

Empirical testing of cryoconite granulation: role of cyanobacteria in the formation of key biogenic structure darkening glaciers in polar regions

This is an R script of Wejnerowski et al. Correspondence: Krzysztof Zawierucha (k.zawierucha@amu.edu.pl)

```
library(visreg)
library(glmmTMB)
library(ggplot2)
library(ggpubr)
```

```
## Registered S3 methods overwritten by 'car':
##   method                      from
##   influence.merMod             lme4
##   cooks.distance.influence.merMod lme4
##   dfbeta.influence.merMod      lme4
##   dfbetas.influence.merMod     lme4
```

```
library(gridExtra)
```

```
df2 <- readxl::read_xlsx("Input/Baza_binom.xlsx")
df2
```

```
## # A tibble: 19 x 9
##   Code Explanenation      Cyano~1      N Subst~2 Total  Mats Granu~3 Which~4
##   <chr> <chr>             <chr>   <dbl> <chr>   <dbl> <dbl>   <dbl>   <dbl>
## 1 SLW  Spitsbergen Lyr, woda Longye~ 1 water  4      1      0      1
## 2 SLQ  Spitsbergen, Lyr, kw~ Longye~ 1 quartz 4      4      0      4
## 3 SLC  Spitsbergen, Lyr, kr~ Longye~ 1 cryoco~ 4      4      0      4
## 4 GCEŁ Grenlandia, kriokoni~ Greenl~ 2 cryoco~ 4      0      4      4
## 5 GWŁE Grenlandia, woda, Łu~ Greenl~ 2 water  4      3      1      4
## 6 GRŁE Grenlandia, skały, Ł~ Greenl~ 2 rocks  4      1      3      4
## 7 GQŁE Grenlandia, kwarc, Ł~ Greenl~ 2 quartz 4      0      4      4
## 8 GCŁE Grenlandia, kriokoni~ Greenl~ 2 cryoco~ 4      0      4      4
## 9 SZW  Szwecja, woda      Sweden  1 water  4      1      3      4
## 10 SZQ Szwecja, kwarc     Sweden  1 quartz 4      1      3      4
## 11 SZC Szwecja, kriokonit Sweden  1 cryoco~ 4      0      4      4
## 12 GWE Grenlandia, woda, Ewa Sweden  1 water  4      0      0      NA
## 13 GRE Grenlandia, skały, E~ Greenl~ 1 rocks  4      0      4      4
## 14 GQE Grenlandia, kwarc, E~ Greenl~ 1 quartz 4      0      4      4
## 15 GCE Grenlandia, kriokoni~ Greenl~ 1 cryoco~ 4      0      4      4
## 16 GWŁ Grenlandia, woda, Łu~ Greenl~ 1 water  4      2      0      2
## 17 GRŁ Grenlandia, skały, Ł~ Greenl~ 1 rocks  4      0      2      2
## 18 GQŁ Grenlandia, kwarc, Ł~ Greenl~ 1 quartz 4      0      4      4
## 19 GCŁ Grenlandia, kriokoni~ Greenl~ 1 cryoco~ 4      0      4      4
## # ... with abbreviated variable names 1: Cyanobacteria, 2: Substratum,
## # 3: Granules, 4: Whichever
```

```
### Substratum -----
# Granules formation model
m1.0 <- glmmTMB(cbind(Granules, Total) ~ 1 + (1|Cyanobacteria), family = binomial,
               data = df2); summary(m1.0)
```

```
## Family: binomial (logit)
## Formula:          cbind(Granules, Total) ~ 1 + (1 | Cyanobacteria)
## Data: df2
##
##      AIC      BIC    logLik deviance df.resid
##      62.9     64.8    -29.5     58.9      17
##
## Random effects:
##
## Conditional model:
## Groups          Name          Variance Std.Dev.
## Cyanobacteria (Intercept) 0.1249  0.3534
## Number of obs: 19, groups: Cyanobacteria, 5
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -0.5287     0.2984  -1.772   0.0765 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
m1.1 <- glmmTMB(cbind(Granules, Total) ~ Substratum, family = binomial,
               data = df2); summary(m1.1)
```

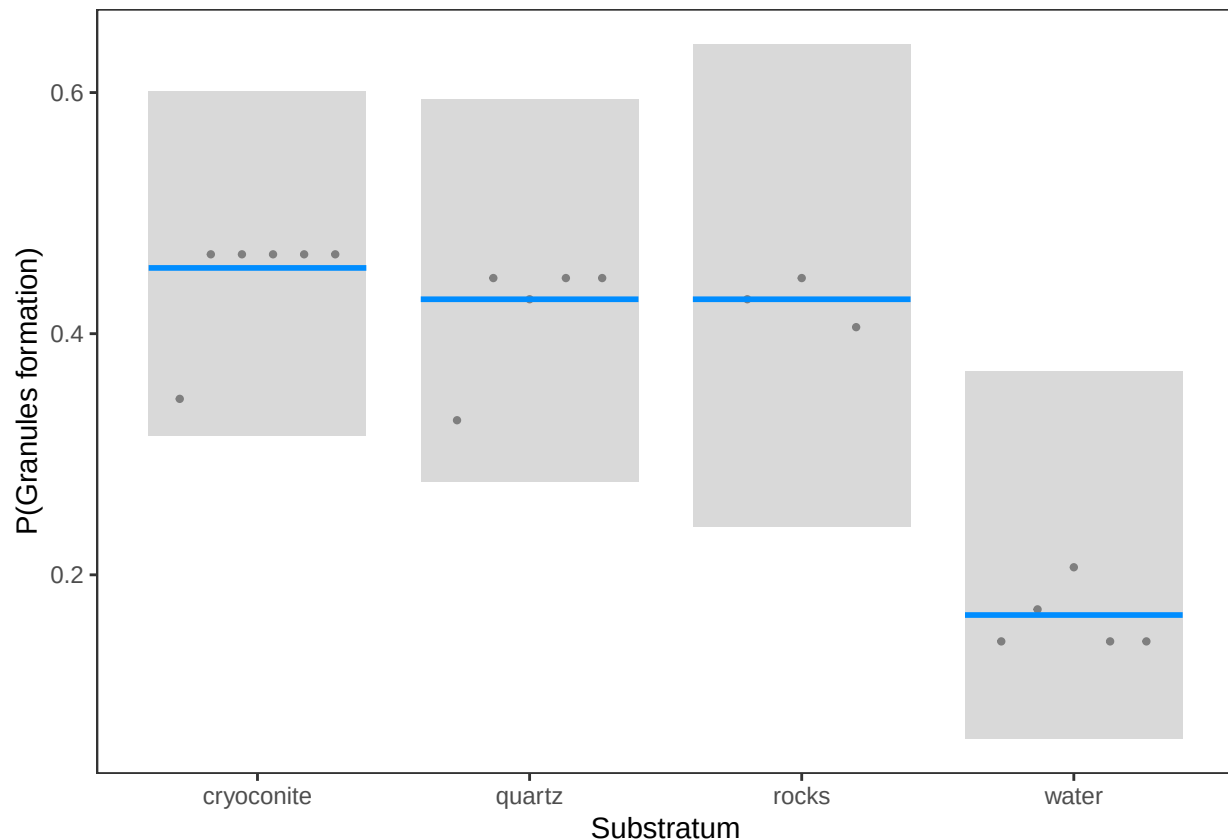
```
## Family: binomial (logit)
## Formula:          cbind(Granules, Total) ~ Substratum
## Data: df2
##
##      AIC      BIC    logLik deviance df.resid
##      60.3     64.1    -26.2     52.3      15
##
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    -0.1823     0.3028  -0.602   0.5470
## Substratumquartz -0.1054     0.4564  -0.231   0.8174
## Substratumrocks  -0.1054     0.5349  -0.197   0.8438
## Substratumwater  -1.4271     0.6258  -2.280   0.0226 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(m1.0, m1.1, type = "Chisq")
```

```
## Data: df2
## Models:
## m1.0: cbind(Granules, Total) ~ 1 + (1 | Cyanobacteria), zi=~0, disp=~1
## m1.1: cbind(Granules, Total) ~ Substratum, zi=~0, disp=~1
##      Df      AIC      BIC logLik deviance Chisq Chi Df Pr(>Chisq)
```

```
## m1.0  2 62.908 64.797 -29.454  58.908
## m1.1  4 60.305 64.083 -26.153  52.305 6.6028      2    0.03683 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
V1 <- visreg(m1.1, scale = "response", ylab = "P(Granules formation)", gg = TRUE,
             rug = FALSE, partial = TRUE)
V1.OUT <- V1 + theme_test(); V1.OUT
```



```
# Mats formation model
m2.0 <- glmmTMB(cbind(Mats, Total) ~ 1 + (1|Cyanobacteria), family = binomial,
               data = df2)
m2.1 <- glmmTMB(cbind(Mats, Total) ~ Substratum + (1|Cyanobacteria), family = binomial,
               data = df2); summary(m2.1)
```

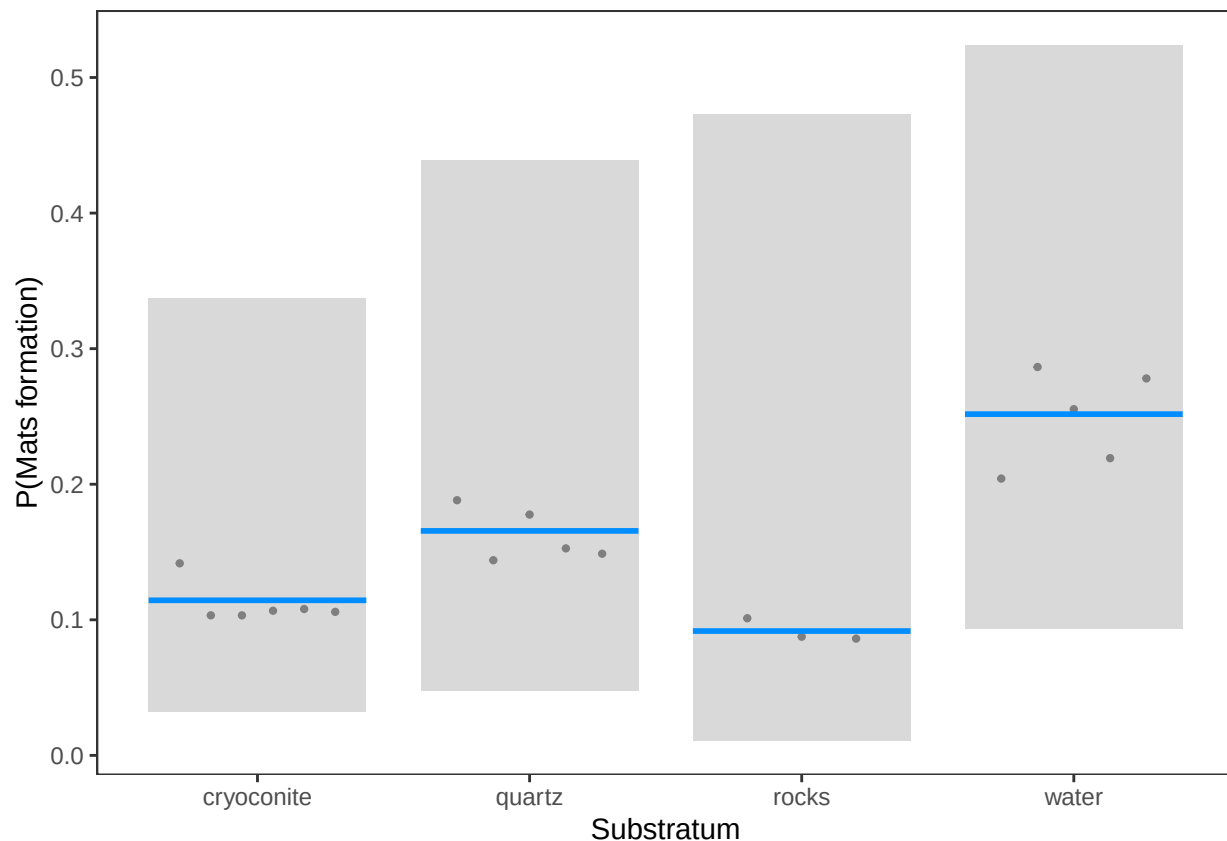
```
## Family: binomial ( logit )
## Formula: cbind(Mats, Total) ~ Substratum + (1 | Cyanobacteria)
## Data: df2
##
##      AIC      BIC   logLik deviance df.resid
##    50.9    55.6    -20.5    40.9      14
##
## Random effects:
##
## Conditional model:
```

```
## Groups      Name      Variance Std.Dev.
## Cyanobacteria (Intercept) 0.5896  0.7678
## Number of obs: 19, groups: Cyanobacteria, 5
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept)    -2.1659     0.7246  -2.989  0.0028 **
## Substratumquartz    0.4295     0.7704   0.557  0.5772
## Substratumrocks   -0.2459     1.2464  -0.197  0.8436
## Substratumwater    0.9573     0.7494   1.278  0.2014
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(m2.0, m2.1, type = "Chisq")
```

```
## Data: df2
## Models:
## m2.0: cbind(Mats, Total) ~ 1 + (1 | Cyanobacteria), zi=~0, disp=~1
## m2.1: cbind(Mats, Total) ~ Substratum + (1 | Cyanobacteria), zi=~0, disp=~1
##      Df      AIC      BIC logLik deviance Chisq Chi Df Pr(>Chisq)
## m2.0  2 47.149 49.038 -21.574  43.149
## m2.1  5 50.902 55.624 -20.451  40.902 2.2469    3    0.5228
```

```
V2 <- visreg(m2.1, scale = "response", ylab = "P(Mats formation)", gg = TRUE,
             rug = FALSE, partial = TRUE)
V2.OUT <- V2 + theme_test(); V2.OUT
```



```

### Number of strains -----
df2$N <- as.factor(df2$N)

# Granules formation model
m3.0 <- glmmTMB(cbind(Granules, Total) ~ 1 + (1|Substratum), family = binomial,
               data = df2)
m3.1 <- glmmTMB(cbind(Granules, Total) ~ N + (1|Substratum), family = binomial,
               data = df2); summary(m3.1)

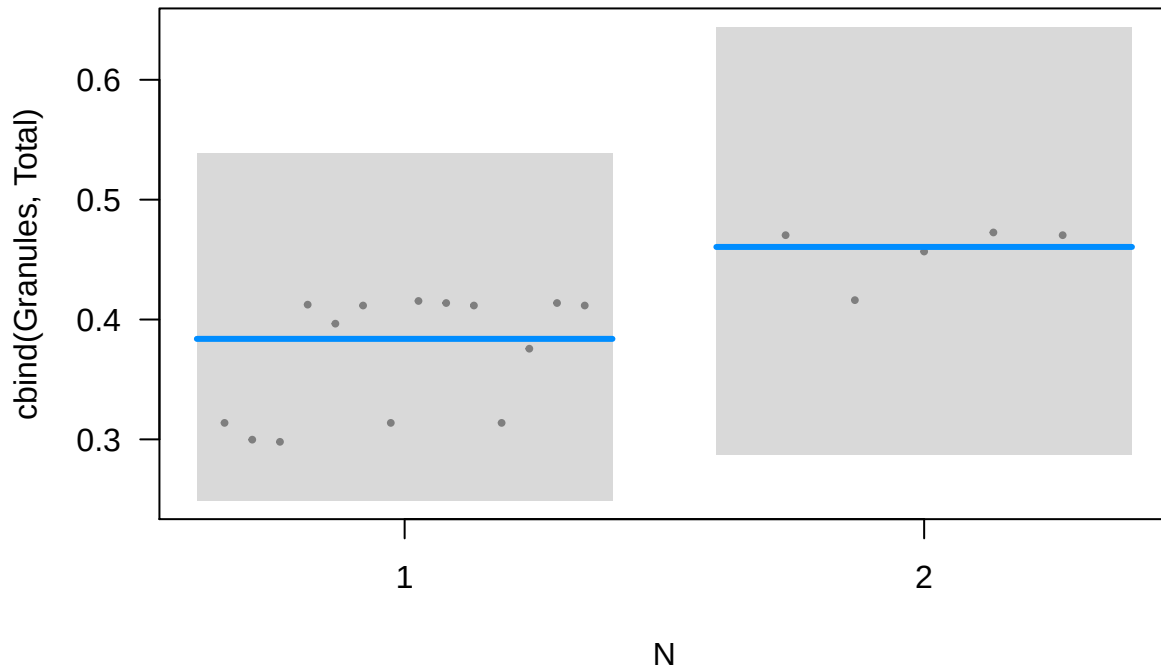
## Family: binomial ( logit )
## Formula:          cbind(Granules, Total) ~ N + (1 | Substratum)
## Data: df2
##
##      AIC      BIC   logLik deviance df.resid
##    64.2    67.0   -29.1    58.2      16
##
## Random effects:
##
## Conditional model:
##   Groups      Name      Variance Std.Dev.
## Substratum (Intercept) 0.0582   0.2412
## Number of obs: 19, groups: Substratum, 4
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -0.5827    0.2608  -2.234   0.0255 *
## N2            0.3151    0.4082   0.772   0.4402
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

anova(m3.0, m3.1, type = "Chisq")

## Data: df2
## Models:
## m3.0: cbind(Granules, Total) ~ 1 + (1 | Substratum), zi=~0, disp=~1
## m3.1: cbind(Granules, Total) ~ N + (1 | Substratum), zi=~0, disp=~1
##      Df      AIC      BIC logLik deviance Chisq Chi Df Pr(>Chisq)
## m3.0  2 62.800 64.689 -29.400  58.800
## m3.1  3 64.209 67.042 -29.105  58.209 0.5913    1    0.4419

visreg(m3.1, scale = "response", rug = FALSE, partial = TRUE)

```



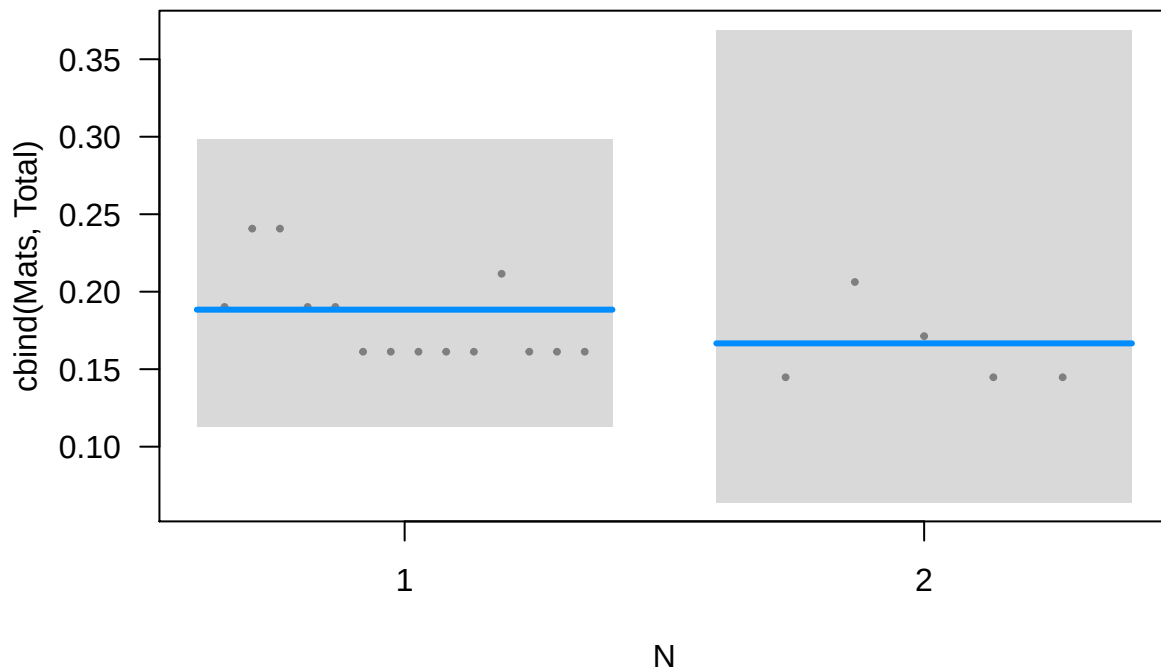
```
# Mats formation model
m4.0 <- glmmTMB(cbind(Mats, Total) ~ 1 + (1|Substratum), family = binomial,
  data = df2)
m4.1 <- glmmTMB(cbind(Mats, Total) ~ N + (1|Substratum), family = binomial,
  data = df2); summary(m4.1)
```

```
## Family: binomial ( logit )
## Formula:          cbind(Mats, Total) ~ N + (1 | Substratum)
## Data: df2
##
##      AIC      BIC   logLik deviance df.resid
##    52.0    54.8   -23.0    46.0      16
##
## Random effects:
##
## Conditional model:
##   Groups      Name      Variance Std.Dev.
## Substratum (Intercept) 9.449e-10 3.074e-05
## Number of obs: 19, groups: Substratum, 4
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -1.4604    0.3079  -4.744  2.1e-06 ***
## N2            -0.1490    0.6283  -0.237   0.813
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(m4.0, m4.1, type = "Chisq")
```

```
## Data: df2
## Models:
## m4.0: cbind(Mats, Total) ~ 1 + (1 | Substratum), zi=~0, disp=~1
## m4.1: cbind(Mats, Total) ~ N + (1 | Substratum), zi=~0, disp=~1
##      Df      AIC      BIC logLik deviance Chisq Chi Df Pr(>Chisq)
## m4.0  2 50.067 51.955 -23.033  46.067
## m4.1  3 52.009 54.843 -23.005  46.009 0.0572    1    0.8109
```

```
visreg(m4.1, scale = "response", rug = FALSE, partial = TRUE)
```



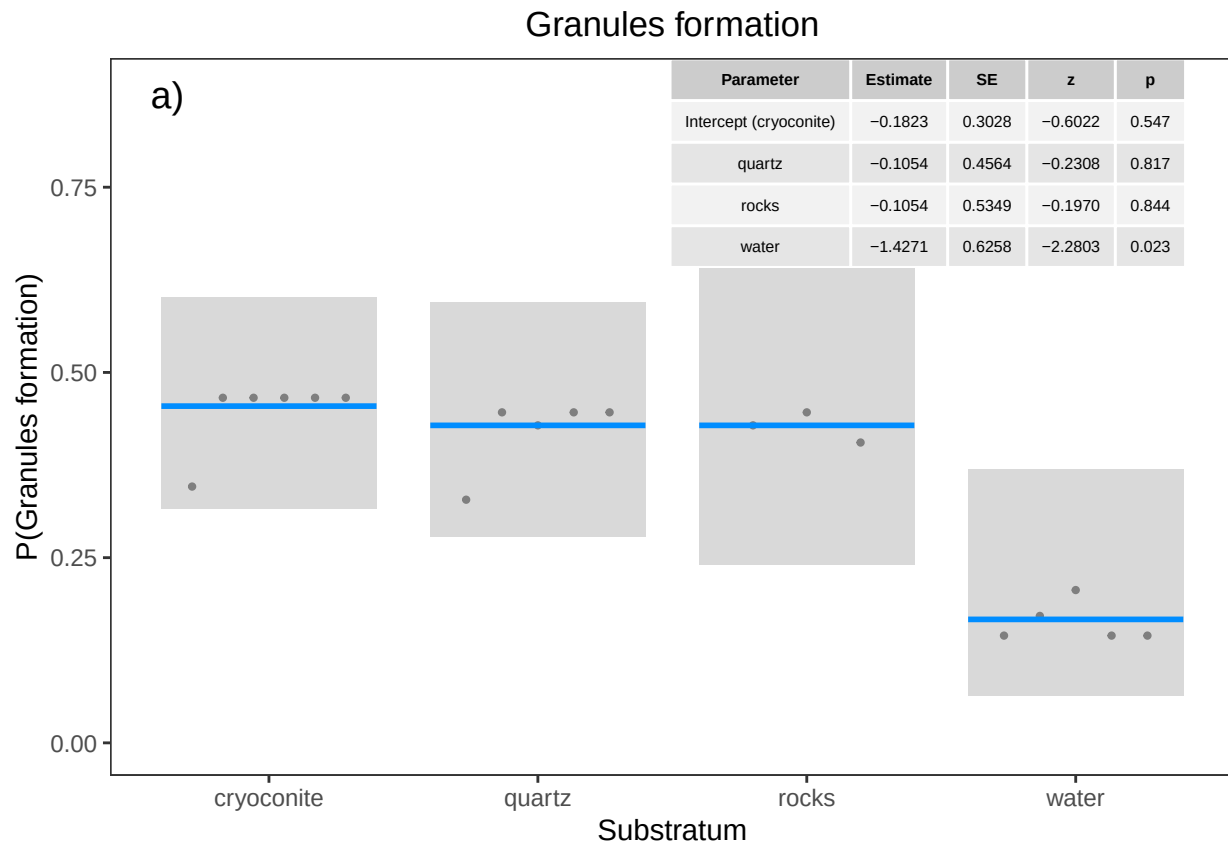
```
### Visualisation -----
## Table added to the graphs
g_t <- data.frame(summary(m1.1)$coefficients$cond)
tab_gran <- data.frame(Parameter = c("Intercept (cryoconite)", "quartz", "rocks", "water"),
                        Estimate = round(g_t[,1],4),
                        SE = round(g_t[,2],4),
                        z = round(g_t[,3],4),
                        p = round(g_t[,4],3))
m_t <- data.frame(summary(m2.1)$coefficients$cond)
tab_mats <- data.frame(Parameter = c("Intercept (cryoconite)", "quartz", "rocks", "water"),
                        Estimate = round(m_t[,1],4),
                        SE = round(m_t[,2],4),
```

```

z = round(m_t[,3],4),
p = round(m_t[,4],3))

## Graphs
V1 <- visreg(m1.1, scale = "response", ylab = "P(Granules formation)", gg = TRUE,
  rug = FALSE, partial = TRUE)
V1.OUT <- V1 + theme_test() + ggtitle("Granules formation") + ylim(0, 0.88) +
  theme(plot.title = element_text(hjust = 0.5)) +
  annotation_custom(tableGrob(tab_gran, rows = NULL,
    theme = ttheme_default(base_size = 6)),
    xmin = 0.55, xmax = 0.95, ymin = 0.7, ymax = 0.865) +
  annotate("text", x = 0.006, y = 0.875, label = "a)", size = 5); V1.OUT

```



```

V2 <- visreg(m2.1, scale = "response", ylab = "P(Mats formation)", gg = TRUE,
  rug = FALSE, partial = TRUE)
V2.OUT <- V2 + theme_test() + ggtitle("Mats formation") + ylim(0, 0.88) +
  theme(plot.title = element_text(hjust = 0.5)) +
  annotation_custom(tableGrob(tab_mats, rows = NULL,
    theme = ttheme_default(base_size = 6)),
    xmin = 0.55, xmax = 0.95, ymin = 0.7, ymax = 0.865) +
  annotate("text", x = 0.006, y = 0.87, label = "b)", size = 5); V2.OUT

```

Mats formation

