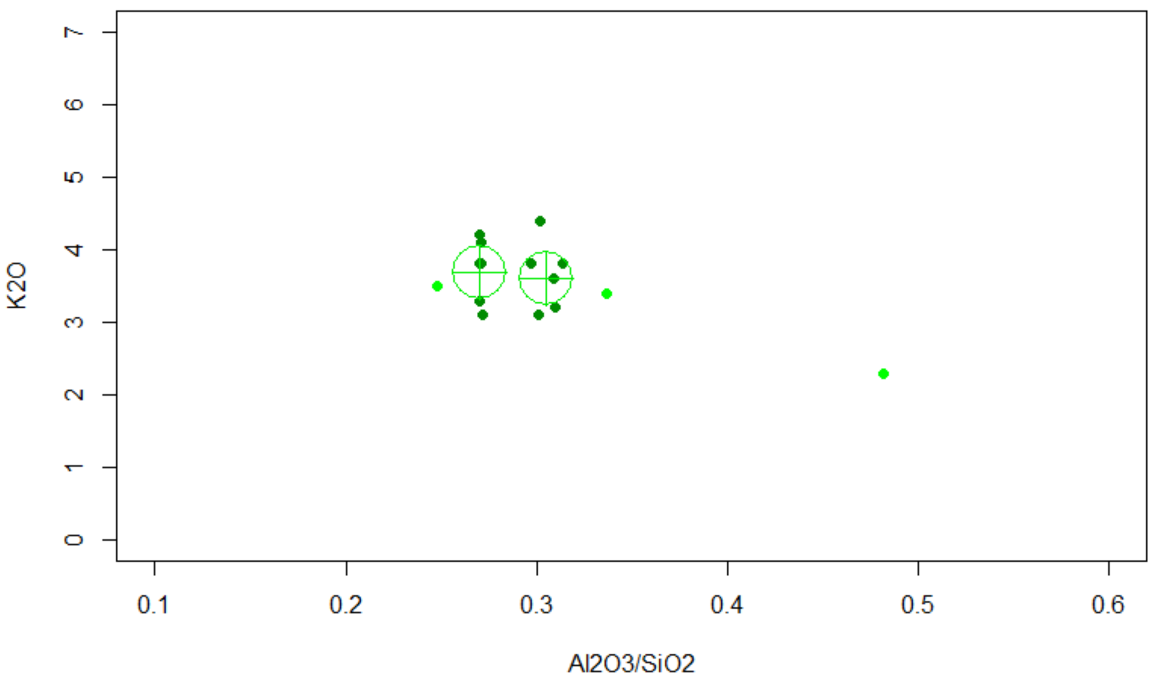
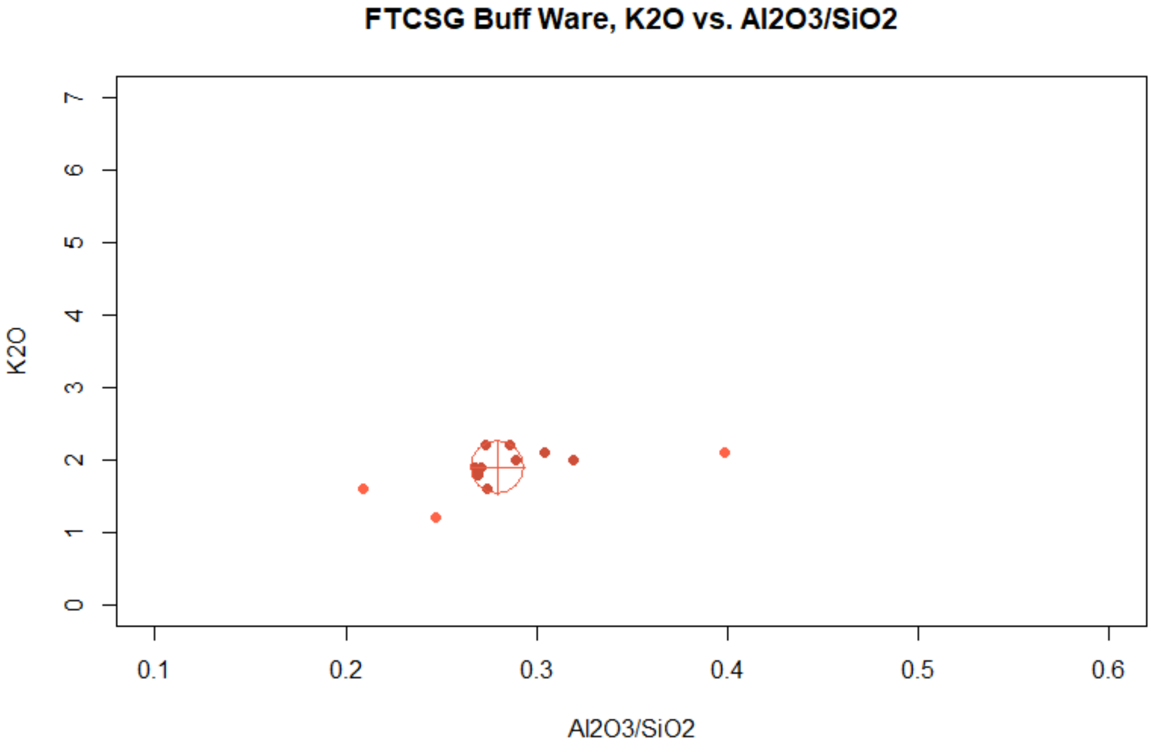
Brittle ware	●	●	⊕
Mercury jars	●	●	⊕
Chinese ceramics	■	◇⊠	n/a

FTCSG Mercury Jars, K2O vs. Al2O3/SiO2



FTCSG Brittle Ware, K2O vs. Al2O3/SiO2




FTCSG Buff Ware, K2O vs. Al2O3/SiO2
K2O
Al2O3/SiO2
0
1
2
3
4
5
6
7
0.1
0.2
0.3
0.4
0.5
0.6