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Supplementary material: The rose of the Sainte-Chapelle in Paris: sophisticated stained glasses for late medieval painters

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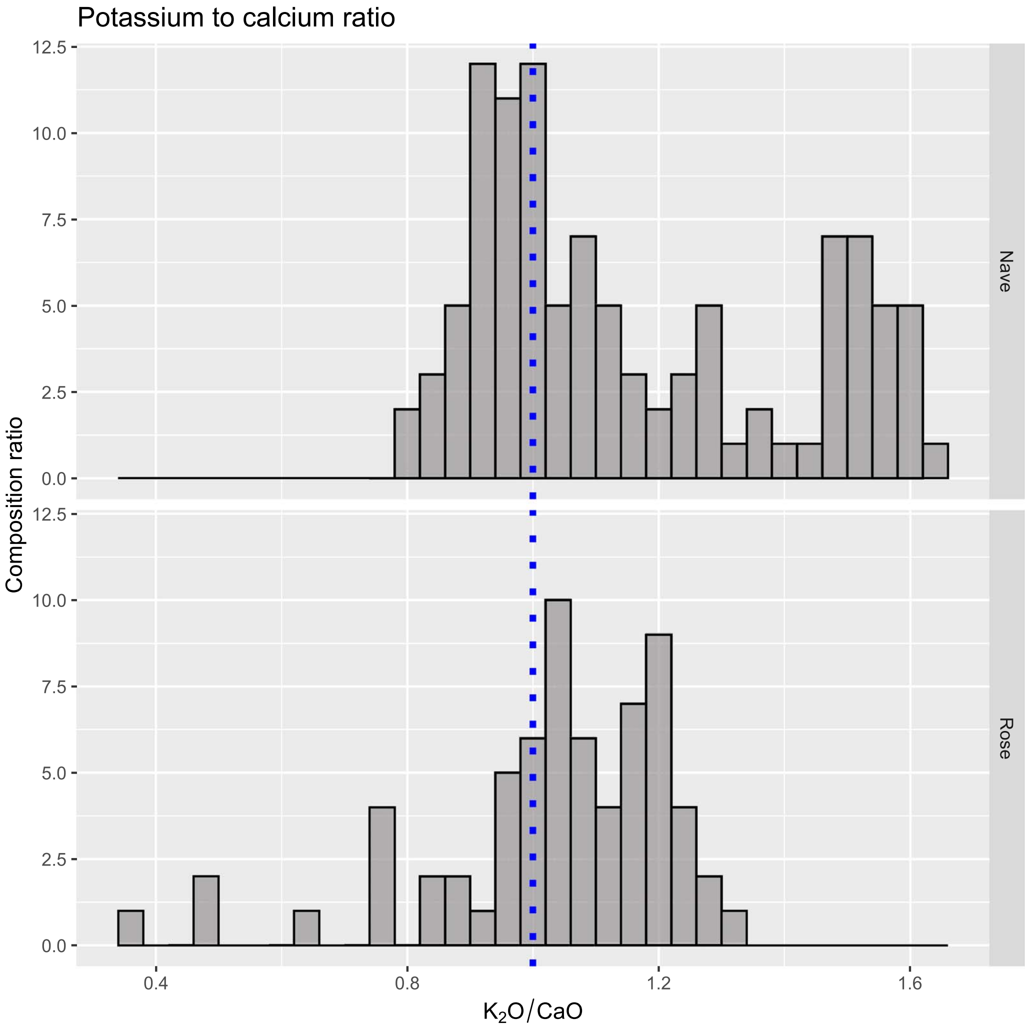
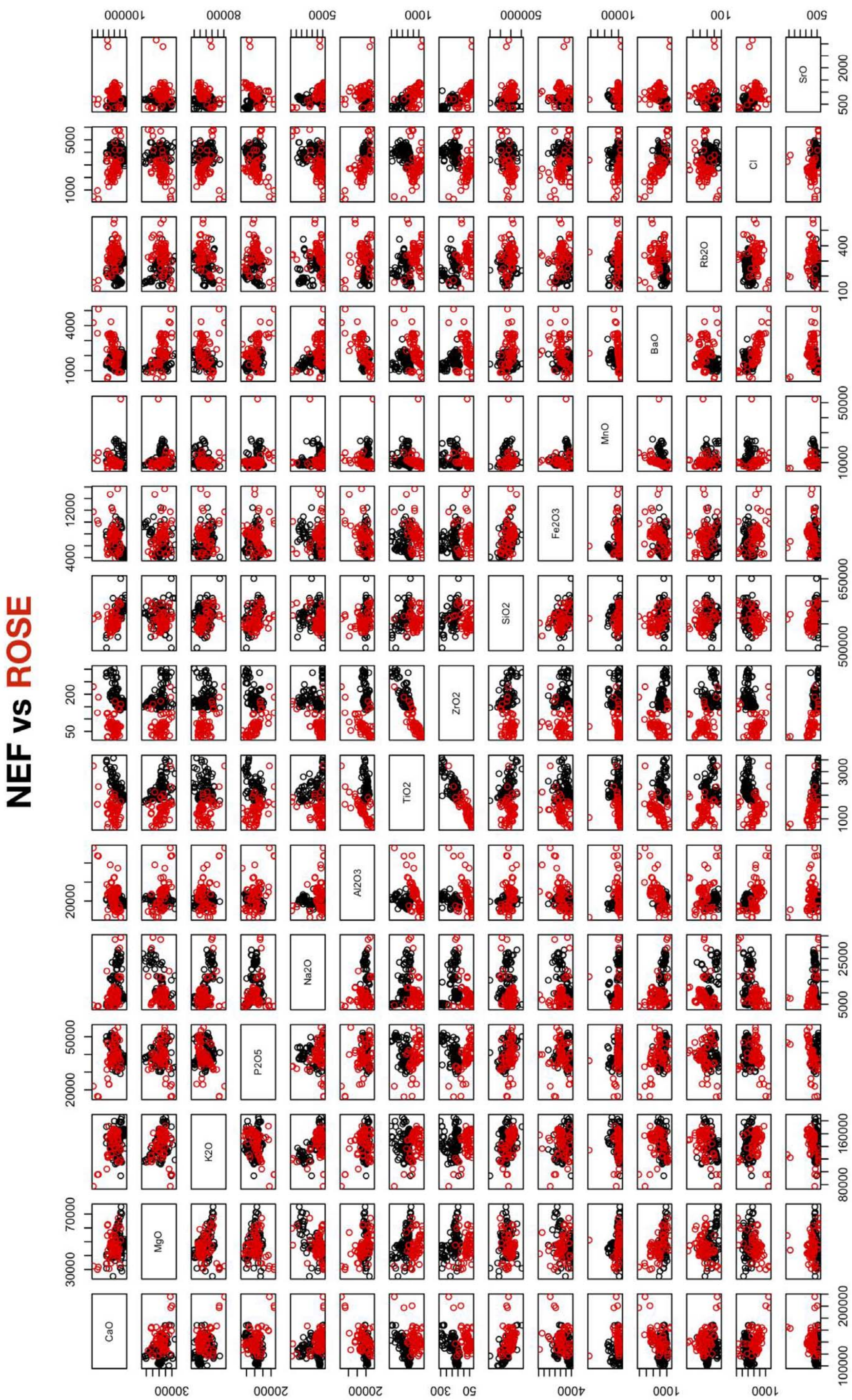
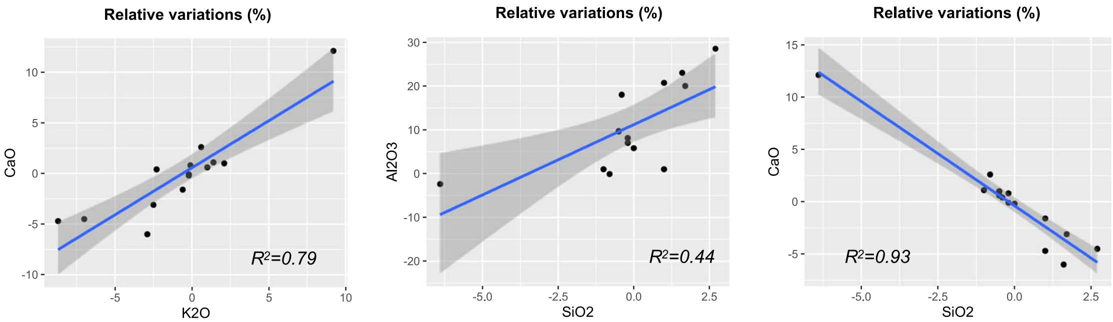


Supplementary Figure S1. Composition ratio between potassium and calcium. We observe that the glasses from the Rose show a different pattern from the glasses from the Nave.



Supplementary Figure S2. Comparison based on bivariate plots between the composition of the nave (black points) and the rose (red points). All data are in ppm. These plots show that the distinction between the glasses of the nave and the rose is found only clearly in their respective Ti and Zr and Cl contents. The graph matrix is symmetric.



Supplementary Figure S3. Correlations between relative variations between interior and exterior side of non-flashed glasses. Linear Regression is indicated with the blue line, the r square-factor is given on each graph and the grey shadow indicates the interval of confidence with level of 0.95.

R Code

```
######## R code to load and make the plots of the paper:
####################################################################
#The Rose of the Sainte-Chapelle in Paris
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#############################################################
#################### HEADER PACKAGES TO LOAD ###########################@
###########statistics###############@
library(corrplot)
library(gridExtra)
library(FactoMineR)
library(PerformanceAnalytics)
######### plotting ###########
library(ggdendro)
library(ggplot2)
library(gridExtra)
library(dendextend)
library(Hmisc)
library(reshape2)
library(dplyr)
library(ggtern)

#################### HEADER PACKAGES TO LOAD ###########################@
### Set your working directory
#setwd(dir="~/XXXXXX")

## load data from NAVE ###
mydata_NEF <- read.table("SI_chemical_compositions_Sainte-Chapelle_Paris_nave.txt", header=TRUE,
 sep="\t", quote ="", dec=".",row.names=1, na.strings = "NA") #na.string = "NULL"
mydata_NEF_sorted <- mydata_NEF[order(mydata_NEF $Na2O) ,]
mydata_NEF_ancient <- mydata_NEF_sorted[c(1:20,22:106),]
mydata_NEF_ancient_num <- mydata_NEF_ancient[,-c(1:6,41)]


## load data from ROSE ###
mydata_glass = read.table("SI_chemical_compositions_Sainte-Chapelle_Paris_rose.txt", header=TRUE,
 sep="\t", quote ="", dec=".",row.names=1, na.strings = "NA") #na.string = "NULL"
mydata_glass_num <- mydata_glass[c(7:40)]


####################################################################################
########Plots from main text ########
####################################################################################
# FIGURE 5 (Ternary diagrams)

ggtern(data = mydata_glass, aes(x =CaO , y = Na2O, z = K2O ))+
 geom_point(color = as.character(mydata_glass$Color))

colors_to_use <- as.character(mydata_glass$Color)
p5 <- ggtern(data = mydata_glass, aes(x =CaO , y = Na2O, z = K2O ))+
 geom_point(color =colors_to_use, shape= mydata_glass $Color_plaquage, labels=mydata_glass $Panel) +
 tern_limits(T=.2,L=0.6,R=0.6)


###NAVE ternary
p <- ggtern(data = mydata_NEF_ancient, aes(x =CaO , y = Na2O, z = K2O )) +
 geom_point(color = "grey", pch = 19) + tern_limits(T=.2,L=0.6,R=0.6) + theme_light()

p <- p + theme_ggtern()
p


# FIGURE 6 a
####################################################################################
my.formula <- y ~ x
p6a <- ggplot(mydata_glass,aes(x= Al2O3, y=TiO2, color="white")) +
```

```
 geom_point(color = 'white', pch=19)+
 geom_smooth(method=lm,se=FALSE, color="black", formula = my.formula) +
#stat_poly_eq(formula = my.formula,  aes(label = paste(..eq.label..,..rr.label.., sep = "~~~")),
 parse = TRUE) +
 geom_point(data = mydata_NEF_ancient, aes(x = Al2O3, y = TiO2), color = 'grey', pch=19) +
      geom_point(data = mydata_glass, aes(x = Al2O3, y = TiO2), color =
 as.character(mydata_glass$Color),pch= as.numeric(mydata_glass$Color_plaquage))

p6a + scale_x_continuous(limits = c(0,52000), expand = c(0,0)) +
  scale_y_continuous(limits = c(0,3800),expand = c(0,0))  +
  labs(x=expression("Al"[2]*"O"[3]* " (ppm)")) +
  labs(y=expression("Ti"[]*"O"[2]* " (ppm)")) + theme_bw()  + theme(aspect.ratio=1)

# FIGURE 6 b
##################################################################################
my.formula <- y ~ x
p6b <- ggplot(mydata_glass,aes(x= ZrO2, y=TiO2, color="white")) +
 geom_point(color = 'white', pch=19)+
 geom_smooth(method=lm,se=FALSE, color="black", formula = my.formula) +
#stat_poly_eq(formula = my.formula,  aes(label = paste(..eq.label..,..rr.label.., sep = "~~~")),
 parse = TRUE) +
 geom_point(data = mydata_NEF_ancient, aes(x = ZrO2, y = TiO2), color = 'grey', pch=19) +
      geom_point(data = mydata_glass, aes(x = ZrO2, y = TiO2), color =
 as.character(mydata_glass$Color),pch= as.numeric(mydata_glass$Color_plaquage))

p6b + scale_x_continuous(limits = c(0,350), expand = c(0,0)) +
  scale_y_continuous(limits = c(0,3800),expand = c(0,0))  +
  labs(x=expression("Zr"[]*"O"[2]* " (ppm)")) +
  labs(y=expression("Ti"[]*"O"[2]* " (ppm)")) + theme_bw()  + theme(aspect.ratio=1)


##################################################
# FIGURE 7
##################################################

majors <- rose_alteration_2[c(5:10,13:15,31,38)]

major_Test <- melt(majors,id.vars='Plaquage',
 measure.vars=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'), variable.name = "element",
 value.name="compo")

Rstd_FE <- data.frame(element=c('Na2O','K2O','CaO','Al2O3','MgO','P2O5','SiO2'), Rstd_FE
 =c(4.6,1.0,1.9,1.8,2.6,2.4,0.9))
Rstd_FI <- data.frame(element=c('Na2O','K2O','CaO','Al2O3','MgO','P2O5','SiO2'),
 Rstd_FI=c(3.3,0.8,1.2,1.7,2.6,1.1,0.5))
Rstd_all <- data.frame(element=c('Na2O','K2O','CaO','Al2O3','MgO','P2O5','SiO2'),
 Rstd_all=c(3.9,0.9,1.5,1.7,2.6,1.8,0.7))


## Nouvel ordre des élements chimiques
Rstd_FE <- data.frame(element=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'), Rstd_FE
 =c(4.6,2.6,1.8,0.9,2.4,1.0,1.9))
Rstd_FI <- data.frame(element=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'),
 Rstd_FI=c(3.3,2.6,1.7,0.5,1.1,0.8,1.2))
Rstd_all <- data.frame(element=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'),
 Rstd_all=c(3.9,2.6,1.7,0.7,1.8,0.9,1.5))

new_data_alteration <- merge(major_Test, Rstd_FE,  by.x = "element", by.y = "element")
new_data_alteration <- merge(new_data_alteration, Rstd_FI,  by.x = "element", by.y = "element")
new_data_alteration <- merge(new_data_alteration, Rstd_all,  by.x = "element", by.y = "element")

p7 <- ggplot(new_data_alteration) +
      geom_boxplot(aes(x=element, y=compo))+  facet_wrap(~element2, scales="free", ncol=2,labeller =
 label_parsed) + labs(title="Effect of alteration",x="", y = "Relative variation (%)") +
 geom_hline(aes(yintercept = Rstd_all,color= 'red')) + geom_hline(aes(yintercept = -Rstd_all,color=
 'red')) +theme(axis.text.x=element_blank())

p7


##################################################
# FIGURE 8
##################################################

rose_diff_FE_FI = read.table("FE_FI_comparaison_RSTDev.txt", header=TRUE, sep="\t", quote ="",
 dec=".",row.names=1, na.strings = "NA") #na.string = "NULL"


rose_diff_FE_FI_Test <- melt(rose_diff_FE_FI,id.vars='Plaquage',
 measure.vars=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'), variable.name = "element",
```

```
 value.name="compo")


workshop_variation <- data.frame(element=c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO'),
 hline=c(14,4,6,1,3,4,7))


new_data <- merge(rose_diff_FE_FI_Test, workshop_variation, by.x = "element", by.y = "element")


element.labs <-
 c(expression("Na"[2]*"O"),expression(paste("MgO")),expression("Al"[2]*"O"[3]),expression("SiO"[2]),
 expression("P"[2]*"O"[5]),expression("K"[2]*"O"),expression("CaO"))
names(element.labs) <- c('Na2O','MgO','Al2O3','SiO2','P2O5','K2O','CaO')

new_data$element2 <- factor(new_data$element, labels =
 c("Na[2]*O","MgO","Al[2]*O[3]","Si*O[2]","P[2]*O[5]","K[2]*O","CaO"))


p8 <- ggplot(new_data) +
      geom_boxplot(aes(x=element, y=compo, color= Plaquage)) +  facet_wrap(~element2, scales="free",
 ncol=2,labeller = label_parsed) +  scale_x_discrete(breaks=NULL) + labs(title="Relative stDev
 between FE and FI",x="",y="Relative stDev (%)",col="Flashed glass") + geom_hline(aes(yintercept =
 hline))
p8


##################################################
# FIGURE 9
##################################################

data <-scale(mydata_glass_num[, c("CaO","MgO","K2O","P2O5","Na2O")]) #SiO2

d_scale <- dist(as.matrix(data))
hc_scale <- hclust(d_scale,method = "ward.D2") # methods : Ward.D2
dend_scale <- as.dendrogram(hc_scale)

dend= dend_scale

colors_to_use <- mydata_glass$Color
labels_to_use <- mydata_glass$Panel
leaves_symbols <- mydata_glass$Color_plaquage

dend %>% set("leaves_pch", 15) %>%  # node point type
  set("leaves_cex", 1) %>%  # node point size
  set("leaves_col", as.character(colors_to_use[order.dendrogram(dend)])) %>% # node point color
  #set("labels_col", c("green", "blue")) %>% # change label color
  set("labels_cex", 0.5) %>% # Change label size
  set("labels", as.character(labels_to_use[order.dendrogram(dend)])) %>% # change label names
  set("leaves_pch", leaves_symbols[order.dendrogram(dend)]) %>%  ## set leaves
  plot(main = "Ca K Na P WARD.D2", xlab = "", ylab = "", sub = "")



#################################################################################
####################### COLOR ANALYSES ###########################
#################################################################################

######################### SPLIT COLORS #####################################################

split_colors <- split(mydata_glass, mydata_glass$Color)

blue_glass <- split_colors$"blue"[,]
colorless_glass <- split_colors$"black"[,]
purple_glass <- split_colors$"hotpink"[,]
green_glass <- split_colors$"green"[,]
yellow_glass <- split_colors$"yellow"[,]
green_glass <- split_colors$"green"[,]
red_glass <- split_colors$"red"[,]
violet_glass <- split_colors$"violet"[,]


df <- split(purple_glass, purple_glass$Face)
new_df <- cbind(df$FI[c("MnO")],df$FE[c("MnO")],df$FI[c("Fe2O3")],df$FE[c("Fe2O3")])
names(new_df)[1] <- "MnO_1"
names(new_df)[2] <- "MnO_2"
names(new_df)[3] <- "Fe2O3_1"
names(new_df)[4] <- "Fe2O3_2"

test_purple <- mutate(purple_glass, paired = rep(1:4,2))
```

```
test_blue <- blue_glass[ order(row.names(blue_glass)), ]
test_blue <- mutate(test_blue, paired = rep(1:7,c(2,2,2,6,2,2,2)))

test_violet <- mutate(violet_glass, paired = rep(1:2,2))


########################## Colorless + Purple GLASSES
 ####################################################
#FIGURE 11a
#########################################
p11a <- ggplot( test_purple) +
     geom_line(aes(x = Fe2O3, y = MnO,group = paired),color="grey", linetype = "dashed")+
     geom_point(data = mydata_glass, aes(x = Fe2O3, y = MnO), color =  "grey" ,pch=
 as.numeric(mydata_glass $Color_plaquage)) +          geom_point(data = colorless_glass, aes(x =
 Fe2O3, y = MnO), color =  "black",pch= as.numeric(colorless_glass $Color_plaquage)) +
     geom_point(data= test_purple ,aes(x = Fe2O3, y = MnO), color =  "hotpink",pch=
 as.numeric(purple_glass $Color_plaquage))+
     geom_point(data = test_violet, aes(x = Fe2O3, y = MnO), color =  "violet",pch=
 as.numeric(test_violet$Color_plaquage) ) +
 geom_line(data = test_violet, aes(x = Fe2O3, y = MnO,group = paired),color="grey", linetype =
 "dashed")

p11a <- p11a + coord_cartesian(xlim = c(0,18000), ylim = c(0,20000))+
 scale_x_continuous( expand = c(0,0)) +
 scale_y_continuous(expand = c(0,0))  +
     labs(x=expression("Fe"[2]*"O"[3]* " (ppm)")) +
     labs(y=expression("Mn"[]*"O"[]* " (ppm)")) + theme(aspect.ratio=1) + theme_bw()
p11a

####################################################
#FIGURE 11b
#########################################

p11b  <- ggplot( test_purple) +
 geom_line(aes(x = BaO, y = MnO,group = paired),color="grey", linetype = "dashed")+
     geom_point(data = mydata_glass, aes(x = BaO, y = MnO), color =  "grey" ,pch=
 as.numeric(mydata_glass $Color_plaquage)) +                  geom_point(data = colorless_glass,
 aes(x = BaO, y = MnO), color =  "black",pch= as.numeric(colorless_glass $Color_plaquage)) +
     geom_point(data = purple_glass, aes(x = BaO, y = MnO), color =  "hotpink",pch=
 as.numeric(purple_glass $Color_plaquage))

p11b <- p11b + coord_cartesian(xlim = c(0,5200), ylim = c(0,20000))+
 scale_x_continuous(expand = c(0,0)) +
     scale_y_continuous(expand = c(0,0))  +
     labs(x=expression("Ba"[]*"O"[]* " (ppm)")) +
     labs(y=expression("Mn"[]*"O"[]* " (ppm)")) + theme(aspect.ratio=1) + theme_bw()
p11b


####################################################
#FIGURE 13
#########################################
# MoO3

p <- ggplot(test_blue) +
 geom_line(aes(x = CoO, y = MoO3,group = paired),color="grey", linetype = "dashed")+
     geom_point(data = mydata_glass, aes(x = CoO, y = MoO3), color =  "grey" ,pch=
 as.numeric(mydata_glass $Color_plaquage)) +              geom_point(data = blue_glass, aes(x =
 CoO, y = MoO3), color =  "blue",pch= as.numeric(blue_glass $Color_plaquage) )+
     geom_point(data = test_violet, aes(x = CoO, y = MoO3), color =  "violet",pch=
 as.numeric(test_violet$Color_plaquage) ) +
 geom_line(data = test_violet, aes(x = CoO, y = MoO3,group = paired),color="grey", linetype =
 "dashed")

p <- p + coord_cartesian(xlim = c(0,4200), ylim = c(0,150))+
 scale_x_continuous(expand = c(0,0)) +
     scale_y_continuous(expand = c(0,0))  +
     labs(x=expression("Co"[]*"O"[]* " (ppm)")) +
     labs(y=expression("Mo"[]*"O"[3]* " (ppm)")) + theme(aspect.ratio=1) + theme_bw()
p
# NiO

p <- ggplot(test_blue) +
 geom_line(aes(x = CoO, y = NiO,group = paired),color="grey", linetype = "dashed")+
     geom_point(data = mydata_glass, aes(x = CoO, y = NiO), color =  "grey" ,pch=
 as.numeric(mydata_glass $Color_plaquage)) +              geom_point(data = blue_glass, aes(x =
 CoO, y = NiO), color =  "blue",pch= as.numeric(blue_glass $Color_plaquage) ) +
     geom_point(data = test_violet, aes(x = CoO, y = NiO), color =  "violet",pch=
 as.numeric(test_violet$Color_plaquage) ) +
```

```
 geom_line(data = test_violet, aes(x = CoO, y = NiO,group = paired),color="grey", linetype =
 "dashed")


p <- p + coord_cartesian(xlim = c(0,4200), ylim = c(0,2200))+
 scale_x_continuous(expand = c(0,0)) +
      scale_y_continuous(expand = c(0,0))  +
  labs(x=expression("Co"[]*"O"[]* " (ppm)")) +
  labs(y=expression("Ni"[]*"O"[]* " (ppm)")) + theme(aspect.ratio=1) + theme_bw()
p

#######################################################
#FIGURE 15b
###########################################
test_green <- mutate(green_glass, paired = rep(1:5,2))

test_red <- red_glass[ order(row.names(red_glass)), ]
test_red <- mutate(test_red, paired = rep(1:5,c(2,2,2,2,1)))

# ZnO

p <- ggplot(test_red) +
 geom_line(aes(x = CuO, y = ZnO,group = paired),color="grey", linetype = "dashed")+
      geom_point(data = mydata_glass, aes(x = CuO, y = ZnO), color =  "grey" ,pch=
 as.numeric(mydata_glass $Color_plaquage)) +              geom_point(data = test_red, aes(x = CuO,
 y = ZnO), color =  "red",pch= as.numeric(test_red $Color_plaquage) ) +
      geom_point(data = test_green, aes(x = CuO, y = ZnO), color =  "green",pch=
 as.numeric(test_green $Color_plaquage) ) +
 geom_line(data= test_green, aes(x = CuO, y = ZnO,group = paired),color="grey", linetype = "dashed")

p <- p + coord_cartesian(xlim = c(0,15400), ylim = c(0,5000))+
 scale_x_continuous(expand = c(0,0)) +
      scale_y_continuous(expand = c(0,0))  +
  labs(x=expression("Cu"[]*"O"[]* " (ppm)")) +
  labs(y=expression("Zn"[]*"O"[]* " (ppm)")) + theme_bw() + theme(aspect.ratio=1)
p


##############################################################################
#######Plots from supporting information ########
#####################################################################################
test <- cbind(mydata_NEF_ancient_num, new_col = "Nave")
test2 <- cbind(mydata_glass_num, new_col = "Rose")
test_merge <- rbind(test, test2)
K_Ca_tot <- test_merge[,c("K2O")]/test_merge[,c("CaO")]
Mg_K_tot <- test_merge[,c("MgO")]/test_merge[,c("K2O")]

test_merge <- cbind(test_merge, K_Ca_tot)
test_merge <- cbind(test_merge, Mg_K_tot)

# FIGURE S1
p1 <- ggplot(test_merge, aes(x= K_Ca_tot)) +
  geom_histogram(color ="black",fill="white", alpha=0.5, position="identity",binwidth=0.04) +
  labs(title="Potassium to calcium ratio",x=expression("K"[2]*"O"/CaO),y="Composition
 ratio",col="")+
  facet_grid(new_col ~ .)+ geom_vline(xintercept = 1,linetype="dotted", color = "blue", size=1.5)
p1


# FIGURE S2
plot(test_merge[
 c("CaO","MgO","K2O","P2O5","Na2O","Al2O3","TiO2","ZrO2","SiO2","Fe2O3","MnO","BaO","Rb2O","Cl","SrO
 ")],col =  test_merge$new_col)


# FIGURE S3
```