SOM4 - Reading and ploting Confocal data

Paixao, Gossa, Marreiros, Gneisinger, Hovers. 2025. Decoding Traces of Acheulean Percussive Technolog

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Brief description of the script

This R markdown document reads, summarizes and plots data for: *Paixao et al. 2025. Decoding Traces of Acheulean Percussive Technology: Experimental Approach to understanding Use-Wear Traces in different raw materials. Submitted to JPA*

The document contains plots of the quantitative surface texture analysis, using Confocal microcopy.

This R project and respective scripts follow the procedures described by Marwick et al. 2017.

The authors would like to thank Ivan Calandra and Lisa Schunk for their help and contribution on several chunks of code included here in the script (pieces of code are also adapated from Calandra et al. 2019, Pedergnana et al. 2020a, 2020b).

To compile this markdown document do not delete or move files from their original folders. Please note that most of the tables and figures in this file do not match the numbering in the paper..

For any questions, comments and inputs, please contact:

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Load data into R project

Imported files are in: '../analysis/raw_data'

Figures are saved in: '../analysis/plots'

Tables are saved in: '../analysis/derived_data'

```
# Load required libraries

library(tidyverse)
```

```
## Warning: package 'tibble' was built under R version 4.3.3

## Warning: package 'tidyr' was built under R version 4.3.1

## Warning: package 'dplyr' was built under R version 4.3.1

## Warning: package 'lubridate' was built under R version 4.3.3
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.6
## v forcats   1.0.1     v stringr   1.6.0
## v ggplot2   4.0.1     v tibble    3.3.0
## v lubridate 1.9.4     v tidyr     1.3.1
## v purrr     1.2.0
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(utils)
library(knitr)
```

```
## Warning: package 'knitr' was built under R version 4.3.3
```

```
library(janitor)
```

```
## Warning: package 'janitor' was built under R version 4.3.3
```

```
##
## Attaching package: 'janitor'
##
## The following objects are masked from 'package:stats':
##
##     chisq.test, fisher.test
```

```
library(kableExtra)
```

```
## Warning: package 'kableExtra' was built under R version 4.3.1
```

```
##
## Attaching package: 'kableExtra'
##
## The following object is masked from 'package:dplyr':
##
##     group_rows
```

```
library(GGally)
library(doBy)
```

```
## Warning: package 'doBy' was built under R version 4.3.3
```

```
##
## Attaching package: 'doBy'
##
## The following object is masked from 'package:dplyr':
##
##     order_by
```

```r
library(ggpubr)
library(tools)
library(ggthemes)
```

```
## Warning: package 'ggthemes' was built under R version 4.3.1
```

```r
library(FactoMineR)
```

```
## Warning: package 'FactoMineR' was built under R version 4.3.1
```

```r
library(factoextra)
```

```
## Welcome! Want to learn more? See two factoextra-related books at https://goo.gl/ve3WBa
```

```r
# See your WD and update the following paths
# getwd()

# Load data from .csv
confocaldata <- read.delim("analysis/data/raw_data/surftext_db.csv", header = T, ";")

data_file <- list.files("analysis/data/raw_data/surftext_db", pattern = "\\.csv$", full.names = TRUE)
md5_in <- md5sum(data_file)
info_in <- data.frame(file = basename(names(md5_in)), checksum = md5_in, row.names = NULL)
```

Confocal micro surface texture data

Import and summarize data

```
# compute descriptive statistics

nminmaxmeanmedsd <- function(x){
    y <- x[!is.na(x)]
    n_test <- length(y)
    min_test <- min(y)
    max_test <- max(y)
    mean_test <- mean(y)
    med_test <- median(y)
    sd_test <- sd(y)
    out <- c(n_test, min_test, max_test, mean_test, med_test, sd_test)
    names(out) <- c("n", "min", "max", "mean", "median", "sd")
    return(out)
}

num.var <- 23:ncol(confocaldata)


confostats <- summaryBy(.~Sample + Worked_material + Raw_material, data=confocaldata[c("Sample", "Worke

write_csv(confostats, "analysis/data/derived_data/confocalstats_arch.csv")

head(confostats, 10)
```

```
##     Sample Worked_material Raw_material Sq.n    Sq.min    Sq.max   Sq.mean
## 1   DWG1S3            bone       Basalt    9  5.063730 10.650124  8.228798
## 2   DWG1S3          no_use       Basalt    3  7.892292 11.631849  9.528152
## 3   DWG3S1            bone       Scoria    9 10.268990 83.562071 27.477733
## 4   DWG3S1          no_use       Scoria    3 14.756695 30.180572 21.990032
## 5   KWG1S1            bone   Glassy_ign    9  4.917584 14.705605  9.591037
## 6   KWG1S1          no_use   Glassy_ign    3  6.177752 12.641063 10.287329
## 7  KWG1S3_            bone   Glassy_ign    8  3.766167  9.883735  7.076967
## 8  KWG1S3_          no_use   Glassy_ign    3  3.577717  6.211463  5.090712
## 9  MW6G2S1            bone  Regular_ign    9  7.503876 21.214706 13.486495
## 10 MW6G2S1          no_use  Regular_ign    3  8.210394 12.331760  9.594486
##    Sq.median     Sq.sd Ssk.n     Ssk.min   Ssk.max   Ssk.mean Ssk.median
## 1   8.648178  1.939212     9 -0.02251418 0.7577052 0.28357010 0.27415163
## 2   9.060314  1.913172     3 -0.14897681 0.1818577 0.02267047 0.03513049
## 3  22.219930 22.258847     9  0.37276137 2.1128103 1.02777103 0.91055760
## 4  21.032828  7.756364     3  0.42534413 1.0881790 0.68413355 0.53887753
## 5   9.813930  3.267261     9 -0.38810870 1.4721812 0.67796861 0.57816045
## 6  12.043172  3.571531     3  0.01244696 0.1114047 0.06844835 0.08149343
## 7   8.078204  2.560580     8 -0.04934925 3.6317140 1.38958223 0.80416487
## 8   5.482956  1.359980     3  0.38477194 1.7332947 0.97502239 0.80700054
## 9  13.625286  3.783788     9 -0.19782916 0.6546132 0.34455717 0.30583174
## 10  8.241303  2.370600     3  1.06912028 1.3486471 1.18832836 1.14721768
##        Ssk.sd Sku.n  Sku.min   Sku.max Sku.mean Sku.median    Sku.sd Sp.n
## 1  0.25123325     9 2.645284  4.479417 3.494612   3.314367 0.5977422    9
```

```
## 2  0.16576885     3 2.757541  3.638224 3.271035   3.417338 0.4582075    3
## 3  0.55292390     9 2.519341 11.163102 6.626228   5.238011 3.0284775    9
## 4  0.35448836     3 3.100749  6.406618 4.667123   4.494004 1.6597199    3
## 5  0.62423622     9 3.262983 10.195028 6.539901   6.846613 2.6503588    9
## 6  0.05075221     3 2.607873 14.630243 6.764393   3.055065 6.8156937    3
## 7  1.43450733     8 3.223886 22.919378 9.667594   5.949720 8.0346084    8
## 8  0.68978395     3 5.404446  9.352493 7.393515   7.423604 1.9741956    3
## 9  0.28236034     9 2.838261  5.931765 4.039210   3.886268 1.0237456    9
## 10 0.14422683     3 5.035714  7.818396 6.313458   6.086265 1.4051838    3
##      Sp.min    Sp.max   Sp.mean Sp.median     Sp.sd Sv.n   Sv.min    Sv.max
## 1  17.18378  39.87515  25.68341  24.58514  6.667521    9 14.97265  34.40767
## 2  23.64134  34.89050  31.01266  34.50615  6.386646    3 25.56008  47.23796
## 3  40.30089 199.88299 106.25727 107.04106 47.219908    9 34.78964 143.30958
## 4  53.13381 101.14910  84.18791  98.28082 26.931854    3 36.56090 102.94767
## 5  17.78106  81.18747  48.89975  45.94380 19.788620    9 15.02573  59.00247
## 6  19.33636  72.59322  42.22180  34.73584 27.406262    3 17.25796  85.60943
## 7  17.26470  64.96520  38.06369  37.78137 18.931496    8 12.67903  32.49597
## 8  16.19630  33.12118  27.17700  32.21352  9.520390    3 13.03301  22.48445
## 9  22.75775  70.05513  52.00632  55.02275 14.510714    9 20.23667  58.05026
## 10 39.76457  62.86922  50.26186  48.15180 11.695957    3 23.72950  30.46131
##     Sv.mean Sv.median     Sv.sd Sz.n   Sz.min    Sz.max   Sz.mean Sz.median
## 1  25.80182  27.13677  6.691041    9 32.72492  67.01192  51.48523  53.26250
## 2  33.59354  27.98257 11.878333    3 49.20142  81.74410  64.60620  62.87308
## 3  81.95437  80.99841 37.894035    9 75.09053 343.19257 188.21164 177.18170
## 4  69.63100  69.38444 33.194071    3 89.69471 204.09678 153.81891 167.66526
## 5  35.12224  33.15965 16.559462    9 32.80680 120.18495  84.02198  92.68390
## 6  50.06462  47.32647 34.257906    3 36.59432 158.20266  92.28643  82.06231
## 7  20.65125  21.44169  6.930091    8 30.35188  88.82715  58.71495  62.50386
## 8  16.52252  14.05009  5.188172    3 29.22931  55.60564  43.69952  46.26361
## 9  43.68278  51.62774 13.521014    9 42.99442 128.10540  95.68911 100.35808
## 10 27.34249  27.83666  3.393004    3 63.49407  90.70588  77.60435  78.61311
##       Sz.sd Sa.n    Sa.min    Sa.max   Sa.mean Sa.median      Sa.sd
## 1  11.05407    9  4.021936  8.297740  6.396206  6.668945  1.5022141
## 2  16.34042    3  6.303812  9.215386  7.590523  7.252370  1.4849502
## 3  79.49558    9  7.600239 68.757057 20.352121 16.748056 18.8435653
## 4  58.44441    3 11.828620 22.091625 16.325167 15.055256  5.2480304
## 5  32.05592    9  3.880155 10.724066  6.981453  6.847019  2.4034272
## 6  61.44548    3  4.900318 10.324936  7.611112  7.608081  2.7123100
## 7  23.44636    8  2.922386  7.799800  4.699231  4.765441  1.6466088
## 8  13.37381    3  2.551167  4.348197  3.563063  3.789825  0.9197255
## 9  26.73483    9  6.049680 15.821603 10.214988 10.173646  2.7191844
## 10 13.63392    3  5.962861  9.005989  7.071227  6.244832  1.6814735
##    Smr..c...1.µm.below.highest.peak..n Smr..c...1.µm.below.highest.peak..min
## 1                                    9                           0.129436652
## 2                                    3                           0.136036764
## 3                                    9                           0.003326797
## 4                                    3                           0.010260262
## 5                                    9                           0.003517030
## 6                                    3                           0.003298784
## 7                                    8                           0.026062347
## 8                                    3                           0.019764275
## 9                                    9                           0.002864635
## 10                                   3                           0.014145319
##    Smr..c...1.µm.below.highest.peak..max Smr..c...1.µm.below.highest.peak..mean
```

```
## 1                         0.25093810                             0.21134175
## 2                         0.17077097                             0.15171297
## 3                         0.09686346                             0.03621447
## 4                         0.02731155                             0.01631209
## 5                         0.11591567                             0.02776300
## 6                         0.18030579                             0.09874595
## 7                         0.16980952                             0.09269989
## 8                         0.17915327                             0.08656442
## 9                         0.19302423                             0.05522177
## 10                        0.03707106                             0.02264030
##    Smr..c...1.µm.below.highest.peak..median
## 1                                0.23035046
## 2                                0.14833118
## 3                                0.01962398
## 4                                0.01136444
## 5                                0.01521358
## 6                                0.11263326
## 7                                0.08514802
## 8                                0.06077572
## 9                                0.02429787
## 10                               0.01670453
##    Smr..c...1.µm.below.highest.peak..sd Smc..p...10...n Smc..p...10...min
## 1                           0.040494607               9          6.691335
## 2                           0.017612314               3         10.320923
## 3                           0.034977543               9         11.058562
## 4                           0.009541802               3         19.783437
## 5                           0.034533409               9          6.171449
## 6                           0.089316926               3          8.294266
## 7                           0.053584958               8          4.493045
## 8                           0.082764762               3          4.059458
## 9                           0.059919024               9          9.722711
## 10                          0.012562742               3          8.844100
##    Smc..p...10...max Smc..p...10...mean Smc..p...10...median Smc..p...10...sd
## 1          14.477477          10.938276            11.530379        2.6523625
## 2          14.746180          12.156261            11.401681        2.3071131
## 3         141.549348          35.649246            23.214725       40.8940784
## 4          40.863905          27.474072            21.774875       11.6386071
## 5          15.041786          10.344946            10.055254        3.4315575
## 6          16.366388          11.981739            11.284563        4.0809719
## 7          13.007607           6.672026             4.940842        3.1507142
## 8           5.908241           5.163481             5.522745        0.9753476
## 9          28.779154          16.539688            14.991565        5.3545996
## 10         15.447508          11.661309            10.692319        3.4066782
##    Sxp..p...50...q...97.5...n Sxp..p...50...q...97.5...min
## 1                           9                     8.126920
## 2                           3                    14.932044
## 3                           9                    14.583036
## 4                           3                    24.598504
## 5                           9                     9.402009
## 6                           3                    12.281577
## 7                           8                     6.770593
## 8                           3                     6.964112
## 9                           9                    14.431524
## 10                          3                    10.444185
```

```
##    Sxp..p...50...q...97.5...max Sxp..p...50...q...97.5...mean
## 1                      19.80979                     14.077415
## 2                      20.19767                     17.349271
## 3                      80.58646                     38.333654
## 4                      52.43185                     37.206342
## 5                      26.08240                     17.380564
## 6                      24.75996                     17.460145
## 7                      16.61239                     11.476646
## 8                      12.32030                      8.998026
## 9                      38.99502                     24.784749
## 10                     16.56297                     13.559731
##    Sxp..p...50...q...97.5...median Sxp..p...50...q...97.5...sd Sal..s...0.2..n
## 1                        14.060023                    3.964723               9
## 2                        16.918101                    2.659160               3
## 3                        35.912080                   21.638165               9
## 4                        34.588675                   14.100103               3
## 5                        16.220668                    5.892286               9
## 6                        15.338894                    6.504022               3
## 7                        11.762347                    3.591365               8
## 8                         7.709669                    2.901219               3
## 9                        24.298570                    7.099866               9
## 10                       13.672034                    3.060939               3
##    Sal..s...0.2..min Sal..s...0.2..max Sal..s...0.2..mean Sal..s...0.2..median
## 1           52.80412          89.81858           72.55206             67.45247
## 2           61.91879          86.93064           71.14821             64.59520
## 3           46.39301         105.05251           63.17700             60.01913
## 4           48.17865          71.49917           59.97350             60.24269
## 5           42.20291          73.66658           60.09439             60.29915
## 6           37.49694          89.63585           66.61831             72.72213
## 7           32.42020          79.58032           55.62719             60.45598
## 8           37.19822          48.70143           44.04602             46.23842
## 9           46.28510          84.34683           57.68914             53.14922
## 10          38.91076          54.21957           47.81911             50.32702
##    Sal..s...0.2..sd Std..Reference.angle...0...n Std..Reference.angle...0...min
## 1         12.775287                            9                       3.253287
## 2         13.733340                            3                       2.757417
## 3         16.723446                            9                      16.500067
## 4         11.662592                            3                       3.753496
## 5          9.121335                            9                      73.251527
## 6         26.599981                            3                      20.000148
## 7         16.115243                            8                      16.493768
## 8          6.056890                            3                      39.252011
## 9         12.802860                            9                      58.002030
## 10         7.956576                            3                       7.759671
##    Std..Reference.angle...0...max Std..Reference.angle...0...mean
## 1                       174.24867                        60.27726
## 2                        86.24629                        47.66927
## 3                       167.25349                        63.13998
## 4                        98.74818                        49.99662
## 5                       173.99388                       114.08134
## 6                        73.25047                        47.83506
## 7                       100.00630                        76.71804
## 8                        93.51012                        73.17181
## 9                       137.74483                       111.97084
```

```
## 10                      163.00255                         81.25326
##    Std..Reference.angle...0...median Std..Reference.angle...0...sd Sdq.n
## 1                           22.50332                      63.76333     9
## 2                           54.00410                      42.10339     3
## 3                           50.50421                      49.60585     9
## 4                           47.48818                      47.54699     3
## 5                           98.49042                      36.70735     9
## 6                           50.25455                      26.70748     3
## 7                           79.99869                      26.26219     8
## 8                           86.75329                      29.56904     3
## 9                          120.50400                      27.26386     9
## 10                          72.99756                      77.95002     3
##      Sdq.min   Sdq.max  Sdq.mean Sdq.median     Sdq.sd Sdr.n   Sdr.min
## 1  0.5884395 0.9309811 0.7006765  0.7016803 0.09898725     9 13.713395
## 2  0.6757145 0.9302041 0.8183018  0.8489867 0.12999003     3 17.018494
## 3  1.0971752 4.9937168 2.6542813  2.2442055 1.24940342     9 30.359955
## 4  1.3396451 2.4753302 2.0027938  2.1934061 0.59135014     3 26.424201
## 5  0.5672499 1.3066440 0.9607505  0.9870976 0.23254134     9 11.363945
## 6  0.6395680 1.3057172 0.9853017  1.0106198 0.33379552     3 14.090017
## 7  0.4935876 1.3520065 0.8000794  0.6770484 0.35102302     8  9.142846
## 8  0.5035897 0.7846100 0.6550251  0.6768755 0.14177866     3  9.750539
## 9  0.6536768 2.0432940 1.3418718  1.2713830 0.41681690     9 15.945458
## 10 0.9446065 1.4581162 1.1680681  1.1014818 0.26315082     3 23.386377
##      Sdr.max Sdr.mean Sdr.median    Sdr.sd Vm..p...10...n Vm..p...10...min
## 1   23.84170 17.68615   17.97856  2.955713              9        0.3201235
## 2   27.12620 22.19458   22.43903  5.058284              3        0.3489735
## 3  104.27514 53.93267   45.30116 26.073466              9        0.8999336
## 4   61.04453 44.88199   47.17725 17.423919              3        0.8142877
## 5   26.97951 20.42928   21.22632  5.333596              9        0.2836160
## 6   28.43362 23.38228   27.62321  8.057532              3        0.3003648
## 7   25.44176 15.97144   15.02754  6.137314              8        0.2254618
## 8   18.28971 13.78189   13.30541  4.289479              3        0.2927578
## 9   54.82298 33.40845   32.01672 11.438759              9        0.3687425
## 10  39.18970 30.68873   29.49013  7.969549              3        0.6872419
##    Vm..p...10...max Vm..p...10...mean Vm..p...10...median Vm..p...10...sd
## 1         0.7716772         0.4867815           0.4420677      0.13705388
## 2         0.5319171         0.4362017           0.4277146      0.09176663
## 3         3.2005335         2.0836236           2.2646496      0.76888228
## 4         2.2955337         1.7731366           2.2095883      0.83149869
## 5         1.4529470         0.7806336           0.7299465      0.39975484
## 6         1.1006135         0.6477983           0.5424166      0.41040036
## 7         1.4390420         0.7262197           0.5971844      0.47004765
## 8         0.6136174         0.4874212           0.5558884      0.17103664
## 9         1.5783698         0.9547482           0.8878558      0.38241026
## 10        1.1523588         0.8508590           0.7129763      0.26142328
##    Vv..p...10...n Vv..p...10...min Vv..p...10...max Vv..p...10...mean
## 1               9         7.011406        15.065817         11.425060
## 2               3        10.669988        15.278133         12.592513
## 3               9        11.958407       143.821705         37.733038
## 4               3        20.597814        43.159485         29.247207
## 5               9         6.455019        16.493383         11.125575
## 6               3         8.594619        16.908842         12.629500
## 7               8         4.837232        13.619321          7.398182
## 8               3         4.352180         6.464198          5.650918
```

```
## 9             9       10.091505        30.357493         17.494477
## 10            3        9.557139        16.599846         12.512158
##    Vv..p...10...median Vv..p...10...sd Vmp..p...10...n Vmp..p...10...min
## 1            12.141650        2.754885               9         0.3201235
## 2            11.829417        2.396974               3         0.3489735
## 3            25.821679       41.100204               9         0.8999336
## 4            23.984323       12.166787               3         0.8142877
## 5            10.871803        3.680743               9         0.2836160
## 6            12.385040        4.162499               3         0.3003648
## 7             5.883944        3.118801               8         0.2254618
## 8             6.136375        1.136621               3         0.2927578
## 9            16.419288        5.652112               9         0.3687425
## 10           11.379487        3.655426               3         0.6872419
##    Vmp..p...10...max Vmp..p...10...mean Vmp..p...10...median Vmp..p...10...sd
## 1          0.7716772          0.4867815            0.4420677       0.13705388
## 2          0.5319171          0.4362017            0.4277146       0.09176663
## 3          3.2005335          2.0836236            2.2646496       0.76888228
## 4          2.2955337          1.7731366            2.2095883       0.83149869
## 5          1.4529470          0.7806336            0.7299465       0.39975484
## 6          1.1006135          0.6477983            0.5424166       0.41040036
## 7          1.4390420          0.7262197            0.5971844       0.47004765
## 8          0.6136174          0.4874212            0.5558884       0.17103664
## 9          1.5783698          0.9547482            0.8878558       0.38241026
## 10         1.1523588          0.8508590            0.7129763       0.26142328
##    Vmc..p...10...q...80...n Vmc..p...10...q...80...min
## 1                         9                   4.450422
## 2                         3                   7.467709
## 3                         9                   7.976398
## 4                         3                  13.587119
## 5                         9                   4.397925
## 6                         3                   5.169091
## 7                         8                   3.102471
## 8                         3                   2.505969
## 9                         9                   6.893585
## 10                        3                   6.229499
##    Vmc..p...10...q...80...max Vmc..p...10...q...80...mean
## 1                    9.592246                    7.096468
## 2                   10.260280                    8.678579
## 3                   63.894370                   19.246766
## 4                   20.738619                   16.329152
## 5                   11.618668                    7.257442
## 6                   11.552078                    8.068189
## 7                    8.515048                    4.572191
## 8                    4.488539                    3.536744
## 9                   16.386982                   11.232513
## 10                   9.091423                    7.238928
##    Vmc..p...10...q...80...median Vmc..p...10...q...80...sd
## 1                       7.003398                 1.8211751
## 2                       8.307747                 1.4327421
## 3                      14.478823                17.4102465
## 4                      14.661717                 3.8563247
## 5                       6.779995                 2.5811942
## 6                       7.483400                 3.2314262
## 7                       3.820601                 1.8489941
```

```
## 8                     3.615725                0.9936424
## 9                    10.824962                2.6821851
## 10                    6.395861                1.6064626
##    Vvc..p...10...q...80...n Vvc..p...10...q...80...min
## 1                         9                   6.578057
## 2                         3                   9.829754
## 3                         9                  10.950992
## 4                         3                  19.388028
## 5                         9                   5.947101
## 6                         3                   7.878771
## 7                         8                   4.306807
## 8                         3                   3.885029
## 9                         9                   9.332079
## 10                        3                   8.780407
##    Vvc..p...10...q...80...max Vvc..p...10...q...80...mean
## 1                   14.144531                   10.612759
## 2                   14.017012                   11.581646
## 3                  138.758852                   35.409369
## 4                   40.128179                   27.149625
## 5                   15.242880                   10.082201
## 6                   15.519505                   11.519225
## 7                   12.731895                    6.697255
## 8                    5.705291                    5.088036
## 9                   28.170450                   16.082099
## 10                  15.689234                   11.767761
##    Vvc..p...10...q...80...median Vvc..p...10...q...80...sd Vvv..p...80...n
## 1                      11.160474                  2.577457               9
## 2                      10.898172                  2.175692               3
## 3                      23.018057                 39.961589               9
## 4                      21.932669                 11.311540               3
## 5                       9.691994                  3.370331               9
## 6                      11.159399                  3.833055               3
## 7                       5.146900                  2.962287               8
## 8                       5.673789                  1.041954               3
## 9                      14.489728                  5.314823               9
## 10                     10.833641                  3.547874               3
##    Vvv..p...80...min Vvv..p...80...max Vvv..p...80...mean Vvv..p...80...median
## 1          0.4333487         1.1209188          0.8123011            0.9146472
## 2          0.8402340         1.2611208          1.0108667            0.9312452
## 3          0.9118226         5.0628535          2.3236692            1.7662483
## 4          1.2097860         3.0313052          2.0975818            2.0516542
## 5          0.5079180         1.5227824          1.0433743            1.1798090
## 6          0.7158476         1.3893372          1.1102753            1.2256412
## 7          0.3750757         0.9281178          0.7009262            0.7370450
## 8          0.4625862         0.7589066          0.5628813            0.4671511
## 9          0.7594260         2.1870439          1.4123781            1.3787802
## 10         0.5458456         0.9106123          0.7443969            0.7767329
##    Vvv..p...80...sd Maximum.depth.of.furrows.n Maximum.depth.of.furrows.min
## 1         0.2172396                          9                     16.75276
## 2         0.2214523                          3                     26.26104
## 3         1.4025854                          9                     31.68333
## 4         0.9116277                          3                     43.47218
## 5         0.3409910                          9                     18.23597
## 6         0.3512535                          3                     18.99557
```

```
## 7        0.2143057                          8                    15.77026
## 8        0.1697782                          3                    17.81542
## 9        0.4705498                          9                    20.92165
## 10       0.1845207                          3                    28.94002
##    Maximum.depth.of.furrows.max Maximum.depth.of.furrows.mean
## 1                      28.83774                      21.54506
## 2                      31.86601                      29.10138
## 3                     157.73925                      91.79489
## 4                      94.90850                      68.66226
## 5                      43.65327                      30.76170
## 6                      52.50780                      38.57436
## 7                      43.72077                      25.72067
## 8                      21.53994                      20.02998
## 9                      81.78266                      48.70766
## 10                     46.65155                      36.33151
##    Maximum.depth.of.furrows.median Maximum.depth.of.furrows.sd
## 1                         21.92627                    3.686675
## 2                         29.17709                    2.803250
## 3                         73.12573                   44.307745
## 4                         67.60612                   25.734420
## 5                         31.80954                    8.295442
## 6                         44.21971                   17.454793
## 7                         26.24559                    9.492498
## 8                         20.73457                    1.959682
## 9                         47.11639                   19.231349
## 10                        33.40297                    9.211778
##    Mean.depth.of.furrows.n Mean.depth.of.furrows.min Mean.depth.of.furrows.max
## 1                        9                  6.002999                  9.051419
## 2                        3                  7.461272                  8.622203
## 3                        9                 11.185208                 46.111107
## 4                        3                 15.187073                 29.205054
## 5                        9                  5.064537                 12.064219
## 6                        3                  5.696616                 10.593519
## 7                        8                  4.347303                  9.174991
## 8                        3                  4.664563                  6.692360
## 9                        9                  7.641667                 23.177453
## 10                       3                  9.069816                 17.681250
##    Mean.depth.of.furrows.mean Mean.depth.of.furrows.median
## 1                    7.843046                     8.187588
## 2                    7.852543                     7.474154
## 3                   26.426294                    26.784884
## 4                   23.349417                    25.656125
## 5                    8.885741                     7.902523
## 6                    8.656570                     9.679574
## 7                    6.845322                     6.933926
## 8                    5.459767                     5.022376
## 9                   13.799330                    12.461877
## 10                  12.941694                    12.074016
##    Mean.depth.of.furrows.sd Mean.density.of.furrows.n
## 1                 0.9466227                         9
## 2                 0.6665760                         3
## 3                13.6833953                         9
## 4                 7.2881153                         3
## 5                 2.5903413                         9
```

```
## 6               2.6038085                           3
## 7               1.7637038                           8
## 8               1.0823459                           3
## 9               4.2665737                           9
## 10              4.3707951                           3
##    Mean.density.of.furrows.min Mean.density.of.furrows.max
## 1                     2298.821                    2605.148
## 2                     2366.364                    2522.769
## 3                     1791.625                    2919.208
## 4                     2297.497                    2494.644
## 5                     2643.277                    2901.836
## 6                     2564.022                    2924.246
## 7                     2680.364                    2971.561
## 8                     2669.025                    2869.392
## 9                     2386.039                    2750.615
## 10                    2378.525                    2699.401
##    Mean.density.of.furrows.mean Mean.density.of.furrows.median
## 1                      2432.042                       2411.718
## 2                      2449.421                       2459.131
## 3                      2439.866                       2475.756
## 4                      2389.146                       2375.297
## 5                      2781.130                       2792.991
## 6                      2718.721                       2667.893
## 7                      2836.581                       2842.739
## 8                      2783.521                       2812.145
## 9                      2495.761                       2453.730
## 10                     2519.780                       2481.414
##    Mean.density.of.furrows.sd First.direction.n First.direction.min
## 1                    90.81019                 9         0.013088863
## 2                    78.65352                 3         0.017821948
## 3                   348.19673                 9         0.007610828
## 4                    99.30027                 3         0.007410580
## 5                    90.04938                 9         0.022110916
## 6                   185.41275                 3         0.009692957
## 7                    89.66514                 8         0.019557202
## 8                   103.20532                 3        44.976009260
## 9                   116.42962                 9         0.009121793
## 10                  163.84231                 3        89.994521960
##    First.direction.max First.direction.mean First.direction.median
## 1            179.99750             99.99916               90.00905
## 2             89.99993             48.75543               56.24853
## 3            135.00784             62.94580               89.98562
## 4            179.99790             75.00878               45.02103
## 5            134.97617             80.00343               90.00258
## 6             90.01321             45.01000               45.00709
## 7            135.00618             84.37119               89.99210
## 8             90.01678             74.99408               89.98945
## 9            135.02644             95.89072              116.49217
## 10           179.99868            120.00121               90.01043
##    First.direction.sd Second.direction.n Second.direction.min
## 1            62.74469                  9          0.002585364
## 2            45.45663                  3          0.006468474
## 3            47.03073                  9          0.002699942
## 4            93.66746                  3         90.002718820
```

```
## 5           37.49037                  9        44.985288150
## 6           45.00176                  3        26.457376620
## 7           44.58743                  8         0.001381717
## 8           25.99642                  3        89.979640140
## 9           46.49592                  9         0.002614089
## 10          51.95933                  3        63.531150460
##    Second.direction.max Second.direction.mean Second.direction.median
## 1             179.99306             119.99597               135.00156
## 2             179.99690             104.99997               134.99653
## 3             179.99947             114.11516               153.50994
## 4             134.99764             119.99888               134.99629
## 5             161.50171              95.00381                90.01268
## 6              89.99463              59.99360                63.52880
## 7             179.98498             100.33798               125.73907
## 8             135.00017             119.99310               134.99950
## 9             135.01137              98.74237               116.44870
## 10            179.98588             126.16501               134.97800
##    Second.direction.sd Third.direction.n Third.direction.min
## 1             74.61905                 9        2.648285e+01
## 2             93.66955                 3        4.499814e+01
## 3             70.07597                 9        1.849645e+01
## 4             25.97744                 3        3.375555e+01
## 5             47.08987                 9        2.750789e-02
## 6             31.91581                 3        8.351778e-03
## 7             66.92108                 8        4.500393e+01
## 8             25.99242                 3        1.164543e+02
## 9             44.75928                 9        7.203658e-03
## 10            58.72544                 3        1.137504e-02
##    Third.direction.max Third.direction.mean Third.direction.median
## 1            134.99924             65.88912               45.02250
## 2             63.51498             51.17054               44.99851
## 3            179.99760             99.99419               90.00803
## 4            135.00765             86.25359               89.99757
## 5            171.76576             84.08464               71.48723
## 6            179.98774             81.17287               63.52252
## 7            135.02127            108.77886              125.73425
## 8            179.96919            143.81446              135.01991
## 9            108.53240             47.50569               45.00770
## 10            45.01071             30.00515               44.99337
##    Third.direction.sd Texture.isotropy.n Texture.isotropy.min
## 1            36.96718                  9             47.13495
## 2            10.69059                  3             70.77438
## 3            61.76833                  9             26.13837
## 4            50.72978                  3             69.61484
## 5            58.77415                  9             11.64210
## 6            91.27867                  3             38.21673
## 7            34.08861                  8             26.78453
## 8            32.65798                  3             70.47470
## 9            43.22885                  9             30.58442
## 10           25.97537                  3             85.89070
##    Texture.isotropy.max Texture.isotropy.mean Texture.isotropy.median
## 1              84.73920              72.46804                75.69371
## 2              75.44572              72.89308                72.45914
## 3              92.30589              71.54840                77.46036
```

```
## 4            79.61672             75.63799             77.68242
## 5            86.22843             58.60758             60.14503
## 6            84.87242             68.72778             83.09420
## 7            86.68026             67.59308             79.56700
## 8            83.74952             76.51237             75.31288
## 9            86.74423             63.83621             69.65782
## 10           92.25443             88.80248             88.26233
##    Texture.isotropy.sd Length.scale.anisotropy..Sfrax...epLsar..n
## 1            11.551649                                          9
## 2             2.365707                                          3
## 3            19.306849                                          9
## 4             5.305107                                          3
## 5            23.702520                                          9
## 6            26.438298                                          3
## 7            24.419322                                          8
## 8             6.718207                                          3
## 9            20.271386                                          9
## 10            3.216065                                          3
##    Length.scale.anisotropy..Sfrax...epLsar..min
## 1                                  0.0003036412
## 2                                  0.0004903408
## 3                                  0.0002322810
## 4                                  0.0006145745
## 5                                  0.0005041829
## 6                                  0.0002173764
## 7                                  0.0007216012
## 8                                  0.0013732855
## 9                                  0.0006712386
## 10                                 0.0004264319
##    Length.scale.anisotropy..Sfrax...epLsar..max
## 1                                   0.001792291
## 2                                   0.001118900
## 3                                   0.006755924
## 4                                   0.003863928
## 5                                   0.005463414
## 6                                   0.003835056
## 7                                   0.004121158
## 8                                   0.003495790
## 9                                   0.003949583
## 10                                  0.002831267
##    Length.scale.anisotropy..Sfrax...epLsar..mean
## 1                                   0.0010222791
## 2                                   0.0008424768
## 3                                   0.0031057825
## 4                                   0.0021953597
## 5                                   0.0026060333
## 6                                   0.0014276674
## 7                                   0.0024981068
## 8                                   0.0021015144
## 9                                   0.0015971049
## 10                                  0.0018796506
##    Length.scale.anisotropy..Sfrax...epLsar..median
## 1                                     0.0009220201
## 2                                     0.0009181891
```

```
## 3                                   0.0022652921
## 4                                   0.0021075769
## 5                                   0.0026682883
## 6                                   0.0002305694
## 7                                   0.0027324841
## 8                                   0.0014354676
## 9                                   0.0014998304
## 10                                  0.0023812526
##    Length.scale.anisotropy..Sfrax...epLsar..sd
## 1                               0.0005312633
## 2                               0.0003210468
## 3                               0.0022981164
## 4                               0.0016264542
## 5                               0.0014524109
## 6                               0.0020848704
## 7                               0.0011636999
## 8                               0.0012078783
## 9                               0.0010293285
## 10                              0.0012784803
##    Length.scale.anisotropy..NewEplsar..n
## 1                                     9
## 2                                     3
## 3                                     9
## 4                                     3
## 5                                     9
## 6                                     3
## 7                                     8
## 8                                     3
## 9                                     9
## 10                                    3
##    Length.scale.anisotropy..NewEplsar..min
## 1                               0.01768289
## 2                               0.01778222
## 3                               0.01755183
## 4                               0.01756227
## 5                               0.01713069
## 6                               0.01746231
## 7                               0.01687653
## 8                               0.01719091
## 9                               0.01701070
## 10                              0.01777294
##    Length.scale.anisotropy..NewEplsar..max
## 1                               0.01834995
## 2                               0.01815137
## 3                               0.01910737
## 4                               0.01805707
## 5                               0.01795282
## 6                               0.01772013
## 7                               0.01777504
## 8                               0.01749688
## 9                               0.01801316
## 10                              0.01783933
##    Length.scale.anisotropy..NewEplsar..mean
## 1                                0.01803226
```

```
## 2                               0.01798564
## 3                               0.01811044
## 4                               0.01775986
## 5                               0.01754005
## 6                               0.01759671
## 7                               0.01731615
## 8                               0.01734158
## 9                               0.01744137
## 10                              0.01780281
##    Length.scale.anisotropy..NewEplsar..median
## 1                                 0.01807702
## 2                                 0.01802332
## 3                                 0.01811201
## 4                                 0.01766025
## 5                                 0.01756788
## 6                                 0.01760767
## 7                                 0.01729995
## 8                                 0.01733696
## 9                                 0.01746496
## 10                                0.01779615
##    Length.scale.anisotropy..NewEplsar..sd Fractal.complexity..Asfc..n
## 1                            1.930067e-04                           9
## 2                            1.874365e-04                           3
## 3                            5.325728e-04                           9
## 4                            2.620097e-04                           3
## 5                            2.960458e-04                           9
## 6                            1.292601e-04                           3
## 7                            2.785530e-04                           8
## 8                            1.530368e-04                           3
## 9                            2.718568e-04                           9
## 10                           3.369016e-05                           3
##    Fractal.complexity..Asfc..min Fractal.complexity..Asfc..max
## 1                       17.90917                      32.86133
## 2                       21.83468                      36.96163
## 3                       31.53697                     144.81210
## 4                       42.84526                      73.08920
## 5                       15.14748                      28.65736
## 6                       18.86207                      30.70305
## 7                       12.26438                      34.95146
## 8                       12.24780                      24.30124
## 9                       17.52856                      55.94547
## 10                      27.36583                      48.41544
##    Fractal.complexity..Asfc..mean Fractal.complexity..Asfc..median
## 1                        23.89955                         22.93562
## 2                        29.17703                         28.73478
## 3                        76.20627                         70.56423
## 4                        62.94505                         72.90068
## 5                        22.18242                         21.91921
## 6                        26.36417                         29.52741
## 7                        20.52695                         16.77779
## 8                        17.64458                         16.38469
## 9                        39.47646                         43.20929
## 10                       38.96393                         41.11050
##    Fractal.complexity..Asfc..sd Scale.of.max.complexity..Smfc..n
```

```
## 1                  4.213738                             9
## 2                  7.573168                             3
## 3                 39.032757                             9
## 4                 17.407177                             3
## 5                  4.584811                             9
## 6                  6.523553                             3
## 7                  9.164681                             8
## 8                  6.124693                             3
## 9                 13.388156                             9
## 10                10.687724                             3
##    Scale.of.max.complexity..Smfc..min Scale.of.max.complexity..Smfc..max
## 1                           19.521476                           46.25603
## 2                           14.265081                           39.54113
## 3                          415.754830                         9576.82518
## 4                          842.119572                         2953.43532
## 5                           28.894201                         2334.25686
## 6                           21.114085                          175.46142
## 7                            5.566202                          985.12871
## 8                           15.428860                           24.69969
## 9                           24.699688                          985.12871
## 10                         162.226585                          415.75483
##    Scale.of.max.complexity..Smfc..mean Scale.of.max.complexity..Smfc..median
## 1                             30.87067                              31.25146
## 2                             29.20241                              33.80103
## 3                           3044.12464                            2730.66144
## 4                           1833.76154                            1705.72973
## 5                            386.50461                             118.54510
## 6                             92.22228                              80.09134
## 7                            168.05218                              28.31882
## 8                             19.88334                              19.52148
## 9                            465.86737                             486.35851
## 10                           293.92973                             303.80777
##    Scale.of.max.complexity..Smfc..sd HAsfc9..HAsfc9..n HAsfc9..HAsfc9..min
## 1                           7.067708                 9           0.1316330
## 2                          13.250666                 3           0.1255464
## 3                        2965.415927                 9           0.4455791
## 4                        1061.464860                 3           0.5851555
## 5                         742.721750                 9           0.2710966
## 6                          77.885458                 3           0.2331469
## 7                         337.614585                 8           0.2132304
## 8                           4.645996                 3           0.2399171
## 9                         305.964329                 9           0.1307847
## 10                        127.052448                 3           0.4507234
##    HAsfc9..HAsfc9..max HAsfc9..HAsfc9..mean HAsfc9..HAsfc9..median
## 1            0.2981468            0.1855606              0.1487189
## 2            0.2493303            0.2006154              0.2269694
## 3           13.3993886            2.6339071              1.1790757
## 4            1.6127738            0.9869700              0.7629809
## 5            6.1967259            1.1809769              0.5654418
## 6            0.9208822            0.4626529              0.2339297
## 7            5.2171286            0.9908077              0.3453896
## 8            0.5555807            0.3814661              0.3489006
## 9            1.9469006            0.8496816              0.7590458
## 10           0.7342881            0.6092278              0.6426717
```

```
##    HAsfc9..HAsfc9..sd HAsfc81..HAsfc81..n HAsfc81..HAsfc81..min
## 1          0.06507991                   9             0.2502991
## 2          0.06596603                   3             0.2922487
## 3          4.12872799                   9                  -Inf
## 4          0.54920687                   3             3.2992331
## 5          1.89658947                   9             0.5763855
## 6          0.39683837                   3             0.4197154
## 7          1.71734602                   8             0.3835358
## 8          0.16033175                   3             0.5153154
## 9          0.66391685                   9             0.4168093
## 10         0.14471043                   3             0.7749490
##    HAsfc81..HAsfc81..max HAsfc81..HAsfc81..mean HAsfc81..HAsfc81..median
## 1              0.4765597              0.3146768                0.2906821
## 2              0.3858270              0.3305777                0.3136574
## 3             29.9869968                   -Inf                3.0279886
## 4              7.1479098              5.1953535                5.1389175
## 5              3.8599229              1.5651485                1.0658350
## 6              1.6018539              0.8442619                0.5112164
## 7             13.4263962              2.5956076                0.6508434
## 8              0.6441176              0.5735222                0.5611335
## 9              3.2954504              1.5500254                1.4498423
## 10             1.2744163              1.0568059                1.1210524
##    HAsfc81..HAsfc81..sd
## 1            0.08511859
## 2            0.04903006
## 3                   NaN
## 4            1.92495890
## 5            1.19102556
## 6            0.65768710
## 7            4.49255308
## 8            0.06528869
## 9            0.93993842
## 10           0.25585662
```

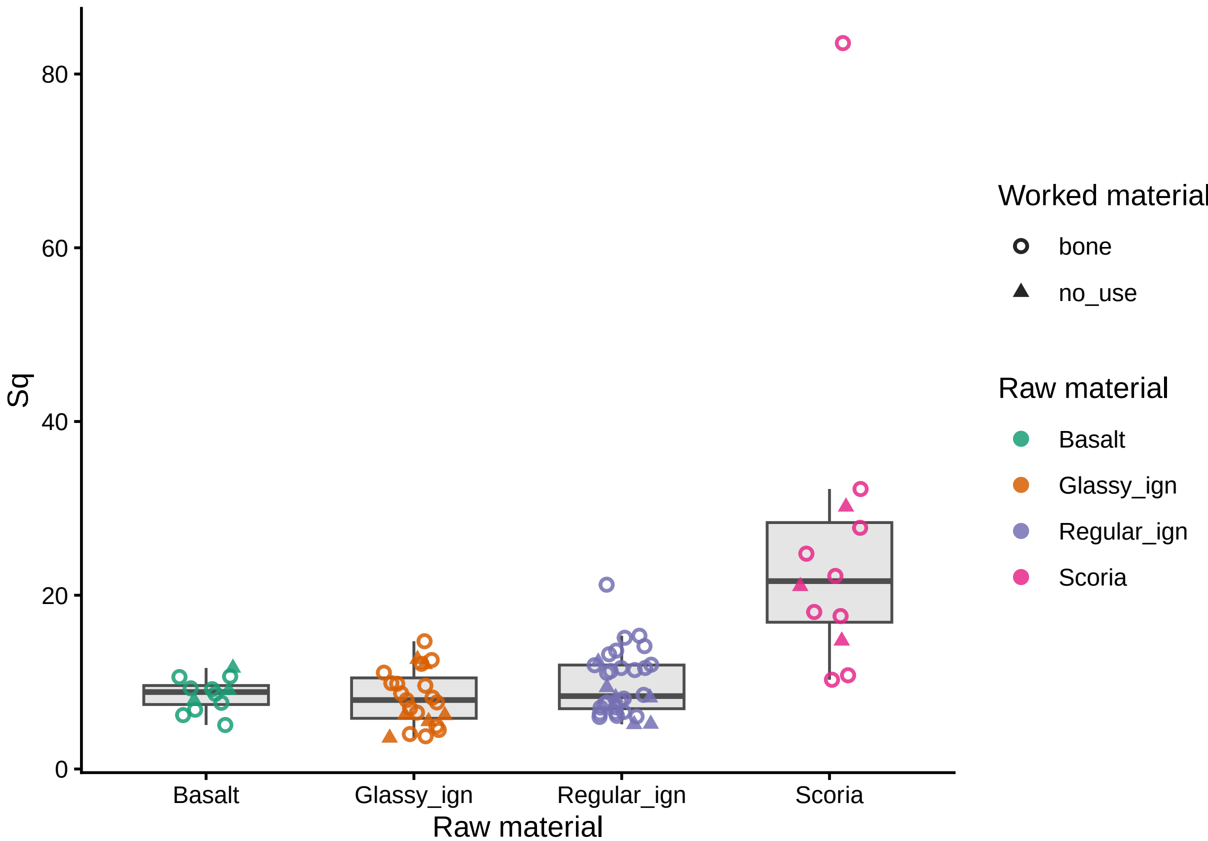
Plot all paramaters organised by Raw material

```
# Loop for plotting all surface texture parameters


for (i in num.var) {

  cat("[", i, "] ", names(confocaldata)[i], "\n", sep = "")

  p <- ggplot(
    confocaldata,
    aes(
      x = Raw_material,
      y = .data[[names(confocaldata)[i]]]
    )
  ) +
    # Neutral boxplot (no categorical encoding)
    geom_boxplot(
```

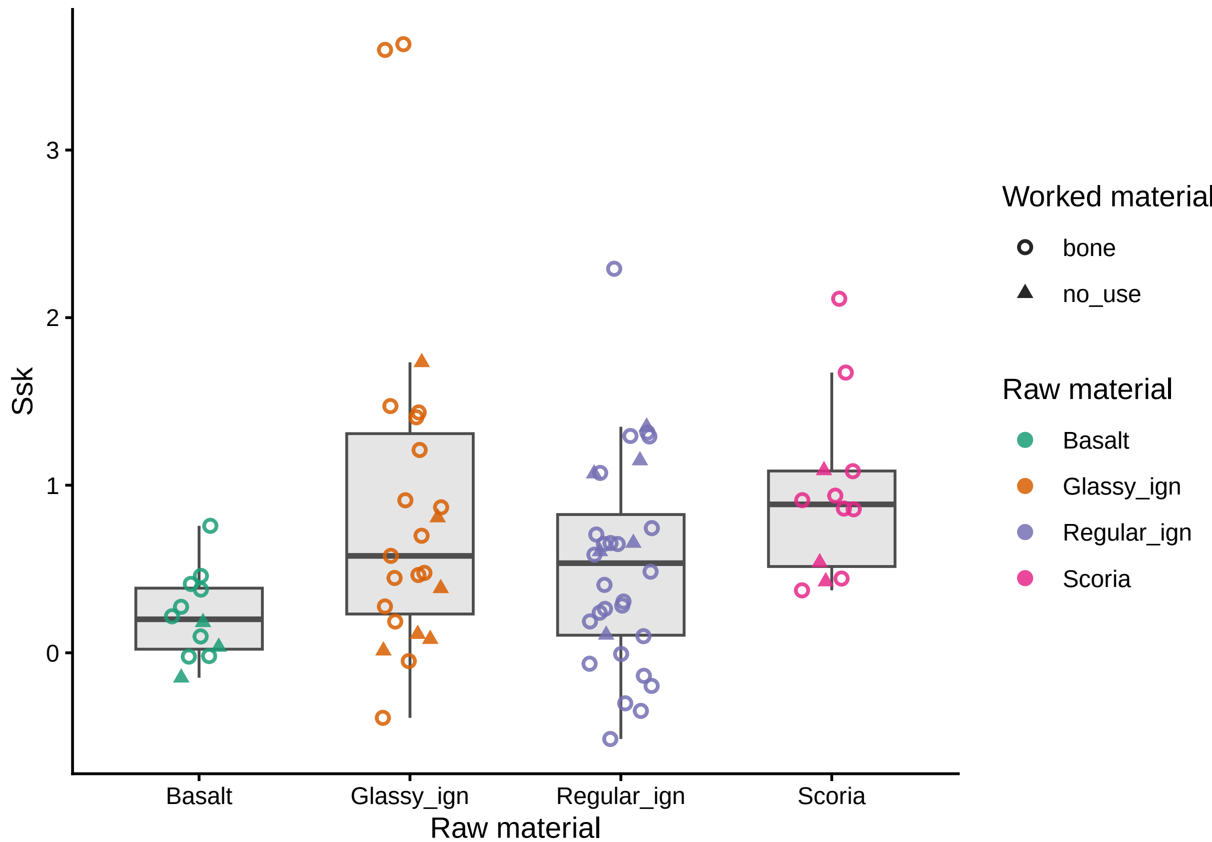
```r
    colour = "grey30",
    fill   = "grey90",
    width  = 0.6,
    outlier.shape = NA
  ) +

  # Overlay points with SAME encoding as scatter plots
  geom_jitter(
    aes(
      colour = Raw_material,
      shape  = Worked_material
    ),
    width  = 0.15,
    size   = 1.5,
    stroke = 1,
    alpha  = 0.85
  ) +

  theme_classic() +
  labs(
    x      = "Raw material",
    y      = gsub("\\.", " ", names(confocaldata)[i]),
    colour = "Raw material",
    shape  = "Worked material"
  ) +

  # Colour-blind-safe palette
  scale_colour_brewer(palette = "Dark2") +

  # Shape mapping (same as scatter plots)
  scale_shape_manual(
    values = c(
      bone   = 1,   # open circle
      no_use = 17   # filled triangle
    )
  )

file_out <- paste0(
  file_path_sans_ext(info_in[["file"]]),
  "_plot_",
  names(confocaldata)[i],
  ".pdf"
)

print(p)

ggsave(
  filename = file_out,
  plot     = p,
  path     = "analysis/plots",
  device   = "pdf",
  width    = 26,
  height   = 21,
```

```
    units     = "cm"
  )
}
```

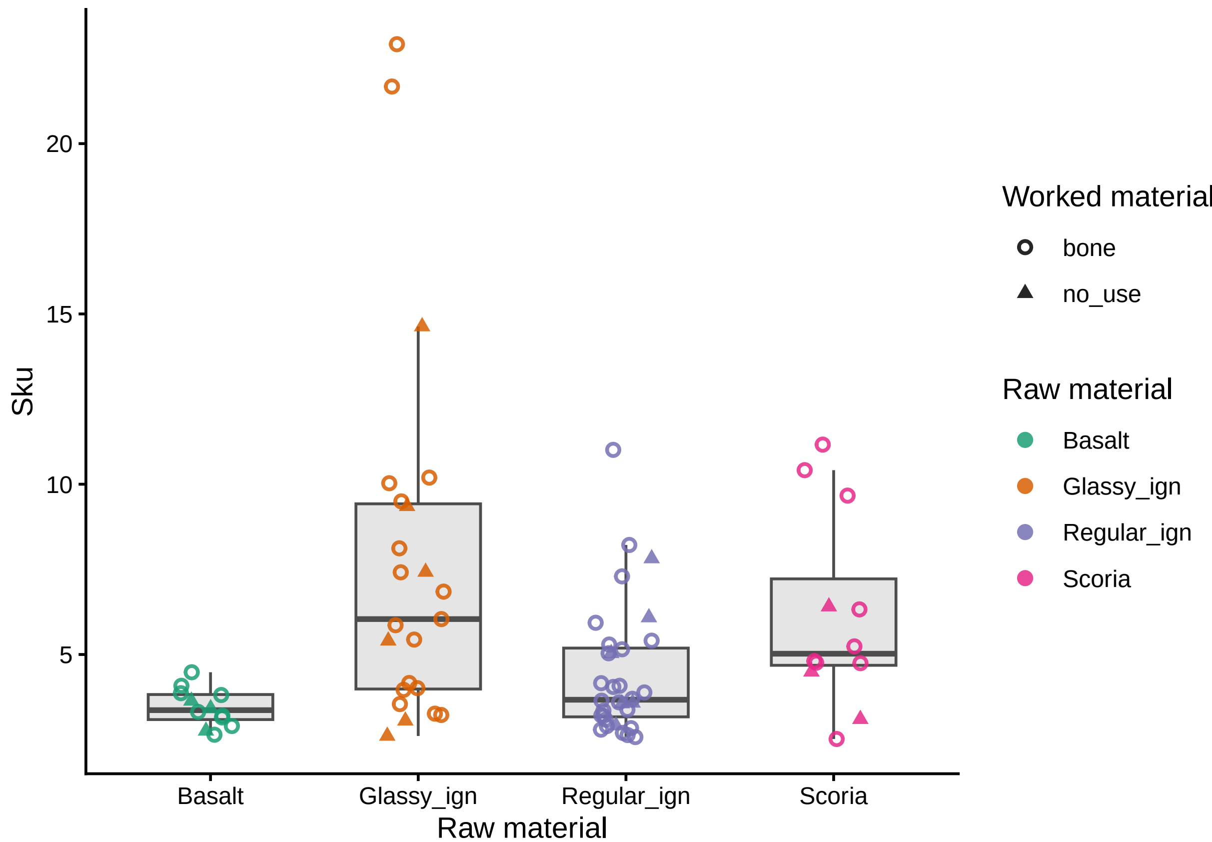
```
## [23] Sq
```




```
## [24] Ssk
```

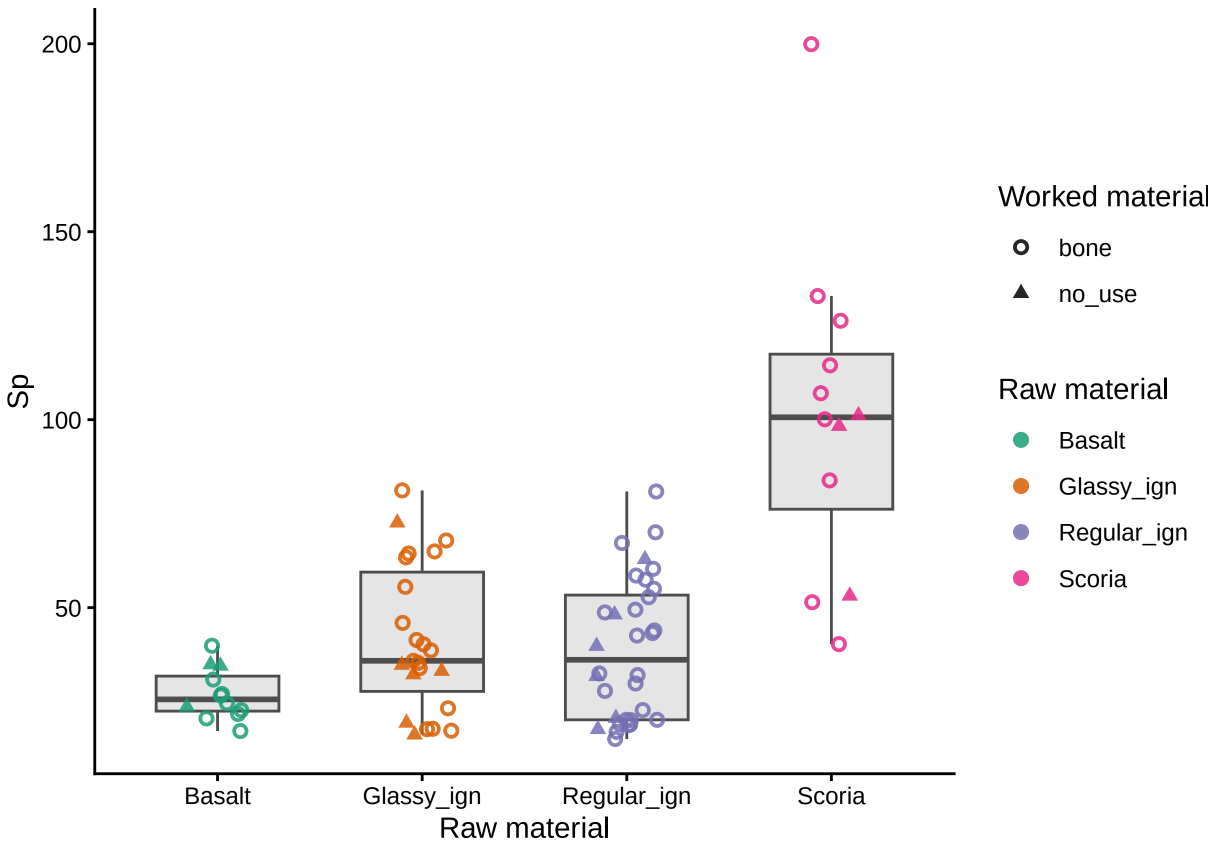

Ssk
3
2
1
0
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

```
## [25] Sku
```



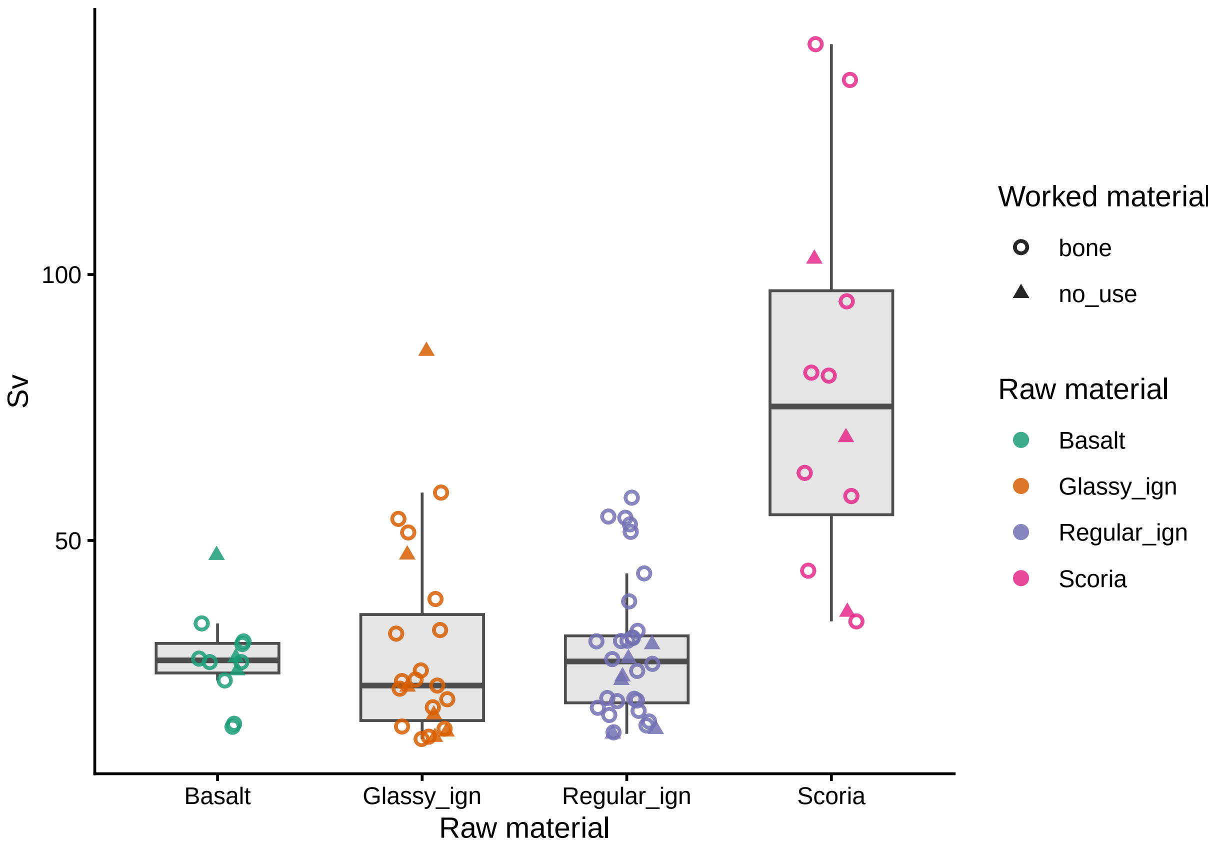
Sku
20
15
10
5
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [26] Sp
```

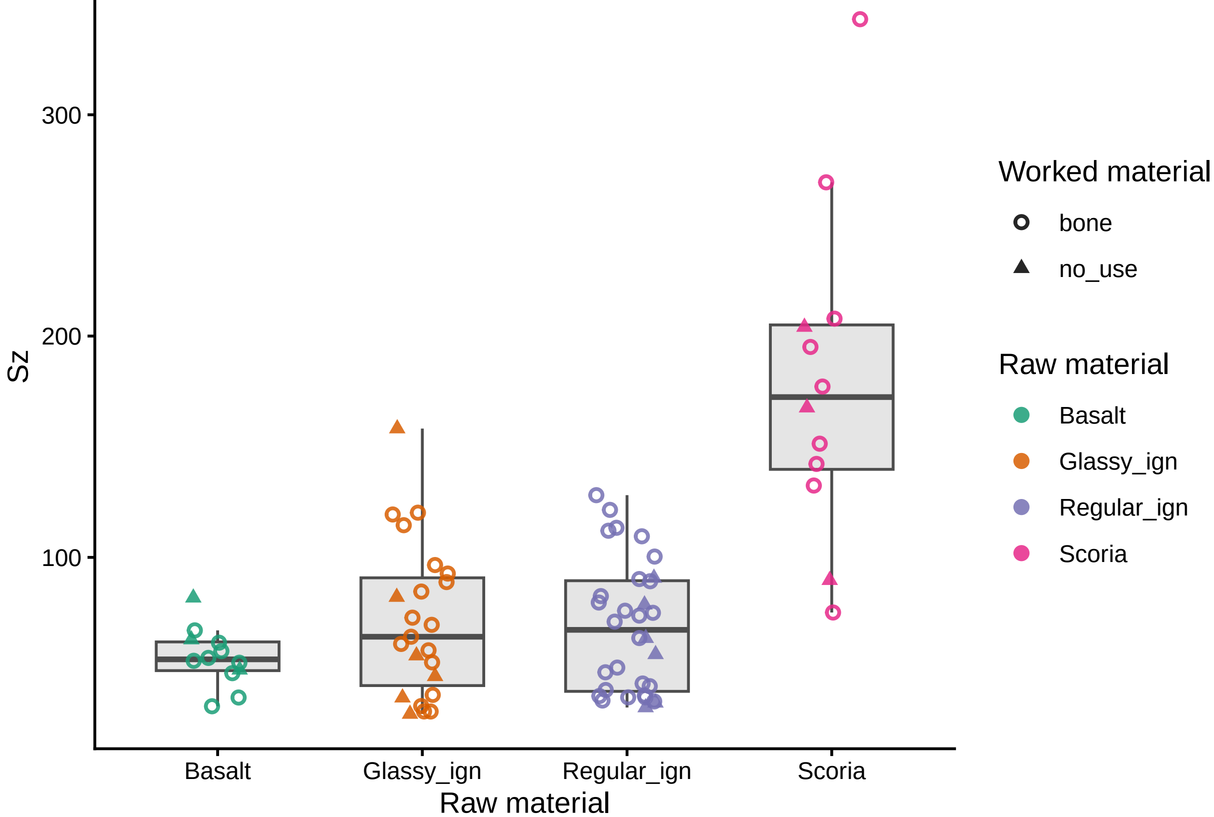


200
150
100
50
Sp
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [27] Sv
```

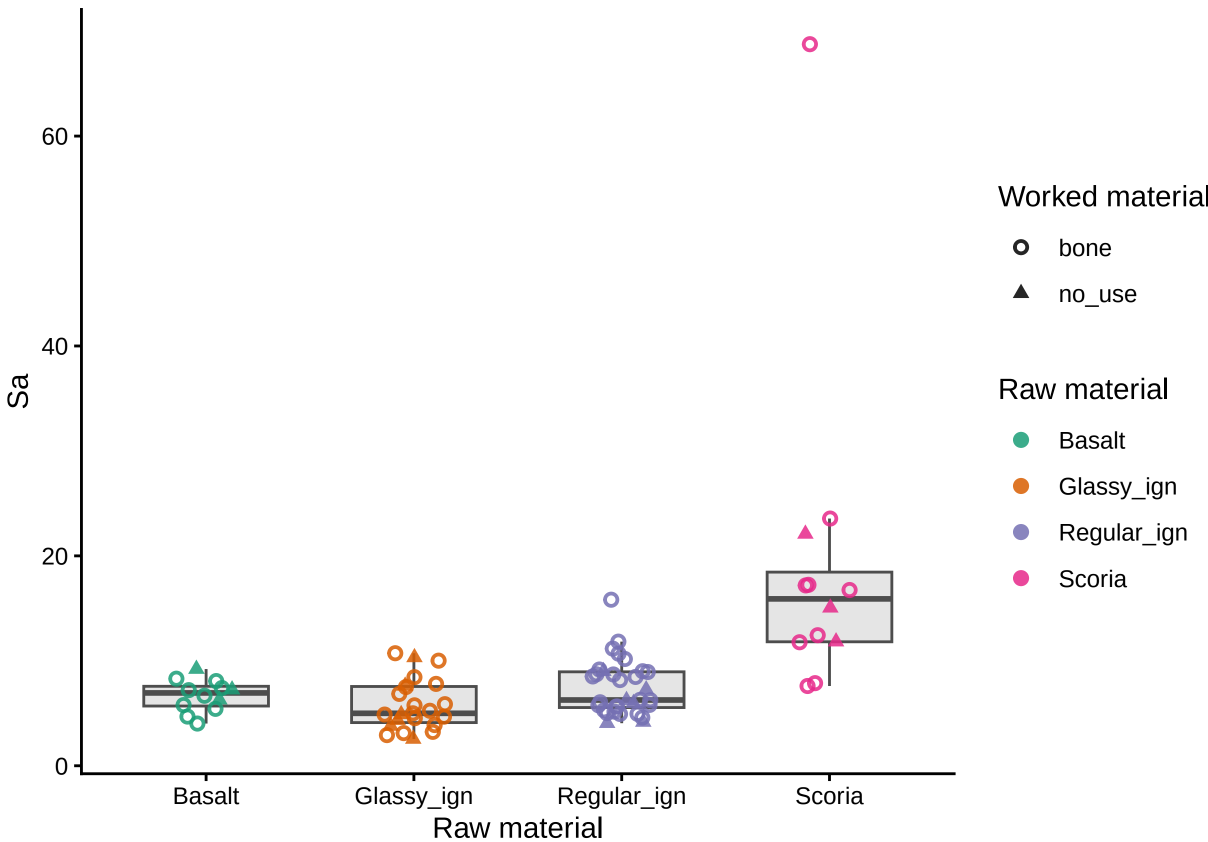

Sv
100
50
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

```
## [28] Sz
```

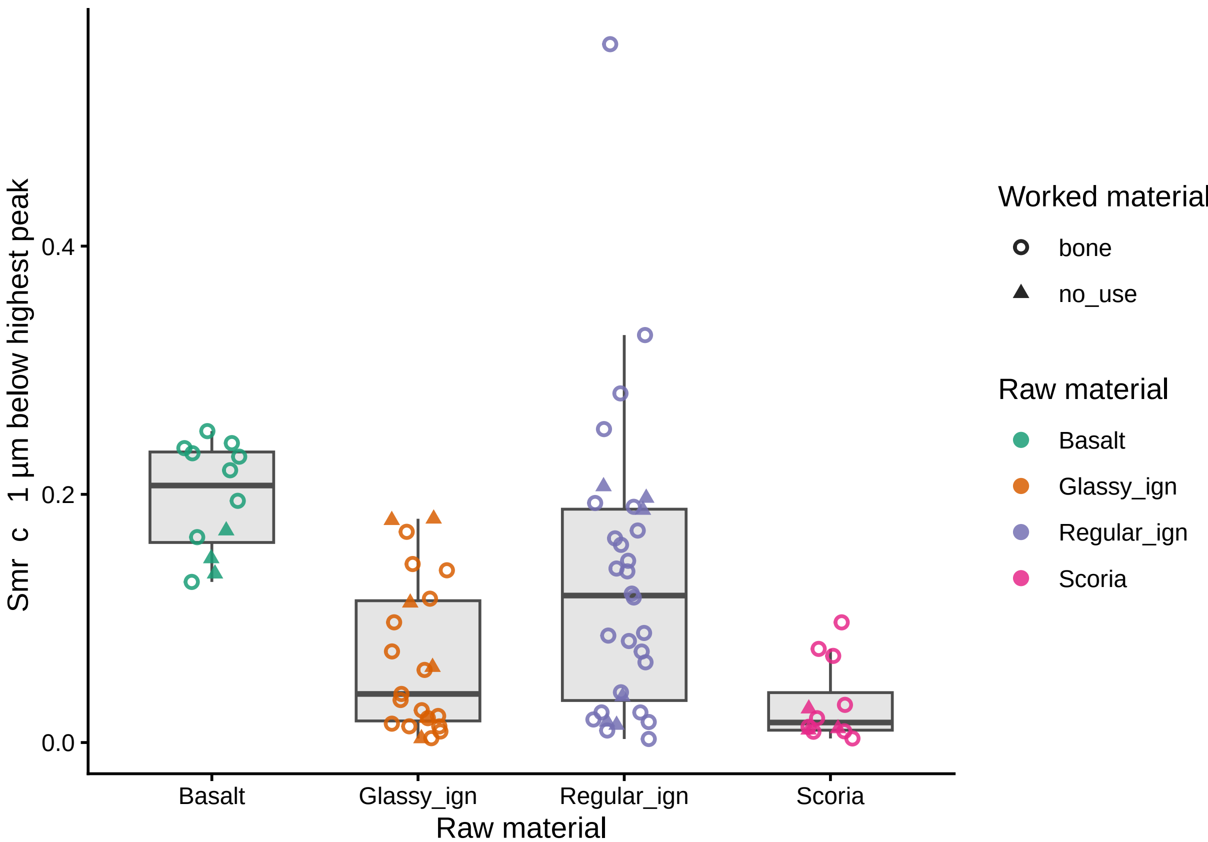


300
200
100
Sz
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [29] Sa
```

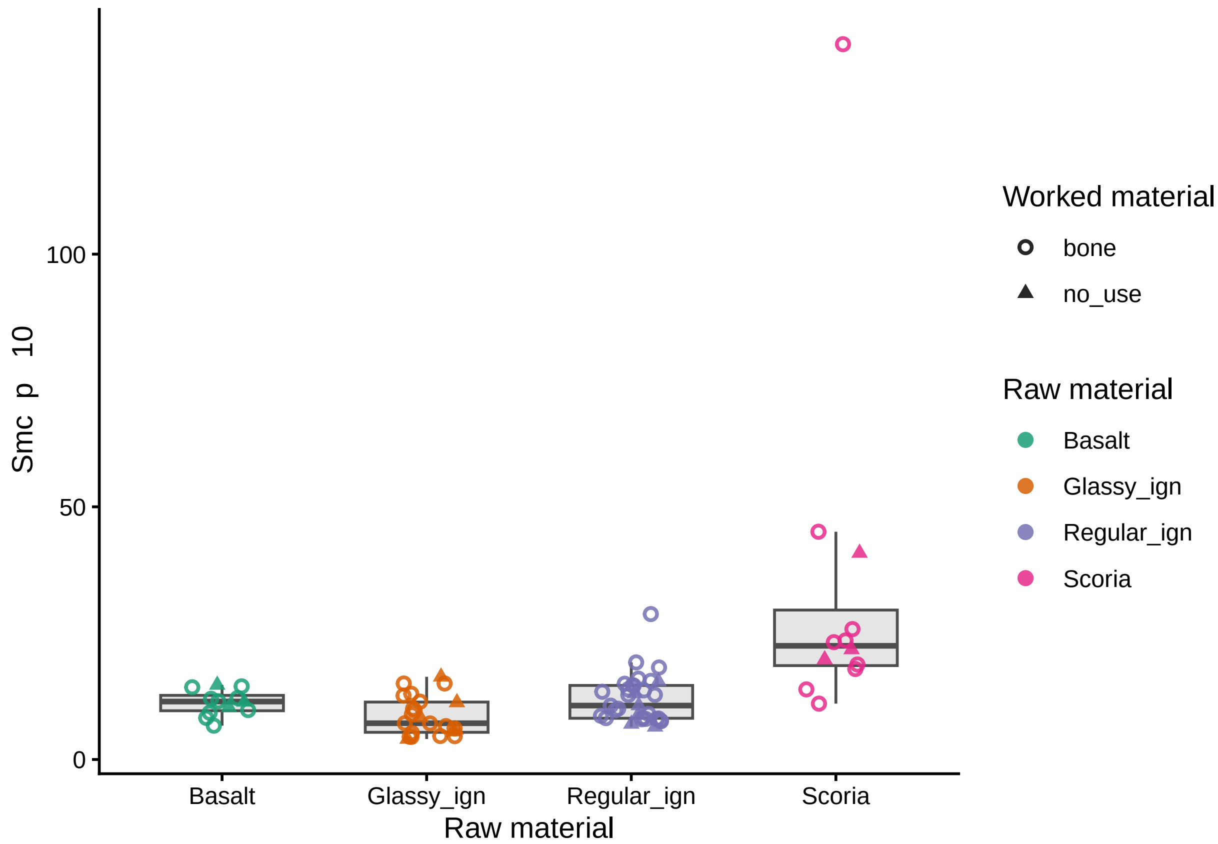



```
## [30] Smr..c...1.µm.below.highest.peak.
```

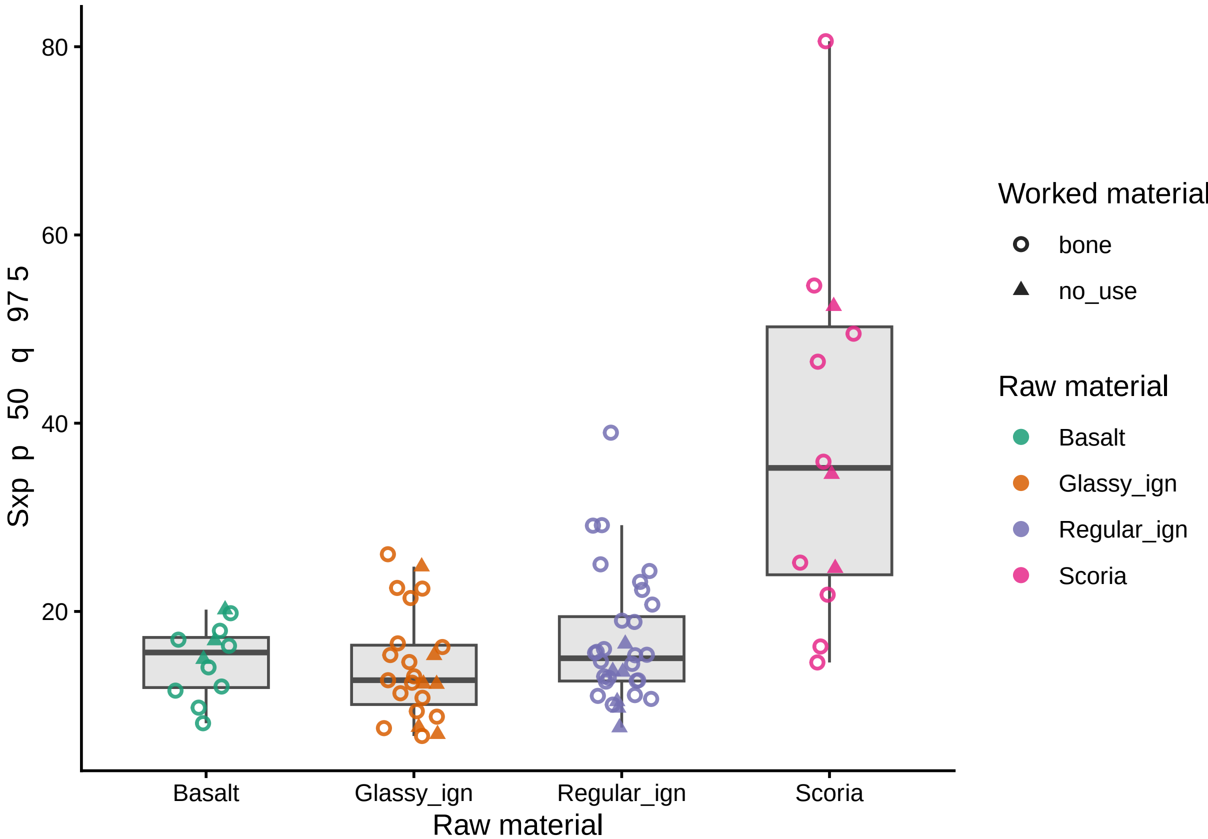


Smr c 1 µm below highest peak
0.0
0.2
0.4
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

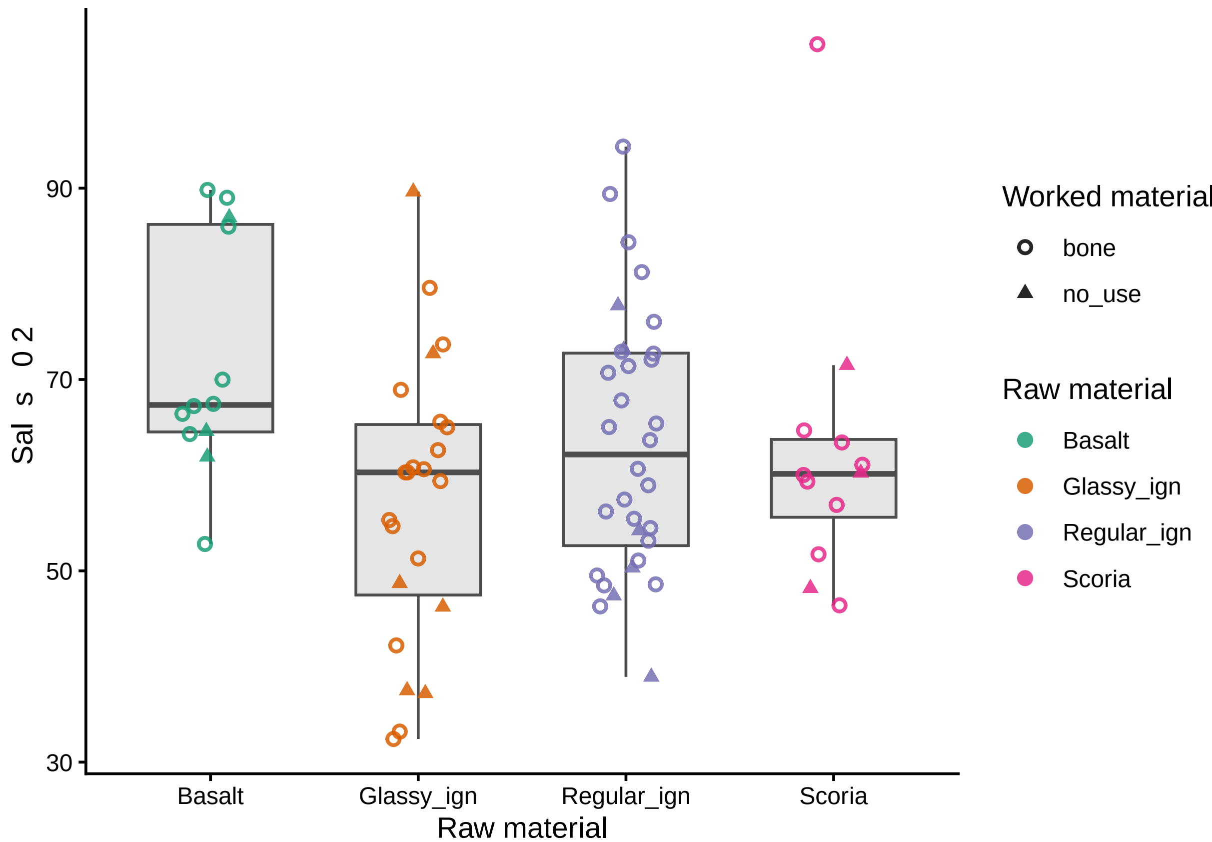

```
## [31] Smc..p...10..
```



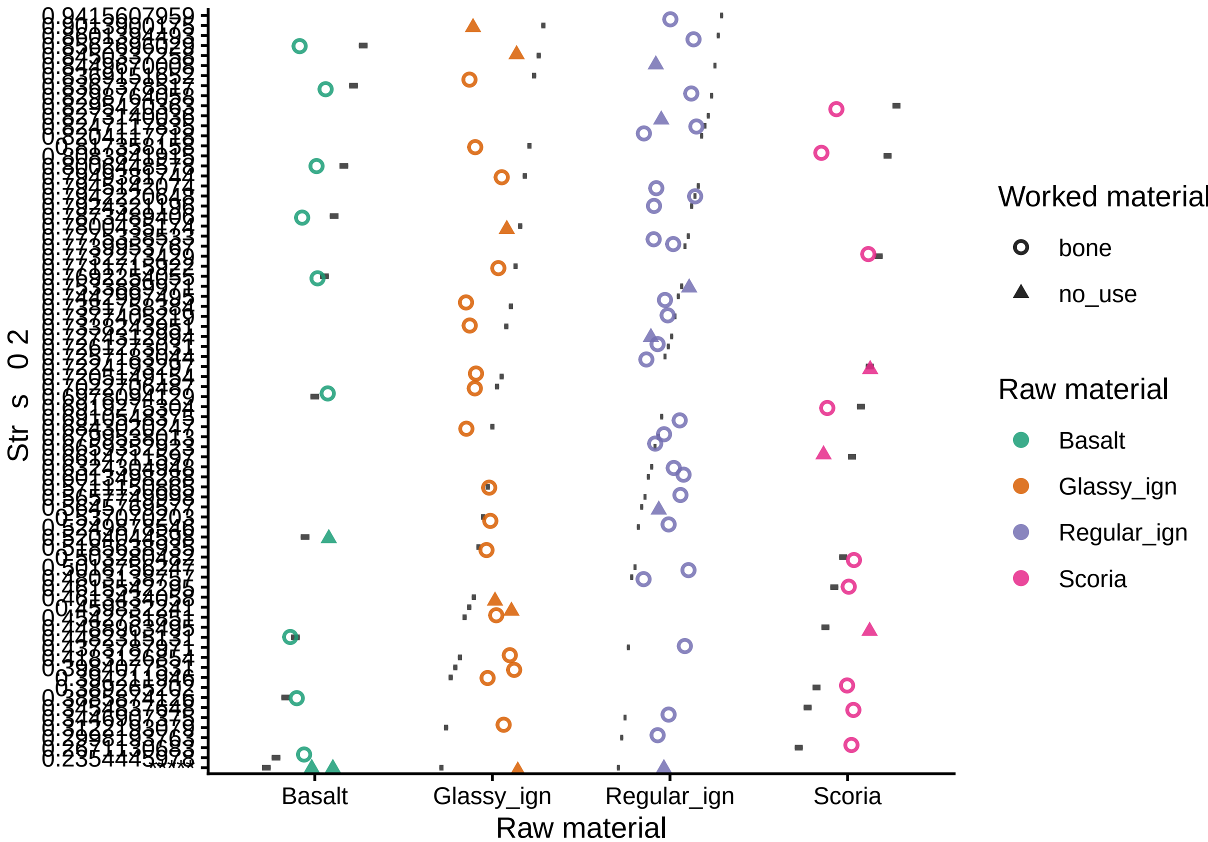

```
## [32] Sxp..p...50...q...97.5..
```


Sxp p 50 q 97 5
80
60
40
20
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

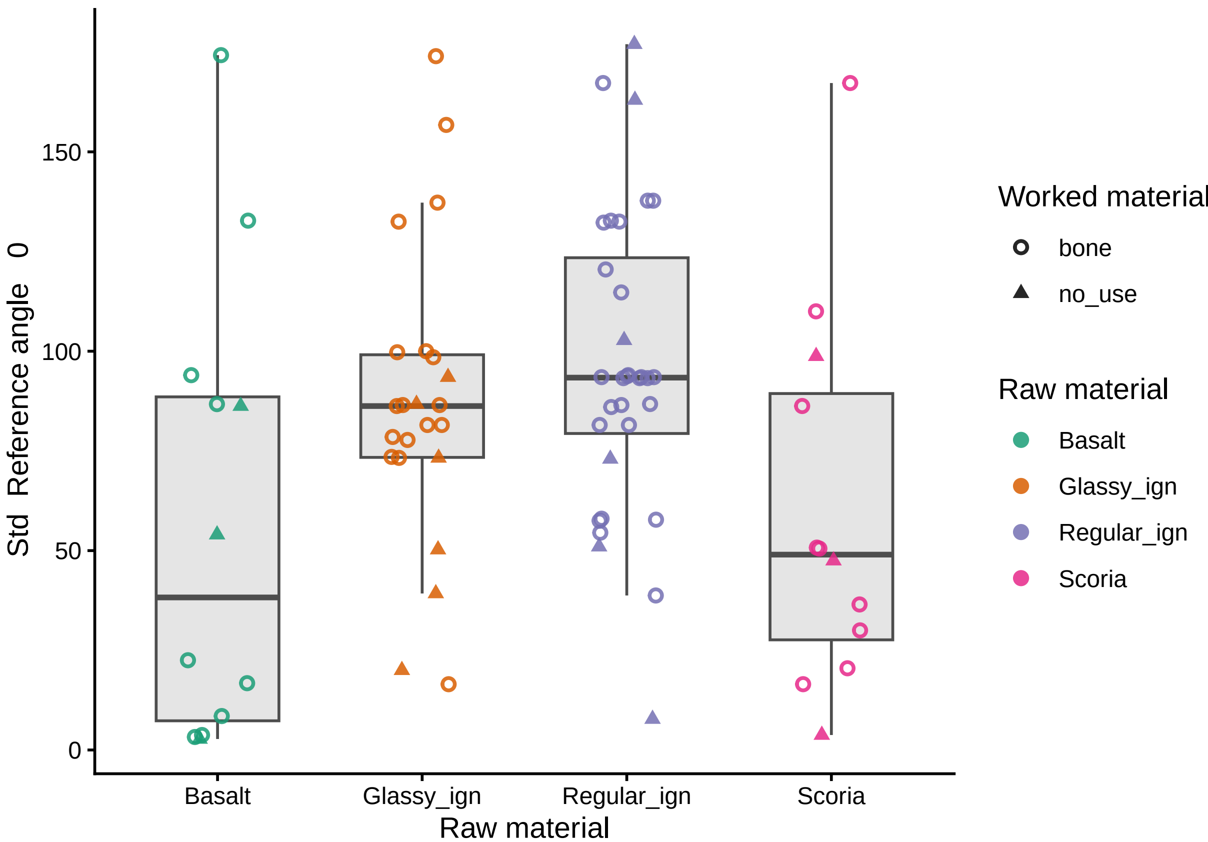
```
## [33] Sal..s...0.2.
```


Sal s 0 2
90
70
50
30
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

```
## [34] Str..s...0.2.
```

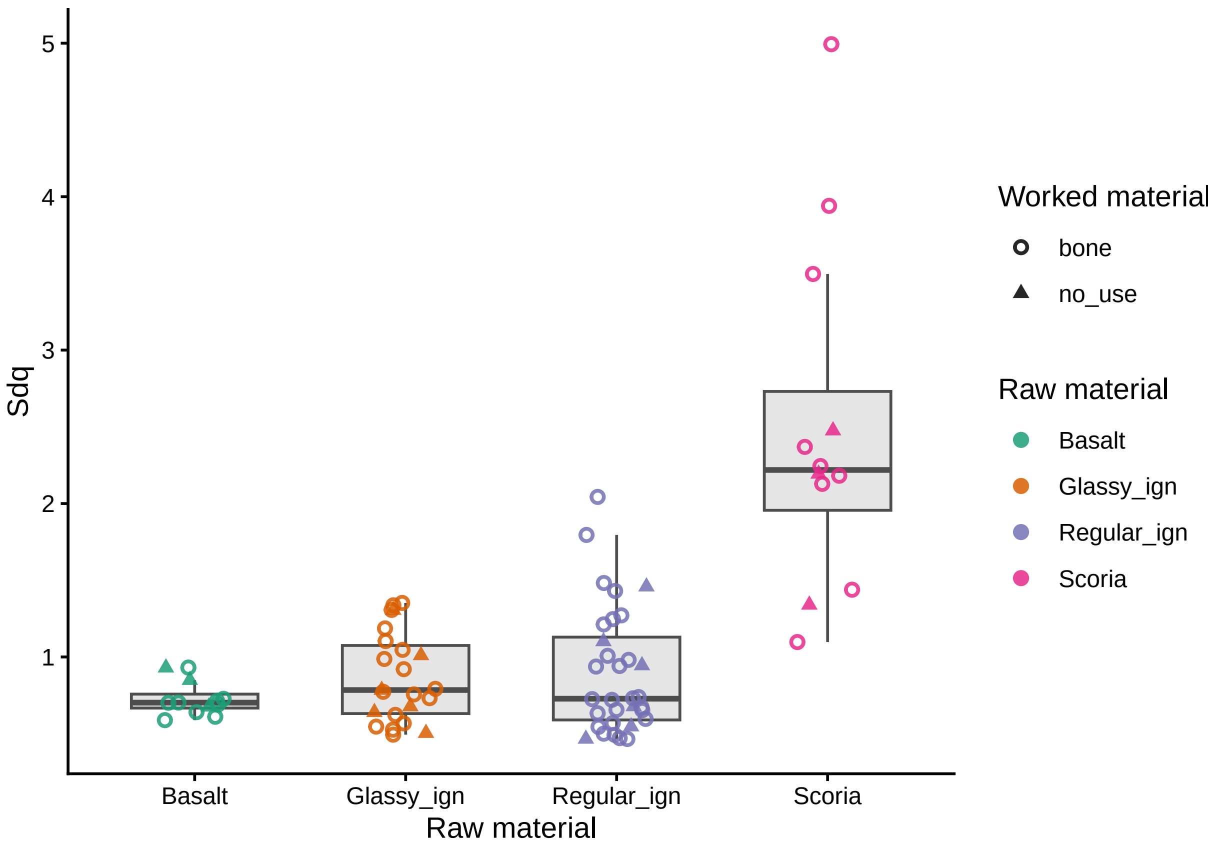



```
## [35] Std..Reference.angle...0..
```



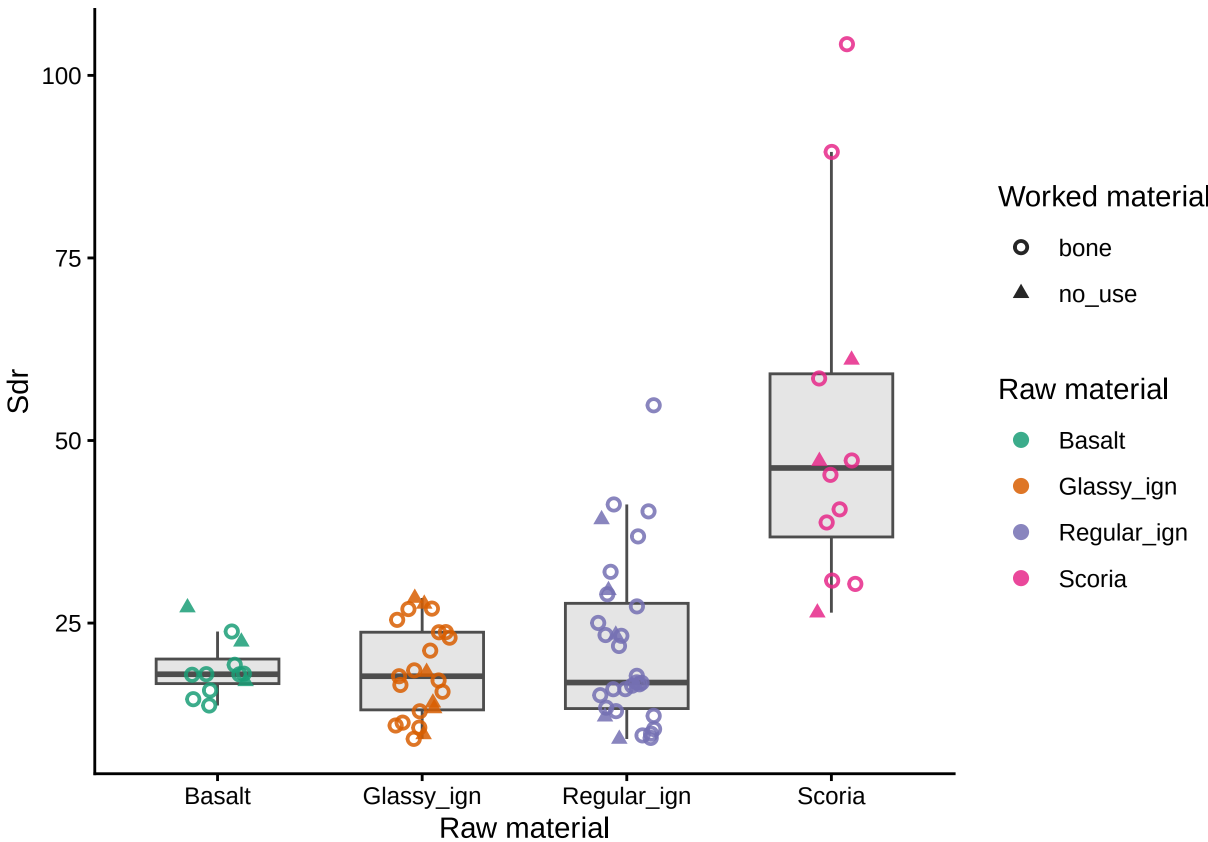
Std Reference angle 0
150
100
50
0
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [36] Sdq
```



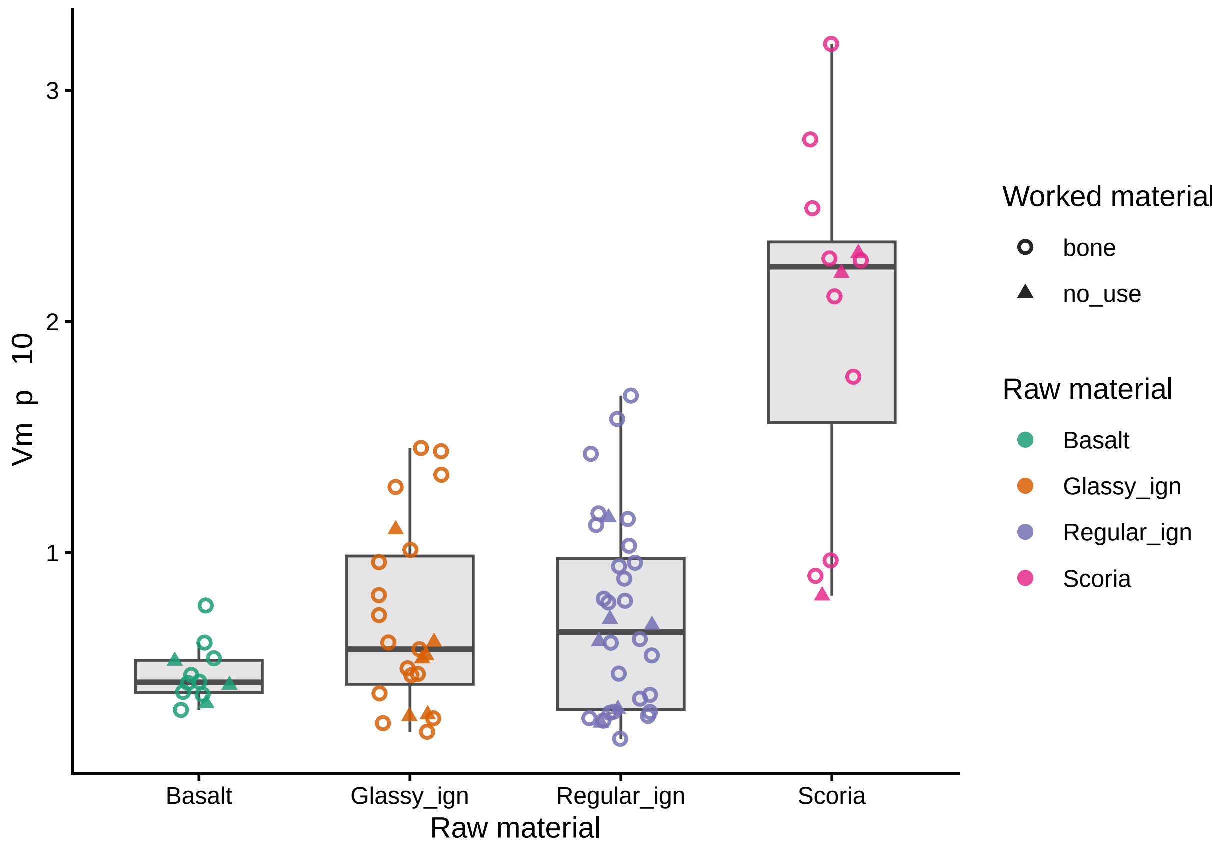
Sdq
5
4
3
2
1
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [37] Sdr
```



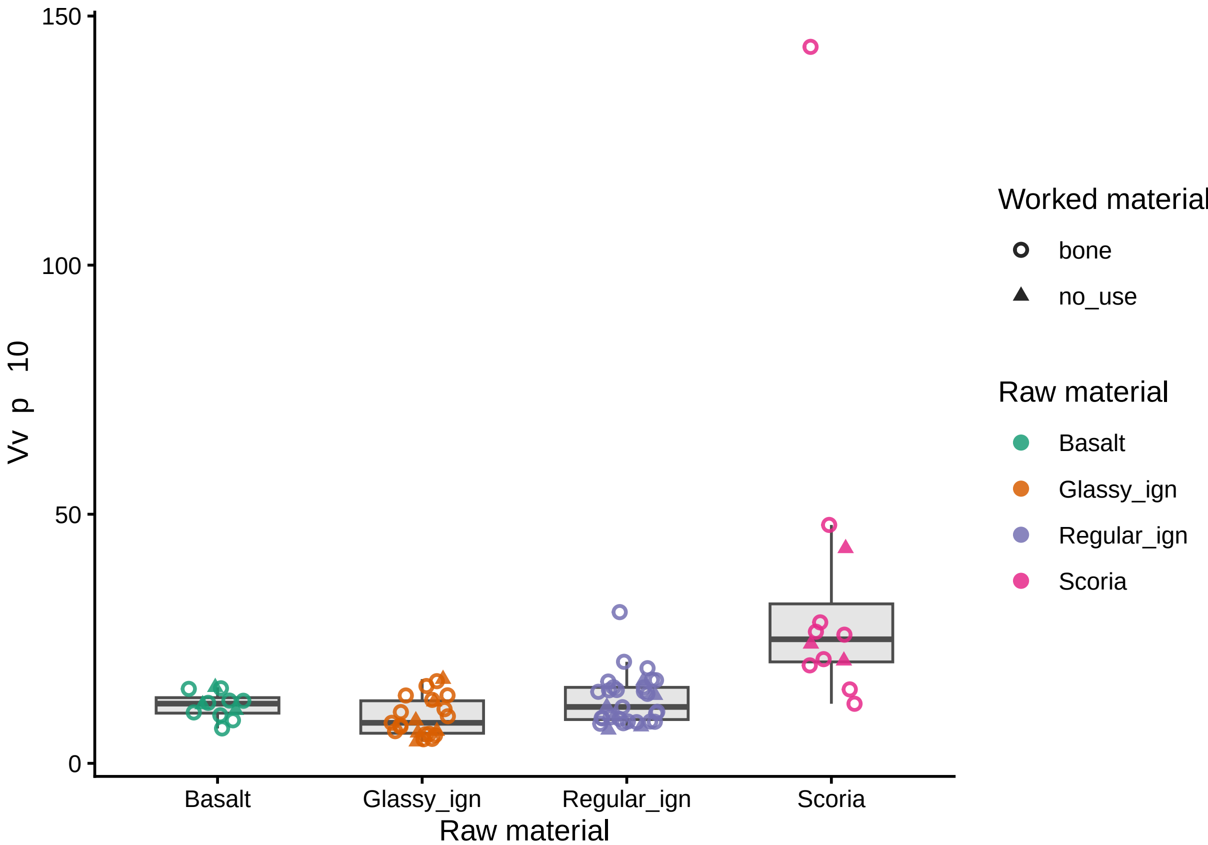
Sdr
100
75
50
25
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria


```
## [38] Vm..p...10..
```

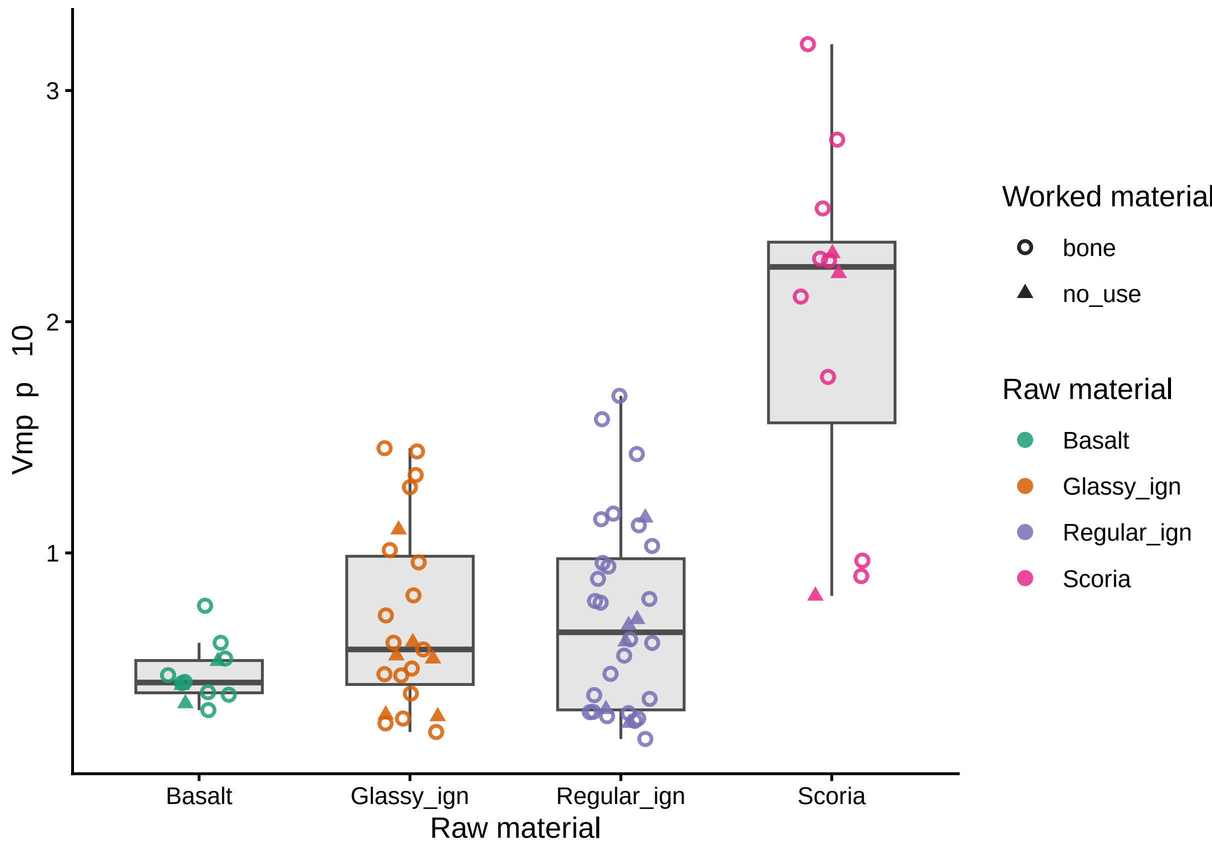


Vm p 10
3
2
1
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

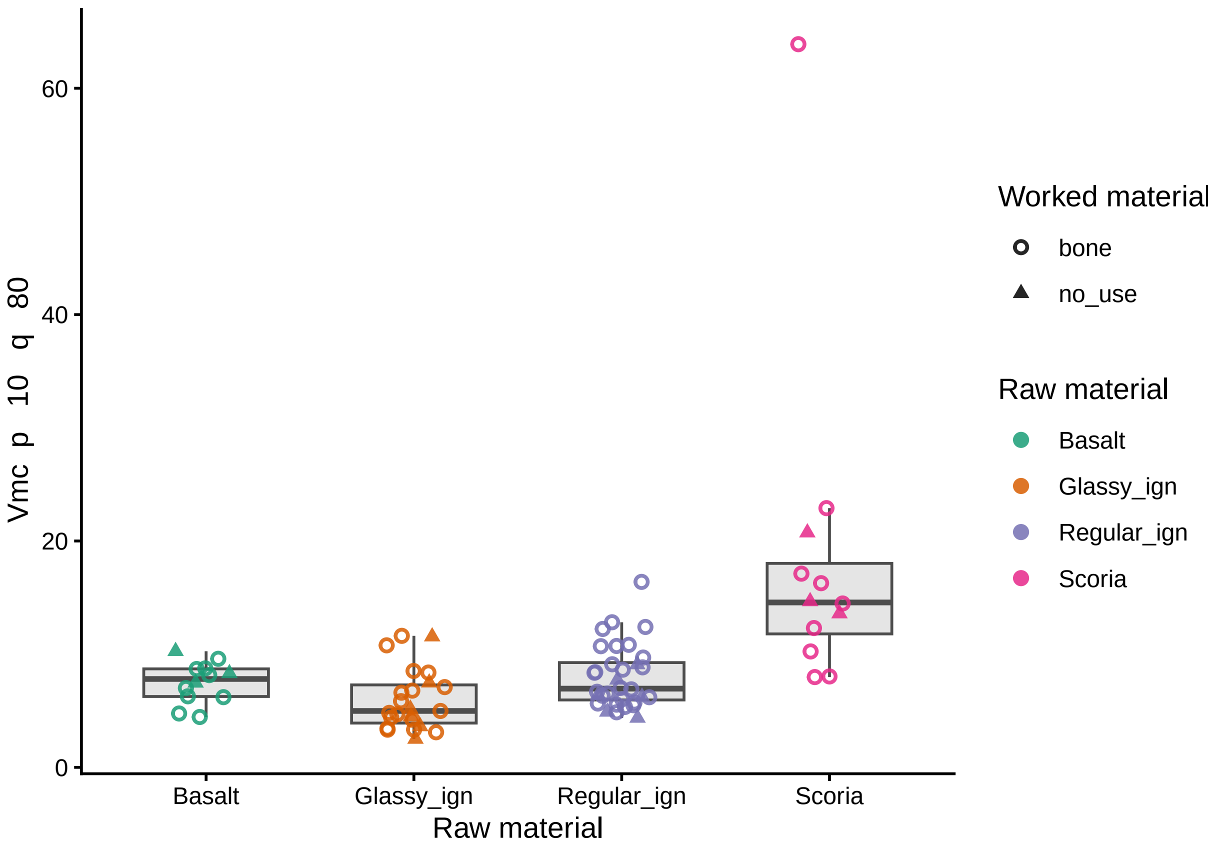

```
## [39] Vv..p...10..
```


150
100
50
0
Vv p 10
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

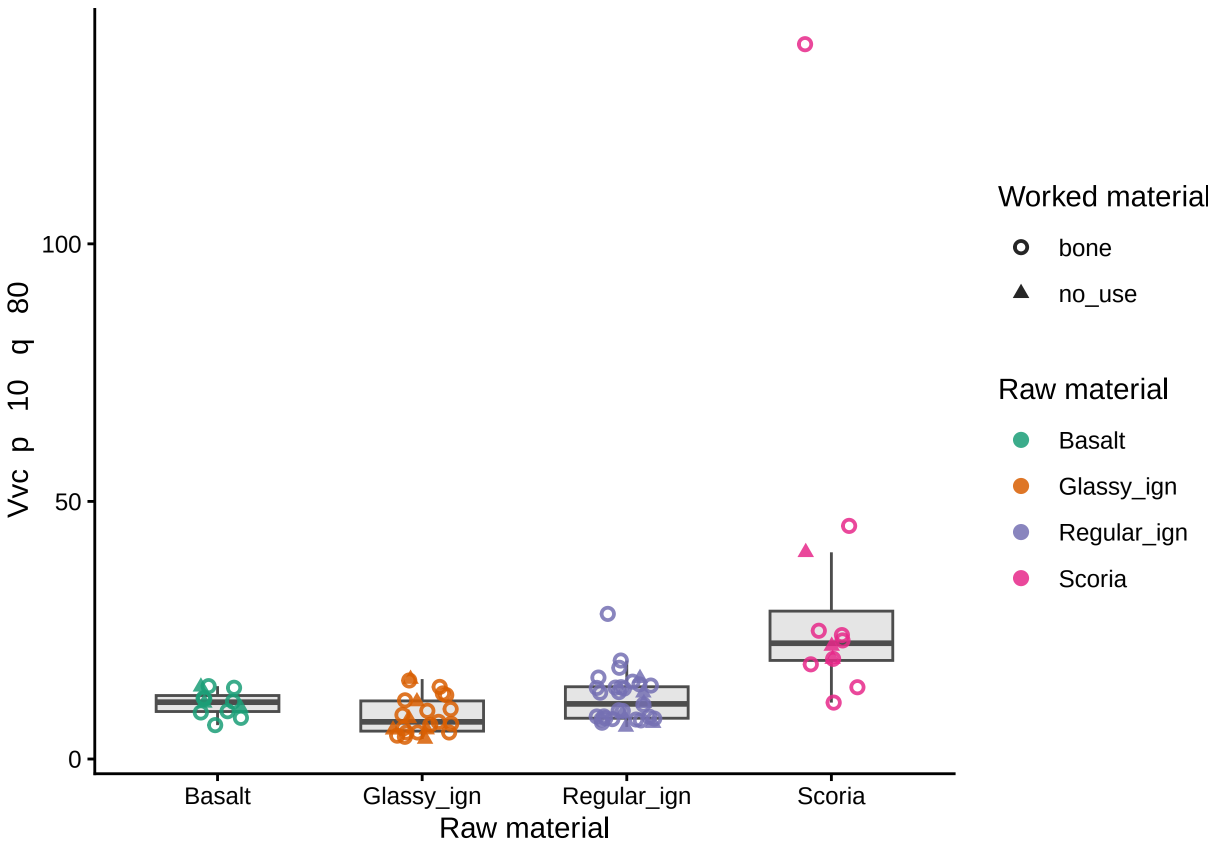
```
## [40] Vmp..p...10..
```



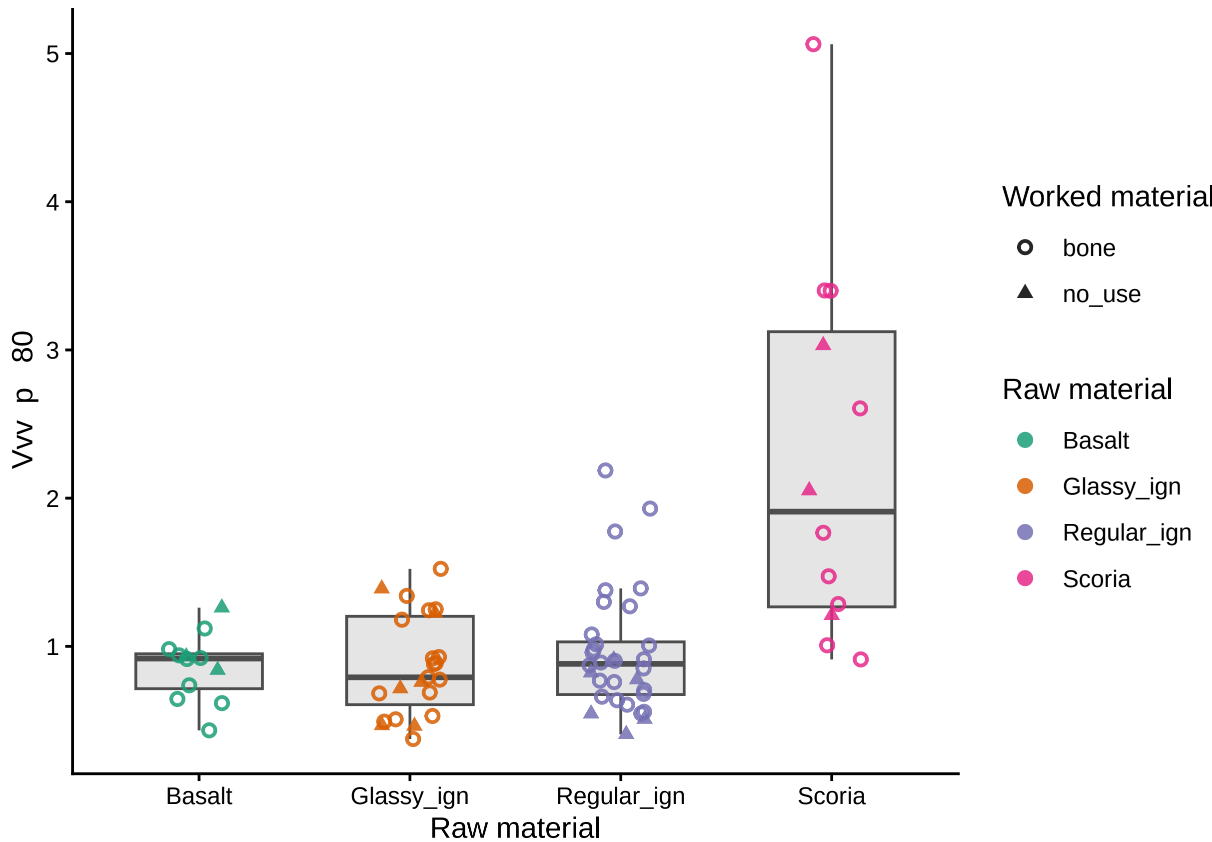

```
## [41] Vmc..p...10...q...80..
```



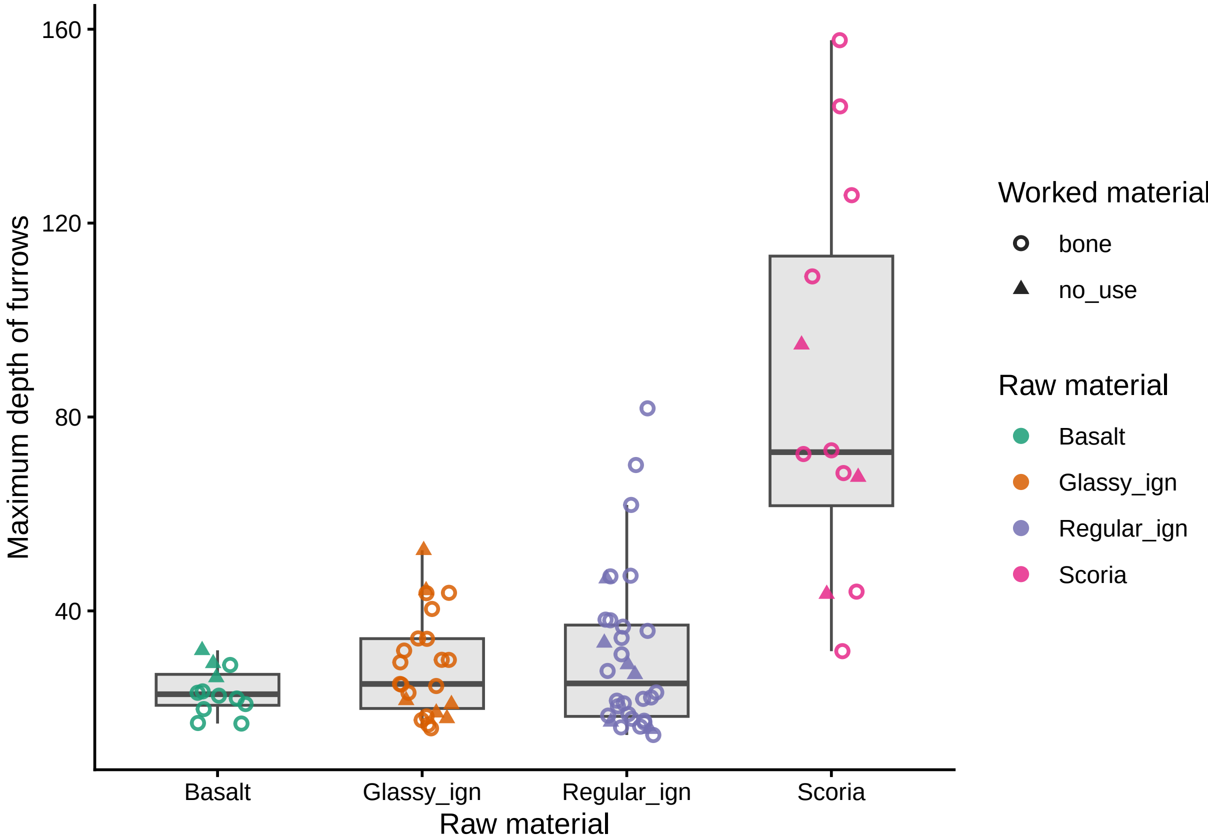

```
## [42] Vvc..p...10...q...80..
```


Vvc p 10 q 80
100
50
0
Basalt
Glassy_ign
Regular_ign
Scoria
Raw material
Worked material
bone
no_use
Raw material
Basalt
Glassy_ign
Regular_ign
Scoria

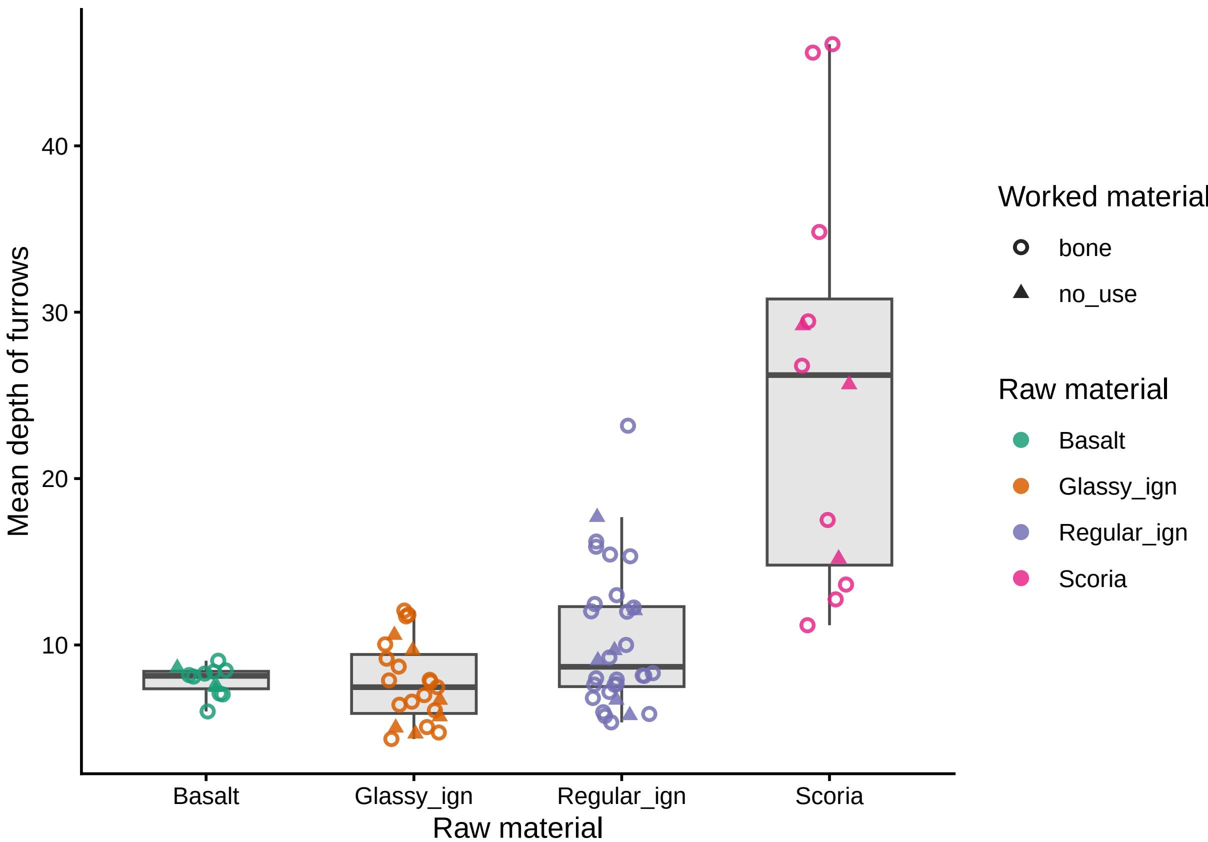
```
## [43] Vvv..p...80..
```



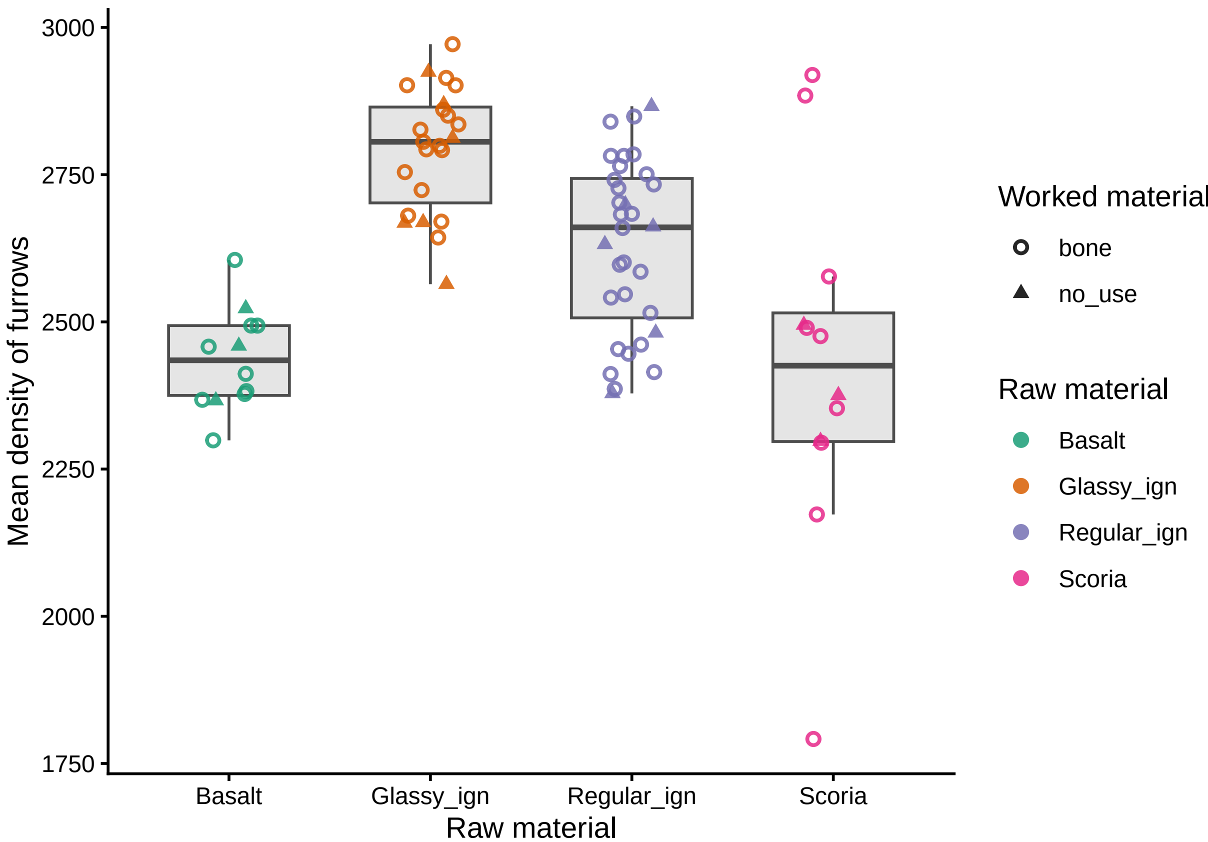

```
## [44] Maximum.depth.of.furrows
```



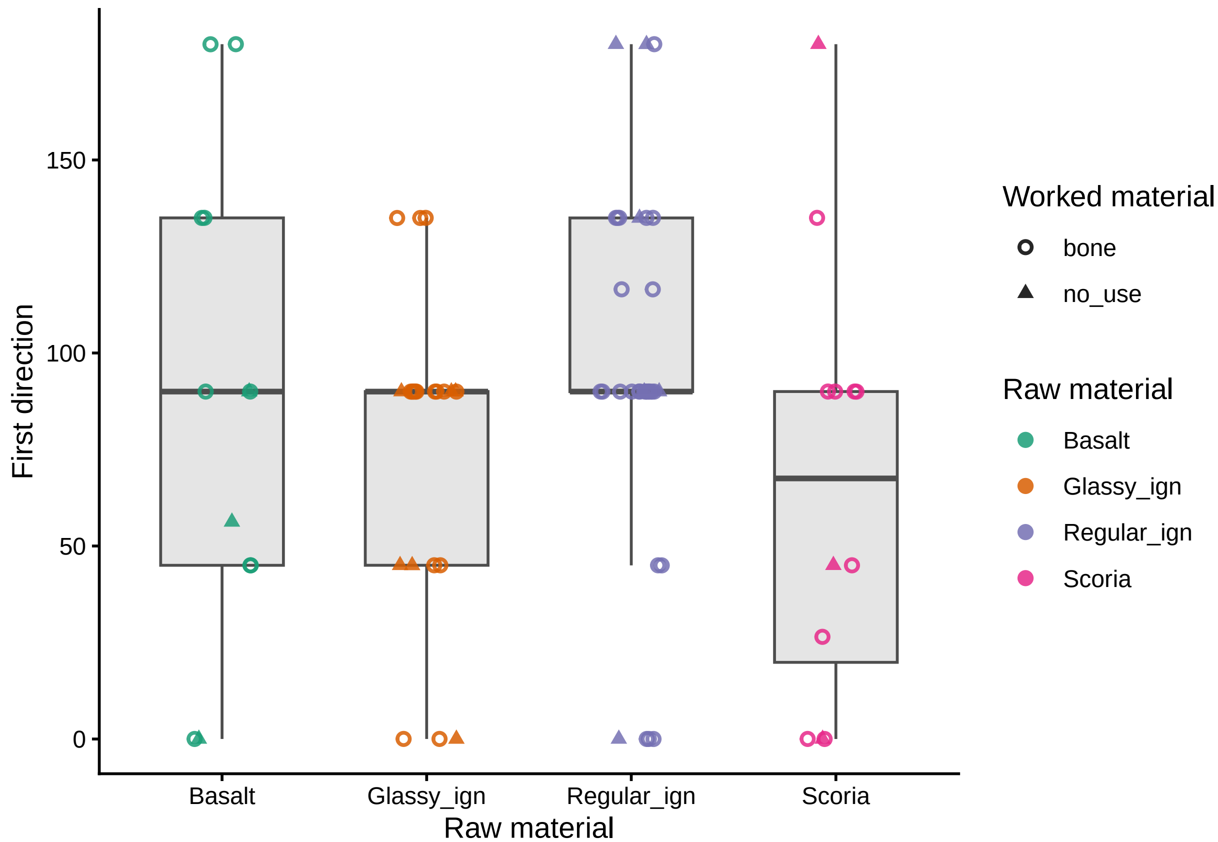

```
## [45] Mean.depth.of.furrows
```



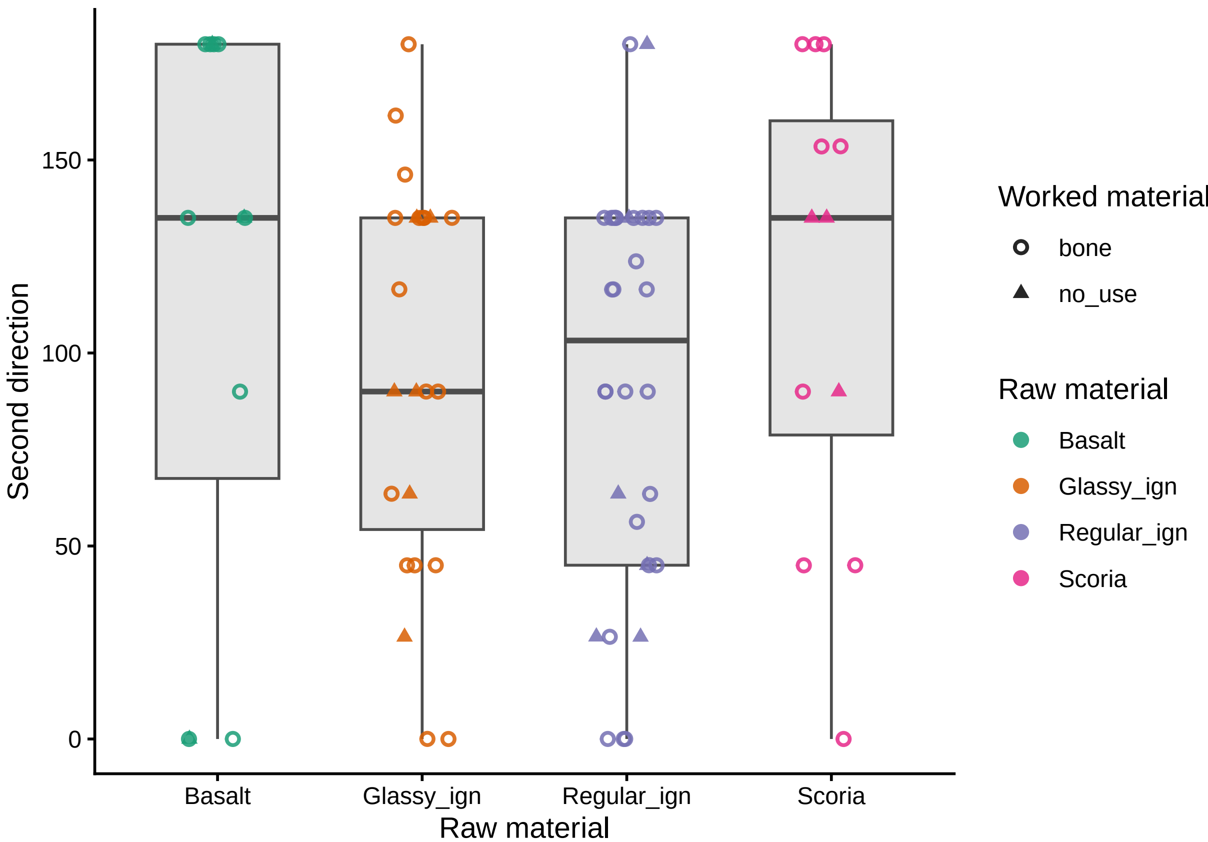

```
## [46] Mean.density.of.furrows
```



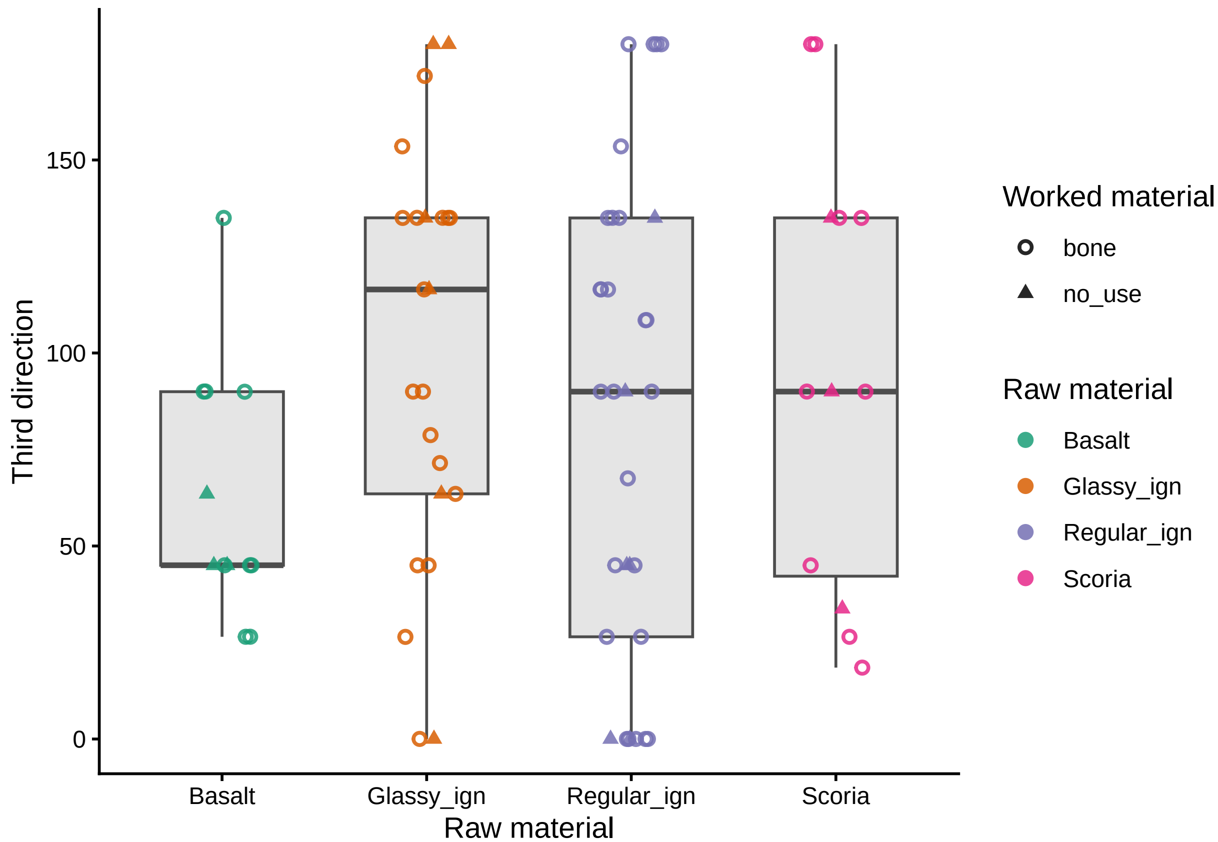

```
## [47] First.direction
```



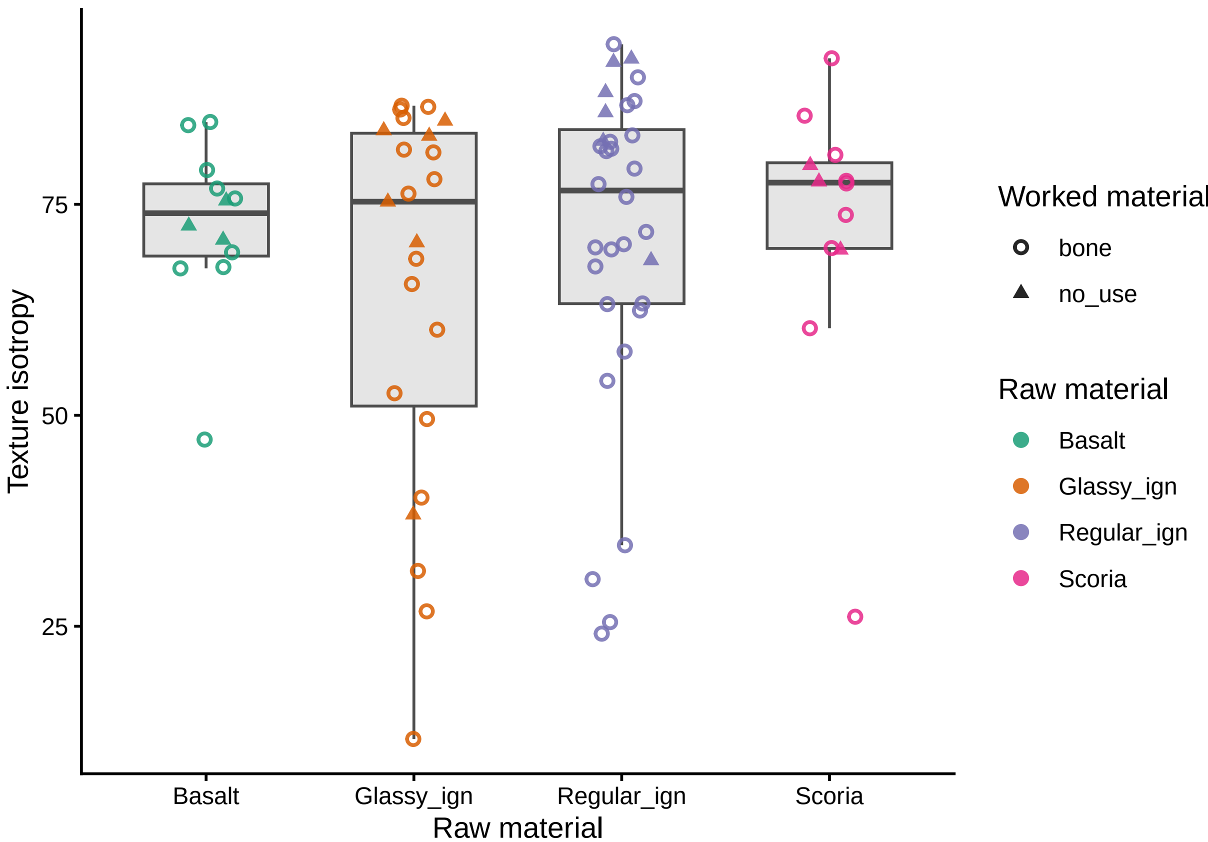

```
## [48] Second.direction
```



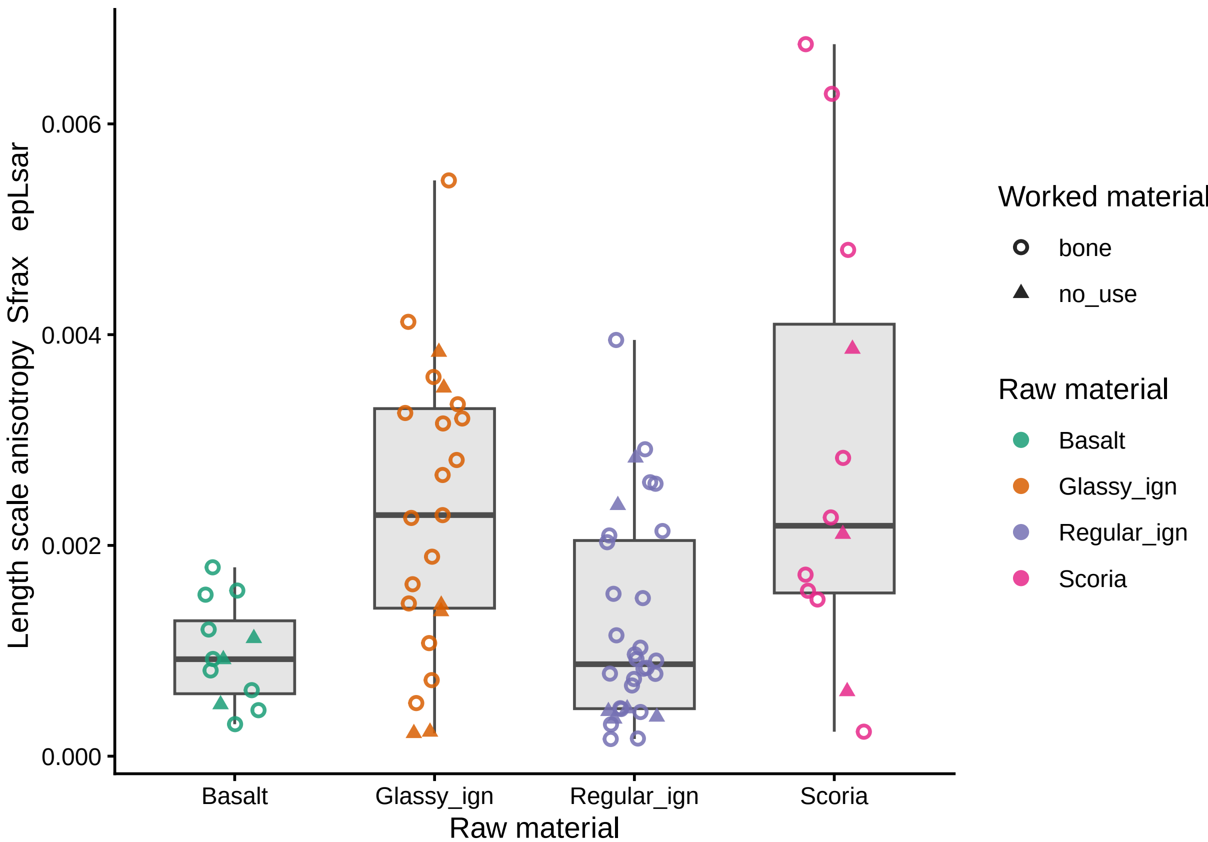

```
## [49] Third.direction
```



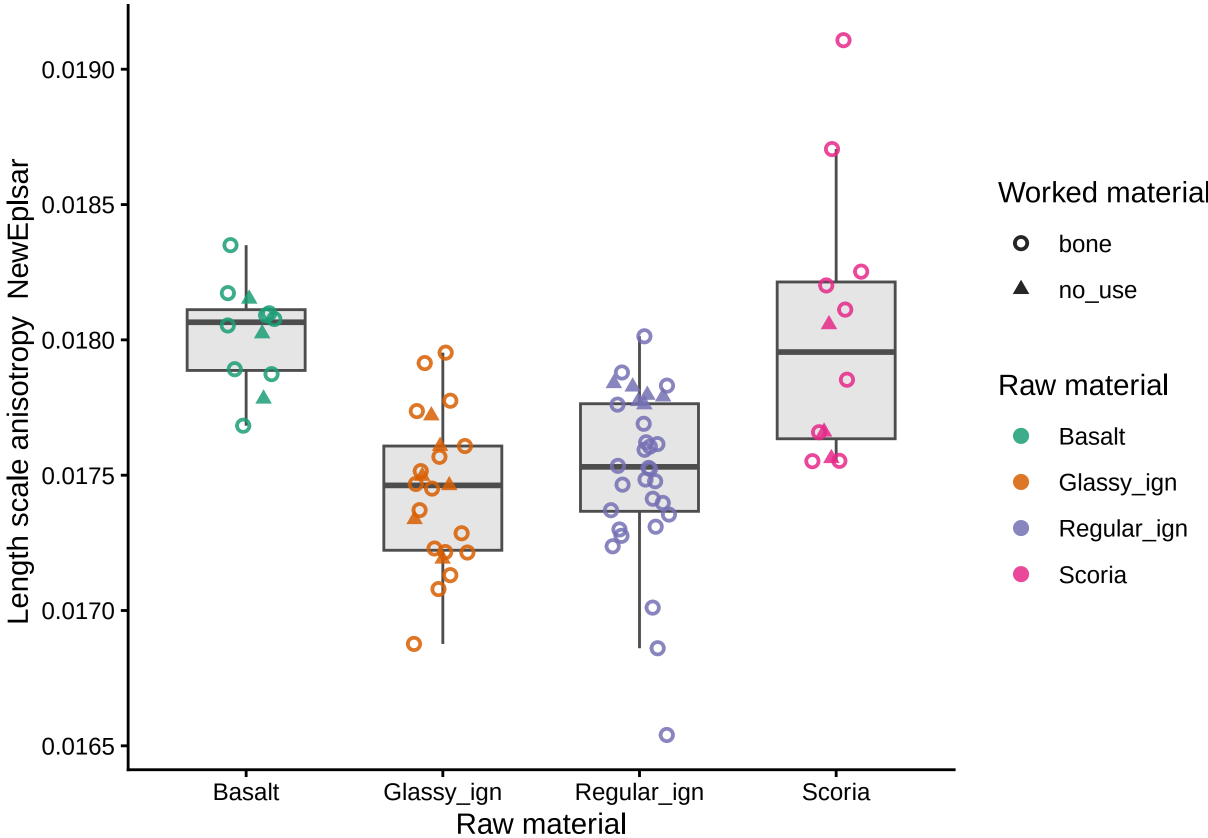

```
## [50] Texture.isotropy
```



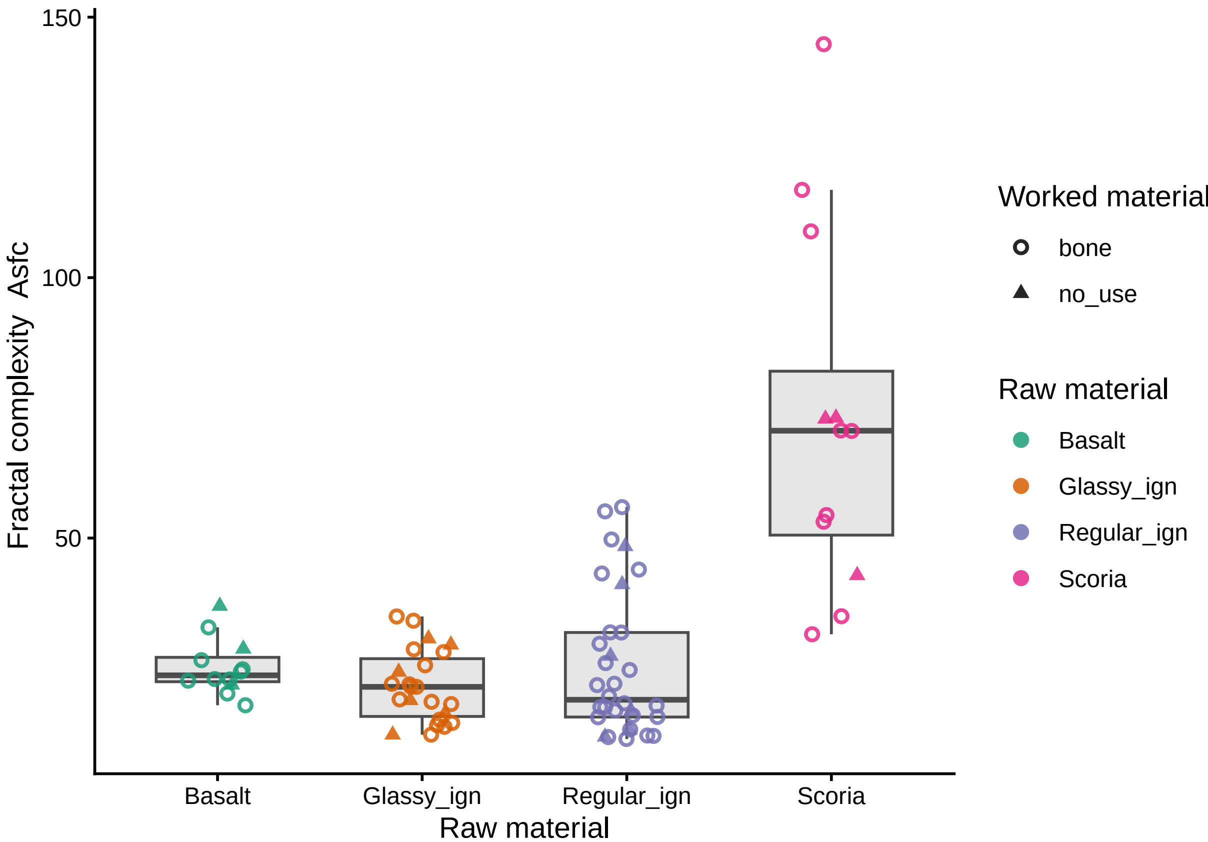

```
## [51] Length.scale.anisotropy..Sfrax...epLsar.
```



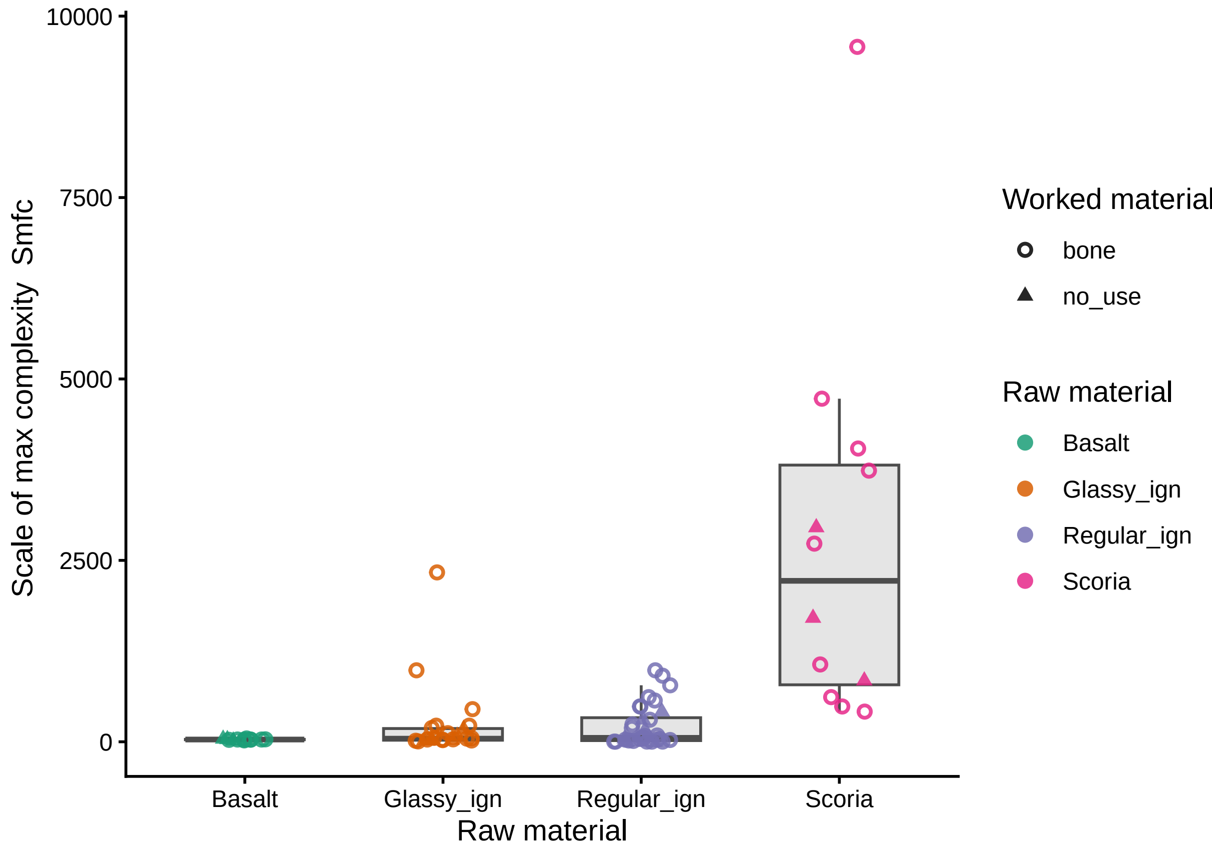

```
## [52] Length.scale.anisotropy..NewEplsar.
```



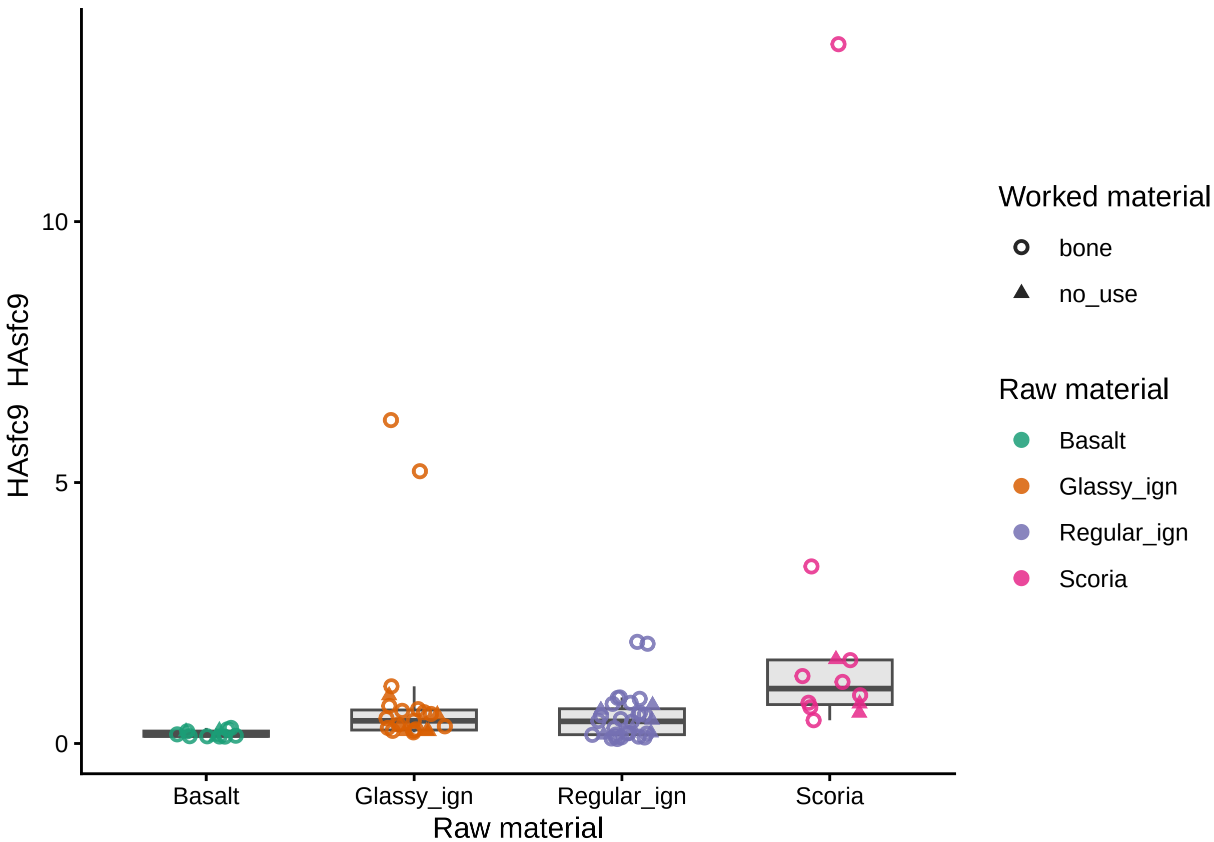

```
## [53] Fractal.complexity..Asfc.
```



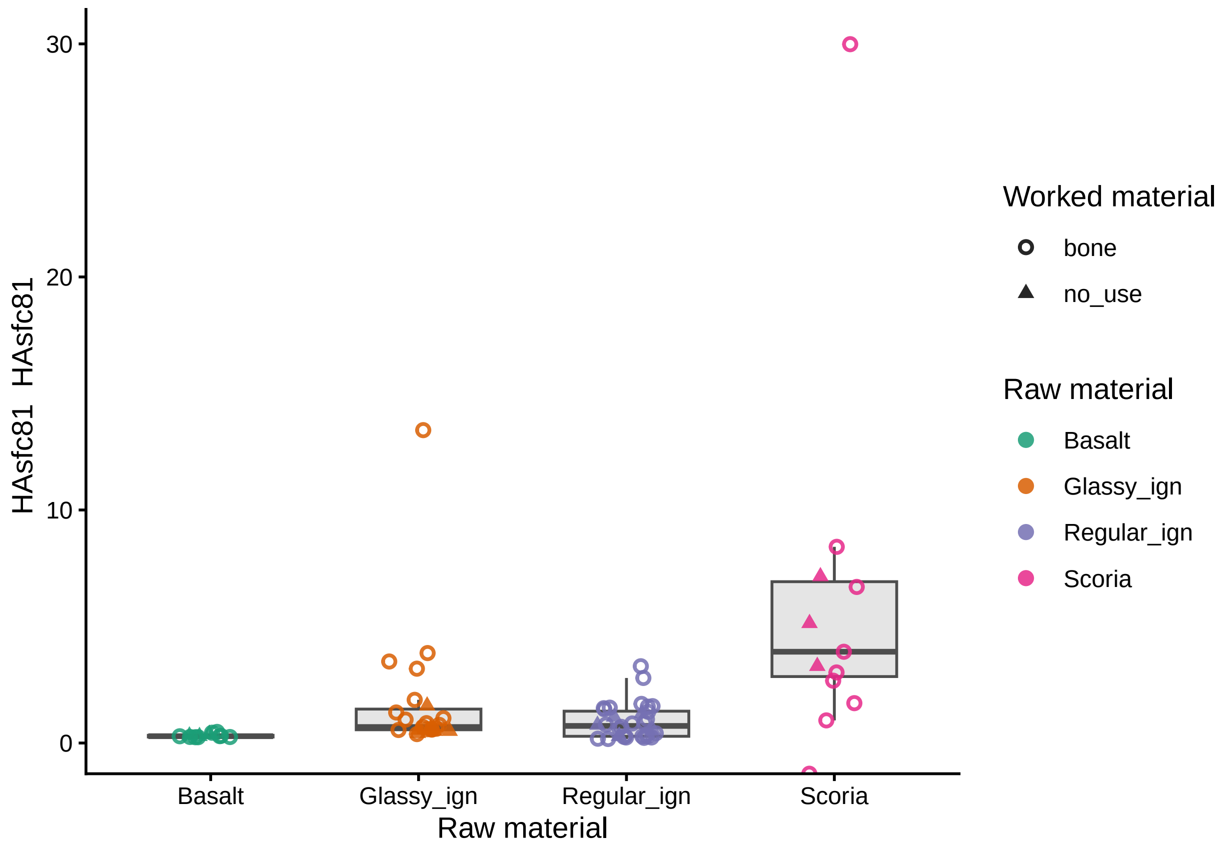

```
## [54] Scale.of.max.complexity..Smfc.
```




```
## [55] HAsfc9..HAsfc9.
```



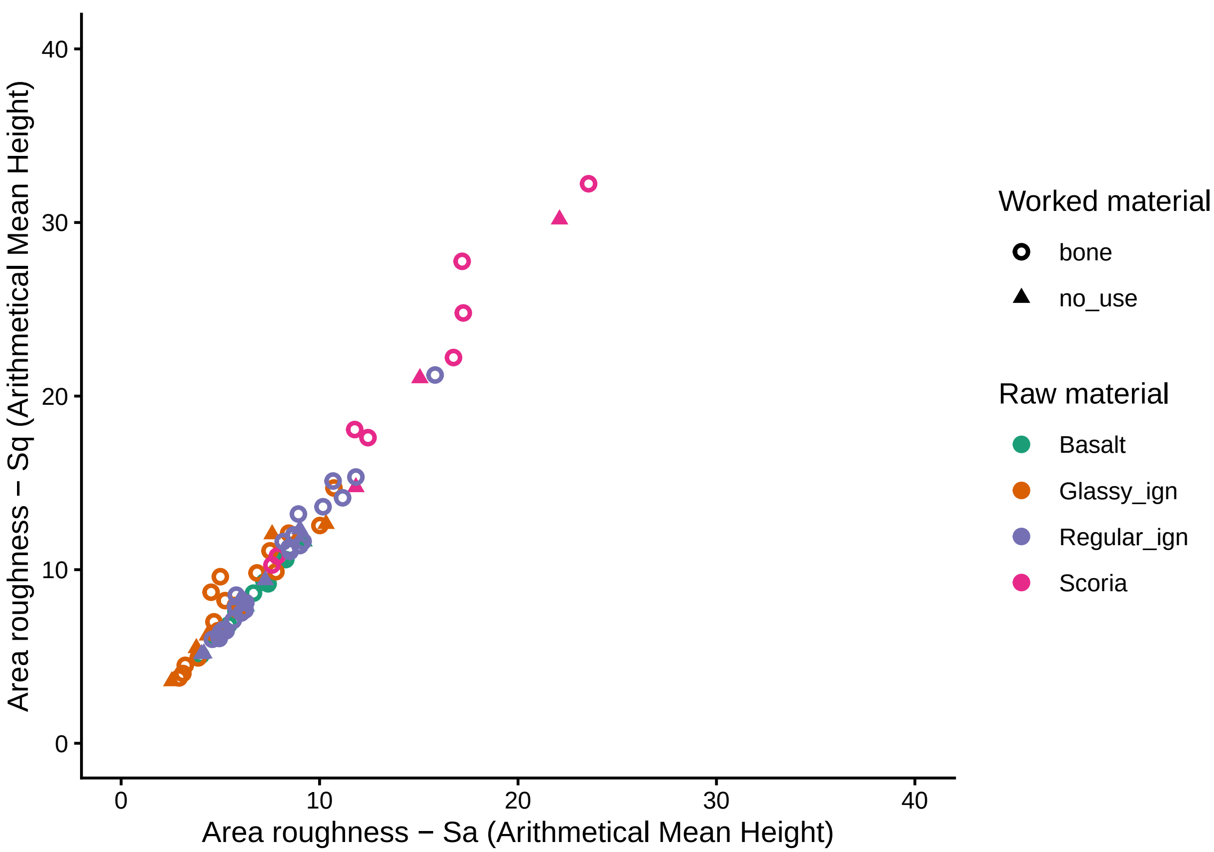

```
## [56] HAsfc81..HAsfc81.

## Warning: Removed 1 row containing non-finite outside the scale range (`stat_boxplot()`).
## Removed 1 row containing non-finite outside the scale range (`stat_boxplot()`).
```



Scatterplots of selected variables combined by "Worked material" and "Motion"

```
# Main parameters
    #   Sq, Sa → overall roughness
    #   Vmc → load-bearing core volume
    #   Asfc / Smfc → complexity (use-wear intensity)
    #   Furrow depth & density → contact mechanics


# Sa vs. Sq, overall roughness


Sa_Sq <- ggplot(confocaldata) +
  geom_point(
    aes(
      x = Sa,
      y = Sq,
      colour = Raw_material,
      shape  = Worked_material
    ),
    size = 1.5,
    stroke = 1.2
  ) +
  coord_cartesian(
    xlim = c(0, 40),
```

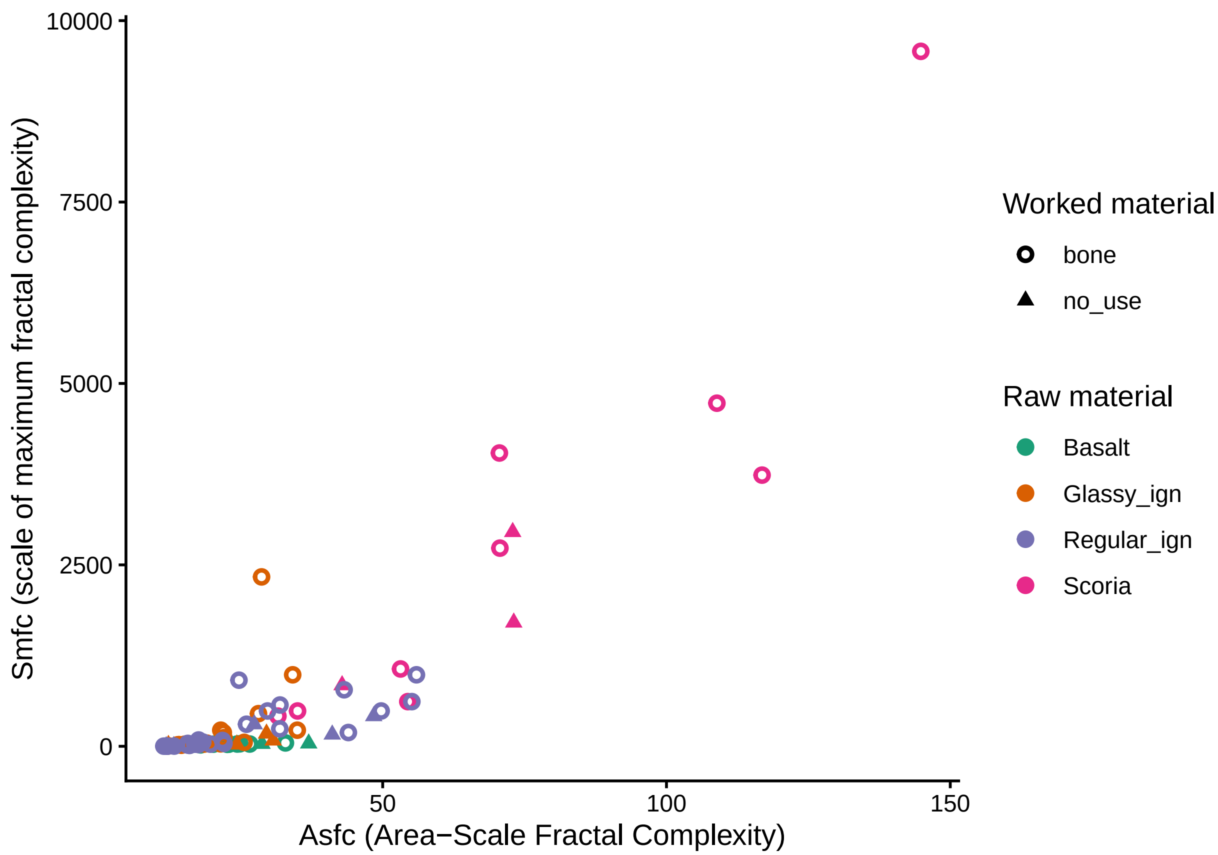
```r
    ylim = c(0, 40)
  ) +
  theme_classic() +
  labs(
    x = "Area roughness - Sa (Arithmetical Mean Height)",
    y = "Area roughness - Sq (Arithmetical Mean Height)",
    colour = "Raw material",
    shape  = "Worked material"
  ) +
  scale_colour_brewer(palette = "Dark2") +
  scale_shape_manual(
    values = c(
      bone   = 1,    # open circle
      no_use = 17    # filled triangle
    )
  )

print(Sa_Sq)
```




```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_scatterplot_Sa-Sq", ".pdf")
ggsave(filename = file_out, plot = Sa_Sq, path = "analysis/plots", device = "pdf")
```

```
## Saving 6.5 x 4.5 in image
```

```r
# Asfc / Smfc → complexity (use-wear intensity)

asfc_smfc <- ggplot(confocaldata) +
  geom_point(
    aes(
      x = Fractal.complexity..Asfc.,
      y = Scale.of.max.complexity..Smfc.,
      colour = Raw_material,
      shape  = Worked_material
    ),
    size = 1.5,
    stroke = 1.2
  ) +
  theme_classic() +
  labs(
    x = "Asfc (Area-Scale Fractal Complexity)",
    y = "Smfc (scale of maximum fractal complexity)",
    colour = "Raw material",
    shape  = "Worked material"
  ) +
  scale_colour_brewer(palette = "Dark2") +
  scale_shape_manual(
    values = c(
      bone   = 1,
      no_use = 17
    )
  )

print(asfc_smfc)
```

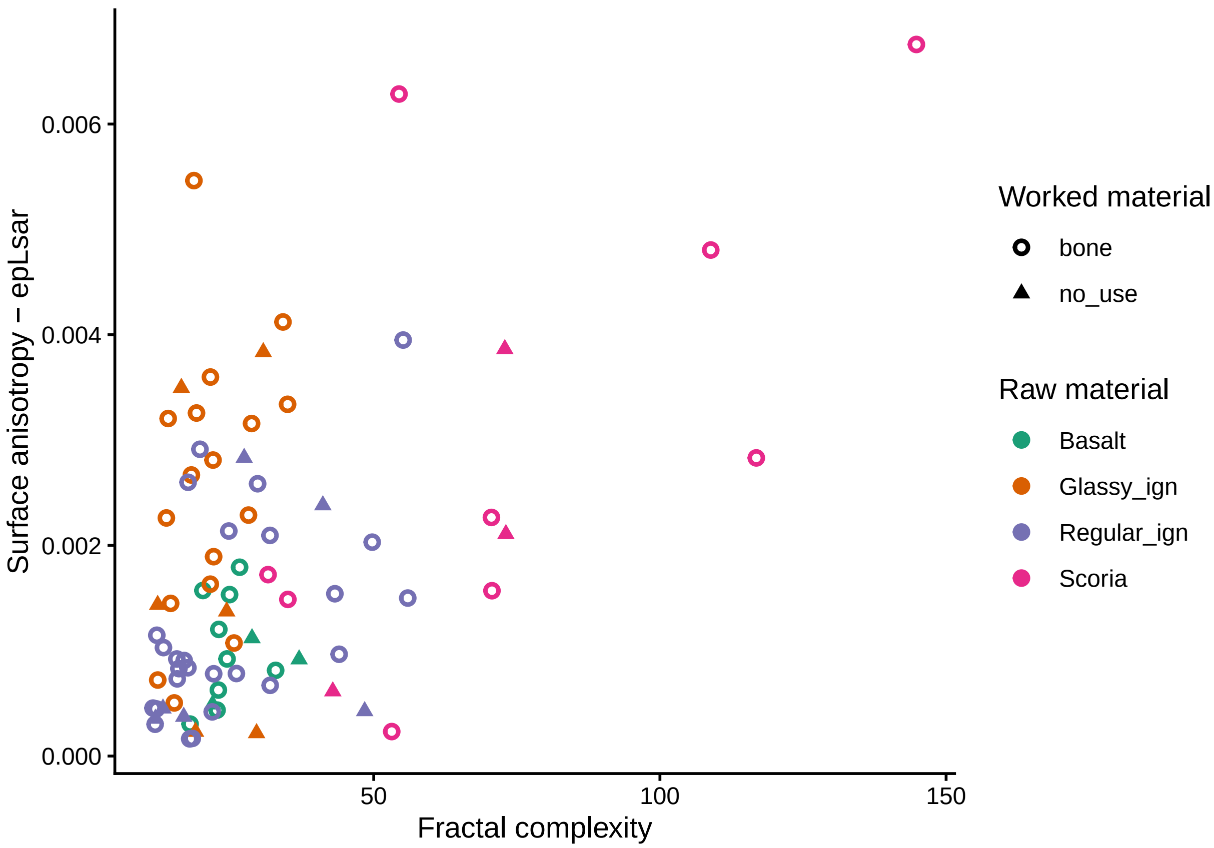



```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_scatterplot_asfc_smfc", ".pdf")
ggsave(filename = file_out, plot = asfc_smfc, path = "analysis/plots", device = "pdf")
```

```
## Saving 6.5 x 4.5 in image
```

```
# epLsar vs. Asfc

ep_As <- ggplot(confocaldata) +
  geom_point(
    aes(
      x = Fractal.complexity..Asfc.,
      y = Length.scale.anisotropy..Sfrax...epLsar.,
      colour = Raw_material,
      shape  = Worked_material
    ),
    size = 1.5,
    stroke = 1.2
  ) +
  theme_classic() +
  labs(
    x = "Fractal complexity",
    y = "Surface anisotropy - epLsar",
    colour = "Raw material",
    shape  = "Worked material"
  ) +
  scale_colour_brewer(palette = "Dark2") +
```

```r
  scale_shape_manual(
    values = c(
      bone   = 1,
      no_use = 17
    )
  )

print(ep_As)
```

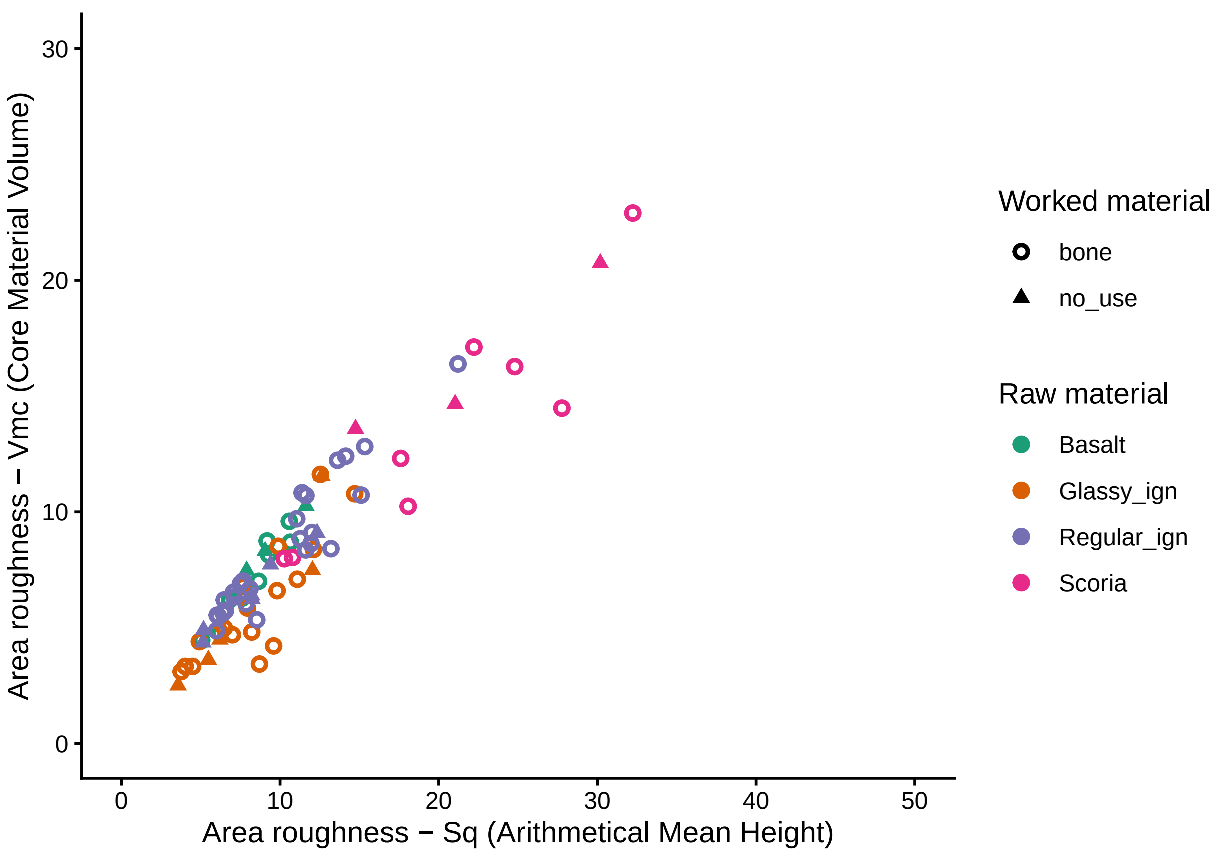



```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_scatterplot_Asfc-epLsar", ".pdf")
ggsave(filename = file_out, plot = ep_As, path = "analysis/plots", device = "pdf")
```

```
## Saving 6.5 x 4.5 in image
```

```r
#   Vmc → load-bearing core volume agains Sq

Sq_Vmc <- ggplot(confocaldata) +
  geom_point(
    aes(
      x = Sq,
      y = Vmc..p...10...q...80..,
      colour = Raw_material,
      shape  = Worked_material
    ),
    size = 1.5,
```

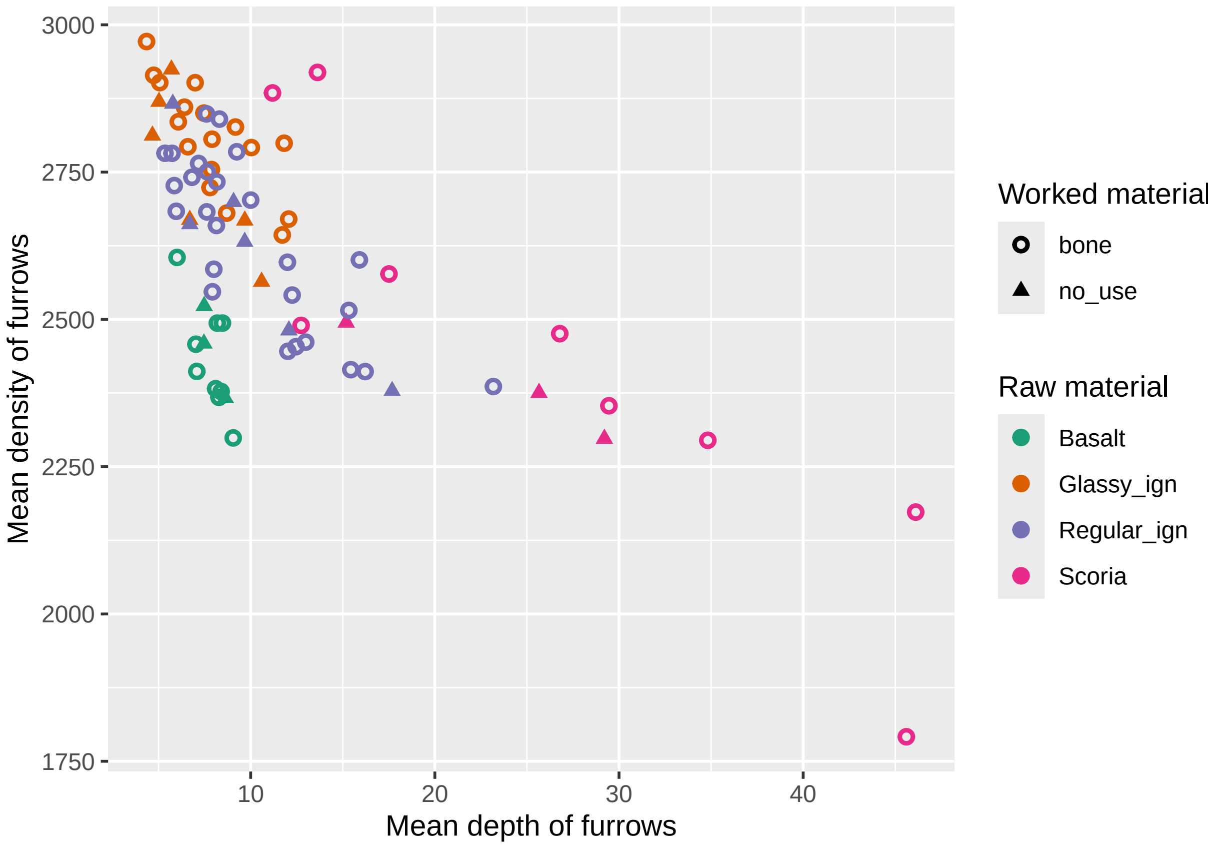
```
    stroke = 1.2
  ) +
  coord_cartesian(
    xlim = c(0, 50),
    ylim = c(0, 30)
  ) +
  theme_classic() +
  labs(
    x = "Area roughness - Sq (Arithmetical Mean Height)",
    y = "Area roughness - Vmc (Core Material Volume)",
    colour = "Raw material",
    shape  = "Worked material"
  ) +
  scale_colour_brewer(palette = "Dark2") +
  scale_shape_manual(
    values = c(
      bone   = 1,
      no_use = 17
    )
  )

print(Sq_Vmc)
```




```
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_scatterplot_Sq-Vmc", ".pdf")
ggsave(filename = file_out, plot = Sq_Vmc, path = "analysis/plots", device = "pdf")
```

```
## Saving 6.5 x 4.5 in image
```

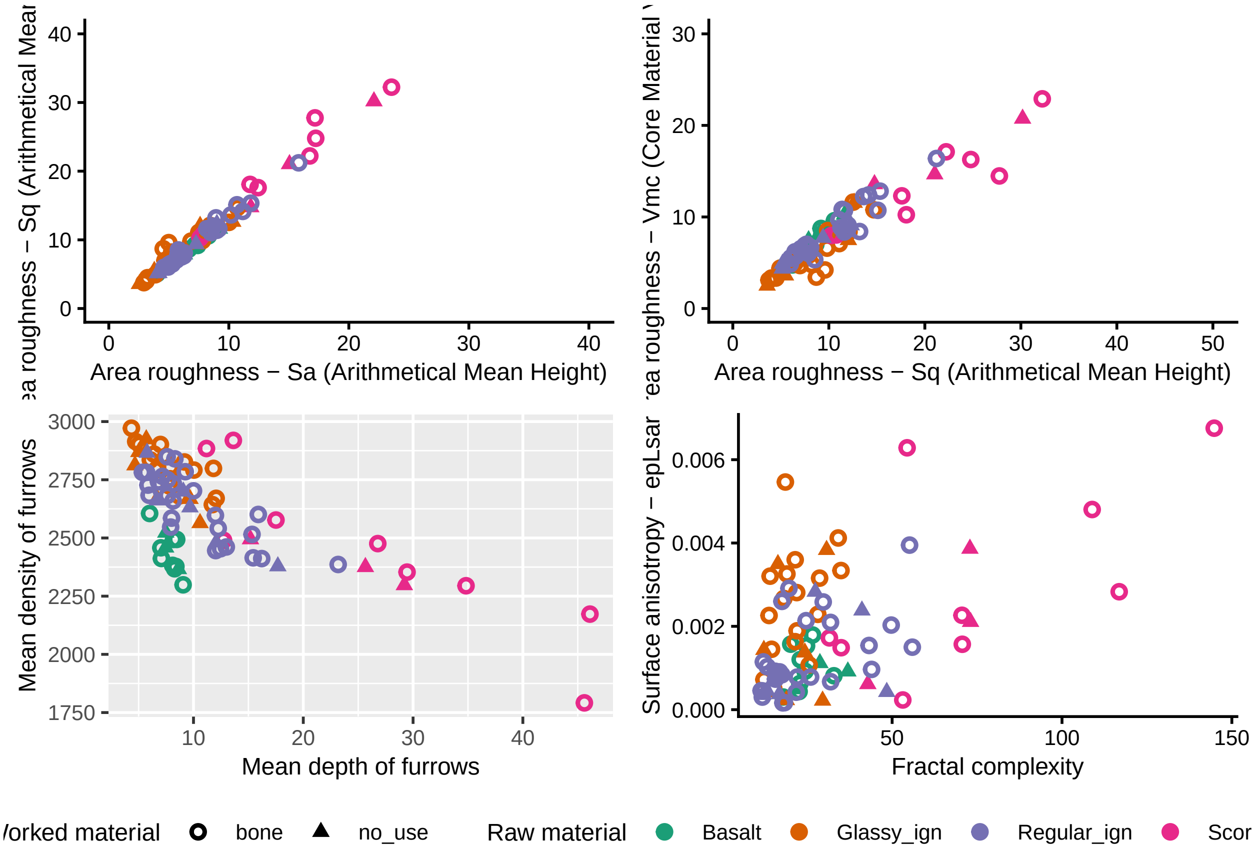
```r
#   Furrow depth & density → contact mechanics

furrows <- ggplot(confocaldata) +
  geom_point(
    aes(
      x = Mean.depth.of.furrows,
      y = Mean.density.of.furrows,
      colour = Raw_material,
      shape  = Worked_material
    ),
    size = 1.5,
    stroke = 1.2
  ) +
 labs(
    x = "Mean depth of furrows",
    y = "Mean density of furrows",
    colour = "Raw material",
    shape  = "Worked material"
  ) +
  scale_colour_brewer(palette = "Dark2") +
  scale_shape_manual(
    values = c(
      bone   = 1,
      no_use = 17
    )
  )


print(furrows)
```




```r
file_out <- paste0(file_path_sans_ext(info_in[["file"]]), "_scatterplot_furrows", ".pdf")
ggsave(filename = file_out, plot = furrows, path = "analysis/plots", device = "pdf")
```

```
## Saving 6.5 x 4.5 in image
```

```r
# combine all in a single image (rearrange sizes)

small_theme <- theme(
  axis.title = element_text(size = 9),
  axis.text  = element_text(size = 8),
  legend.title = element_text(size = 9),
  legend.text  = element_text(size = 8)
)

Sa_Sq   <- Sa_Sq   + small_theme
Sq_Vmc <- Sq_Vmc + small_theme
furrows <- furrows + small_theme
ep_As  <- ep_As  + small_theme

ggarrange(
  Sa_Sq, Sq_Vmc, furrows, ep_As,
  common.legend = TRUE,
  legend = "bottom"
)
```




```
ggsave("analysis/plots/scatterplots.png")
```

```
## Saving 6.5 x 4.5 in image
```

Abbott–Firestone–derived volume parameters (raw material vs worked material)

```
af_long <- confocaldata %>%
  pivot_longer(
    cols = c(Vmc..p...10...q...80.., Vvc..p...10...q...80.., Vvv..p...80..),
    names_to = "Parameter",
    values_to = "Value"
  )


# only Vmc
p_vmc <- ggplot(
  af_long %>% filter(Parameter == "Vmc..p...10...q...80.."),
  aes(
    x = Worked_material,
    y = Value,
    fill = Worked_material
  )
) +
  geom_boxplot(
```

```
    alpha = 0.7,
    outlier.shape = 21,
    outlier.size = 2
  ) +
  facet_wrap(~ Raw_material, scales = "free_y") +
  labs(
    title = "",
    x = "Worked material",
    y = expression(Vmc~(mu*m^3/mu*m^2)),
  ) +
  theme_minimal(base_size = 14) +
  theme(
    legend.position = "none",
    strip.text = element_text(face = "bold")
  )

# all together

p_af_all <- ggplot(
  af_long,
  aes(
    x = Worked_material,
    y = Value,
    fill = Worked_material
  )
) +
  geom_boxplot(alpha = 0.7, outlier.shape = NA) +
  facet_grid(
    Parameter ~ Raw_material,
    scales = "free_y"
  ) +
  labs(
    title = "Abbott-Firestone-Derived Volume Parameters",
    x = "Worked material",
    y = expression(mu*m^3/mu*m^2)
  ) +
  theme_minimal(base_size = 13) +
  theme(
    legend.position = "none",
    strip.text = element_text(face = "bold"),
    axis.text.x = element_text(angle = 45, hjust = 1)
  )

# "Higher Vmc values indicate an expansion of the core material portion of the Abbott-Firestone curve,
```

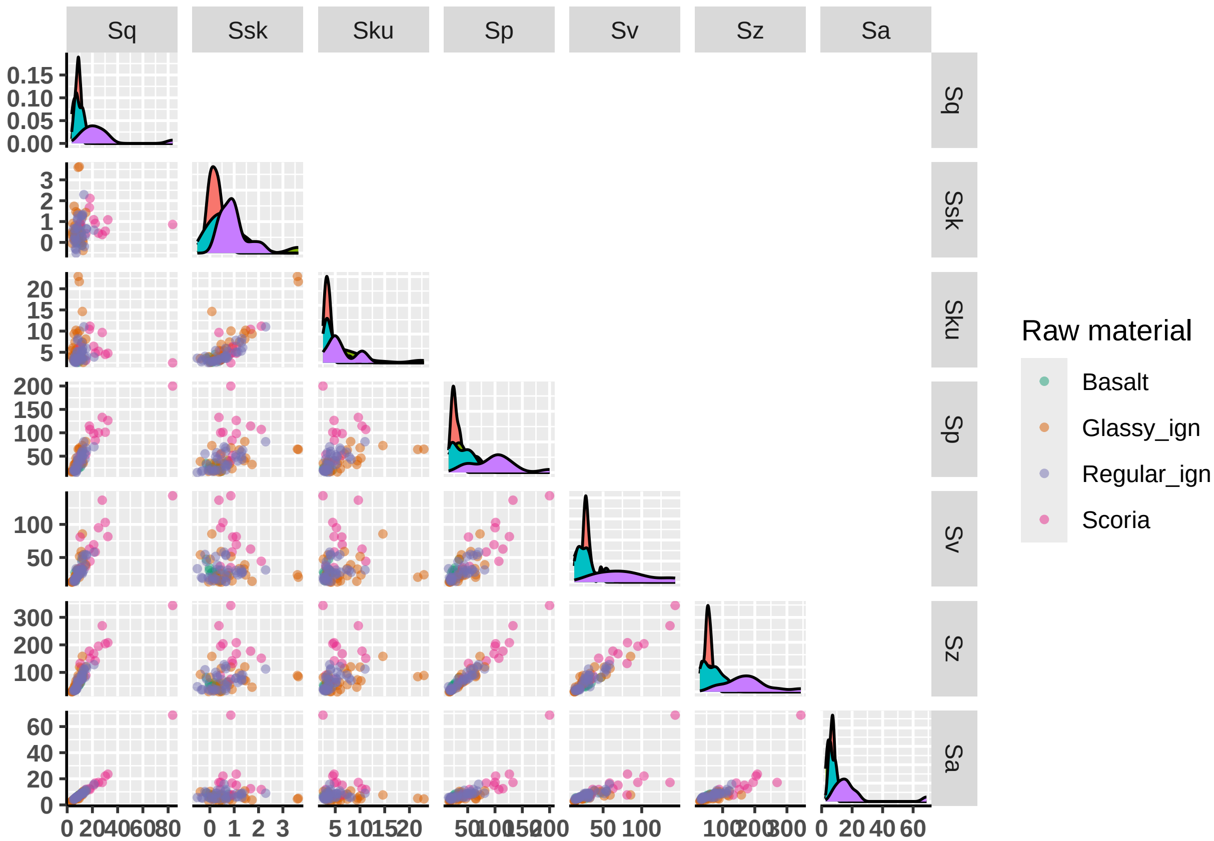
Scatterplot matrix for the ISO 25178 Area scale, Height and volume parameters

```
ggpairs(
  data = confocaldata,
  columns = 23:29,
  cardinality_threshold = 30,
```

```r
  mapping = ggplot2::aes(colour = Raw_material),
  lower = list(
    continuous = wrap("points", alpha = 0.5, size = 1)
  ),
  upper = list(
    continuous = "blank"
  ),
  legend = c(2, 1)
) +
  scale_colour_brewer(palette = "Dark2") +
  theme(
    legend.position = "right",
    axis.text.x = element_text(face = "bold"),
    axis.text.y = element_text(face = "bold"),
    axis.line   = element_line(color = "black", size = 0.5, linetype = "solid")
  ) +
  labs(
    colour = "Raw material"
  )
```

```
## Warning: The `size` argument of `element_line()` is deprecated as of ggplot2 3.4.0.
## i Please use the `linewidth` argument instead.
## This warning is displayed once every 8 hours.
## Call `lifecycle::last_lifecycle_warnings()` to see where this warning was
## generated.
```

```
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
```



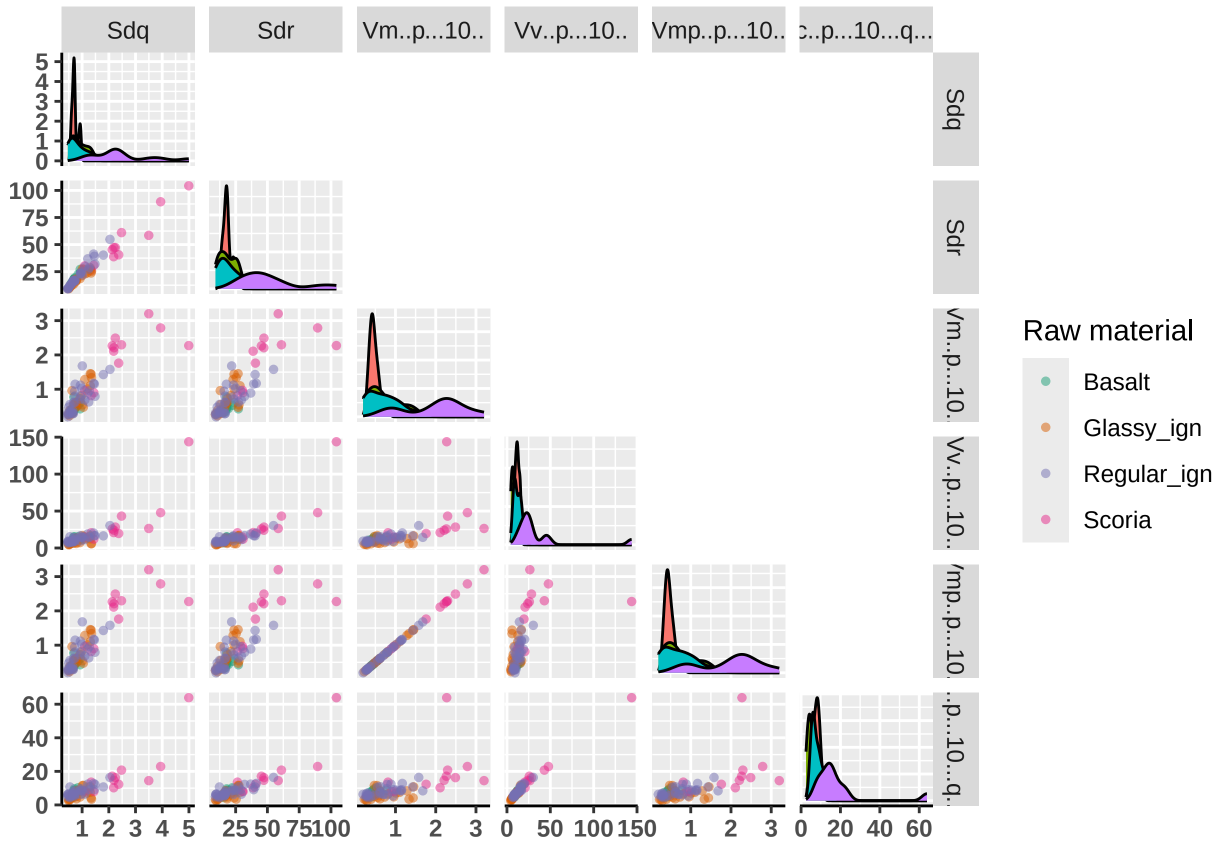

```r
ggsave("analysis/plots/confocalarea_matrix.png")
```

```
## Saving 6.5 x 4.5 in image
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
```

```r
# Volume parameters

ggpairs(
  data = confocaldata,
  columns = 36:41,
  cardinality_threshold = 30,
  mapping = ggplot2::aes(colour = Raw_material),
  lower = list(
```

```r
    continuous = wrap("points", alpha = 0.5, size = 1)
  ),
  upper = list(
    continuous = "blank"
  ),
  legend = c(2, 1)
) +
  scale_colour_brewer(palette = "Dark2") +
  theme(
    legend.position = "right",
    axis.text.x = element_text(face = "bold"),
    axis.text.y = element_text(face = "bold"),
    axis.line   = element_line(color = "black", size = 0.5, linetype = "solid")
  ) +
  labs(
    colour = "Raw material"
  )
```

```
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
```




```
ggsave("analysis/plots/confocalvolume_matrix.png")
```

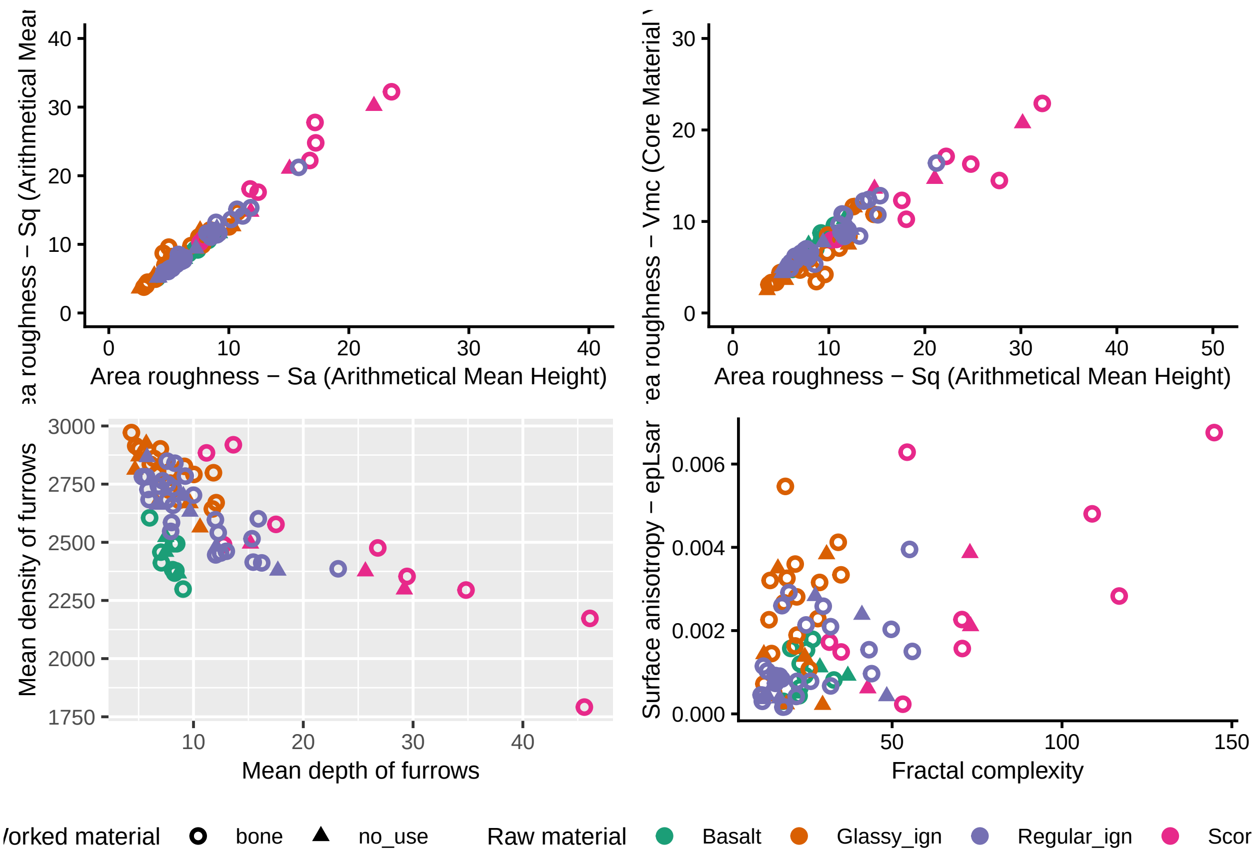
```
## Saving 6.5 x 4.5 in image
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
## Ignoring unknown labels:
## * colour : "Raw material"
```

Plot confostats for the ISO 25178 Area-scale, Height and volume parameters

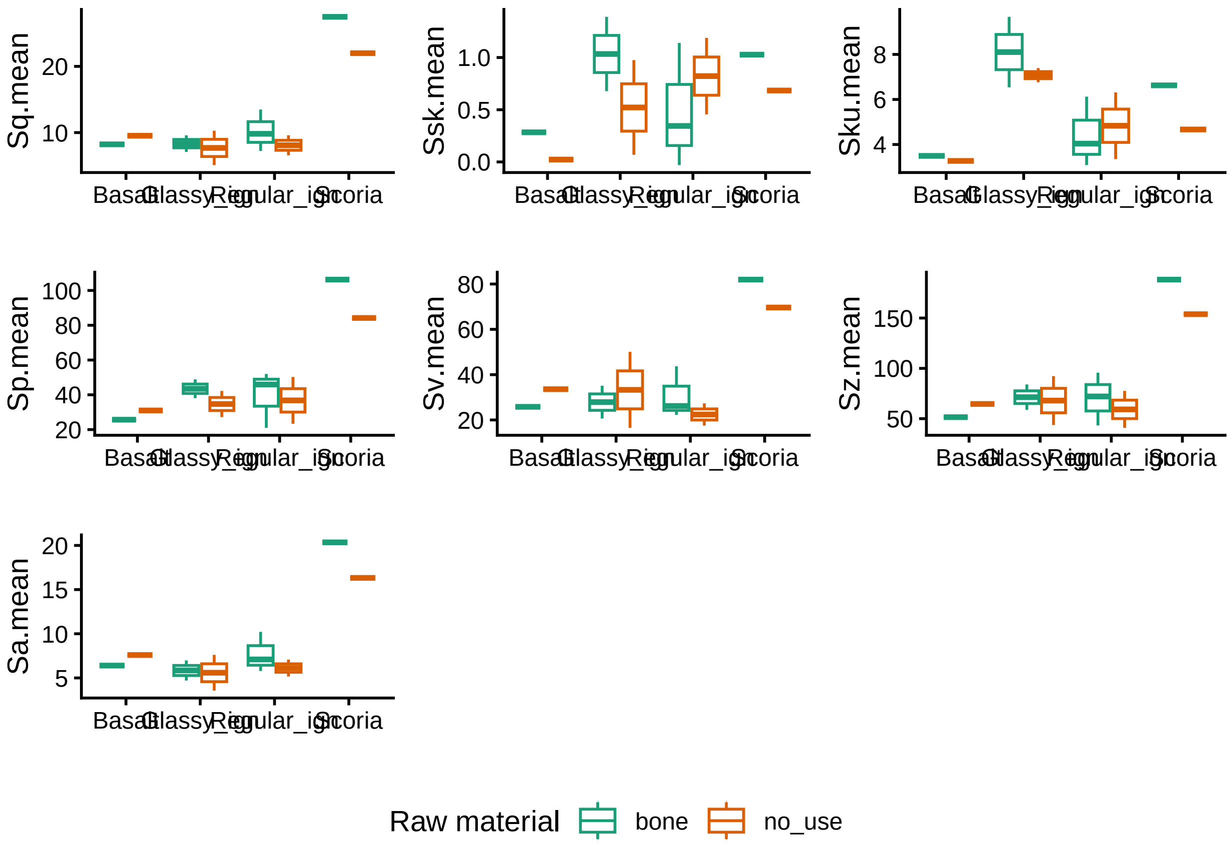
```
heightconfostats <- select(confostats,Worked_material, Raw_material, Sq.mean,Ssk.mean,Sku.mean,Sp.mean,S

library(ggplot2)

p1 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sq.mean, colour = Worked_material)) +
```

```r
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p2 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Ssk.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p3 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sku.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p4 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sp.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p5 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sv.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p6 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sz.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

p7 <- ggplot(heightconfostats,
             aes(x = Raw_material, y = Sa.mean, colour = Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x = "", colour = "Raw material")

# joint and rescale plots

small_theme <- theme(
  axis.title = element_text(size = 9),
  axis.text  = element_text(size = 8),
  legend.title = element_text(size = 9),
```

```
  legend.text  = element_text(size = 8)
)

Sa_Sq   <- Sa_Sq   + small_theme
Sq_Vmc <- Sq_Vmc + small_theme
furrows <- furrows + small_theme
ep_As  <- ep_As  + small_theme

ggarrange(
  Sa_Sq, Sq_Vmc, furrows, ep_As,
  common.legend = TRUE,
  legend = "bottom"
)
```




```
ggarrange(p1, p2, p3, p4, p5, p6, p7, common.legend = TRUE, font.label = list(size=8), legend="bottom")
```

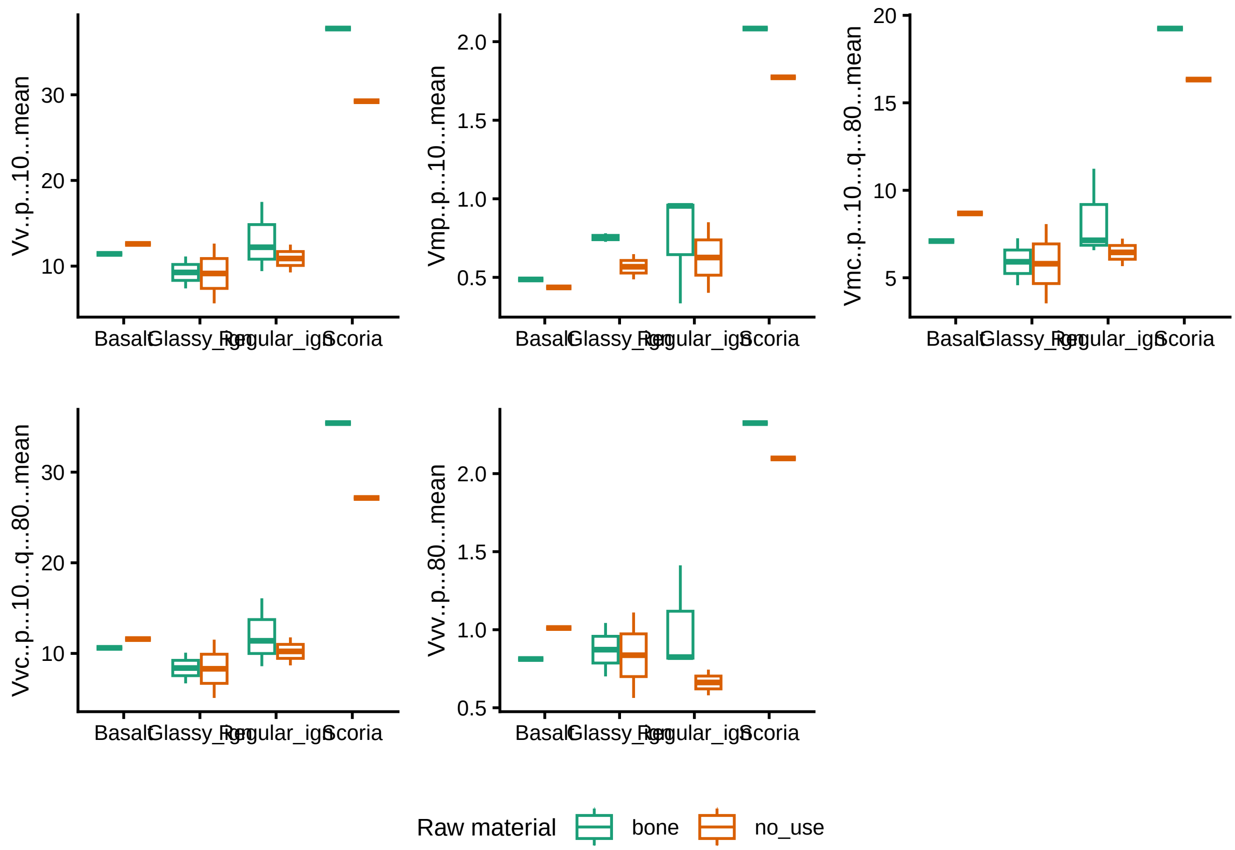



```
ggsave("analysis/plots/confostats_boxplots.png")
```

```
## Saving 6.5 x 4.5 in image
```

```
# Now Volume parameters

volumeconfostats <- select(confostats,Raw_material,Worked_material, Vm..p...10...mean,Vv..p...10...mean

p8 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vm..p...10...mean, colour=Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")

p9 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vv..p...10...mean, colour=Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")

p10 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vmp..p...10...mean, colour=Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")
```

```r
p11 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vmc..p...10...q...80...mean, colour=Worked_materi
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")

p12 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vvc..p...10...q...80...mean, colour=Worked_materi
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")

p13 <- ggplot(volumeconfostats, aes(x=Raw_material, y=Vvv..p...80...mean, colour=Worked_material)) +
  geom_boxplot() +
  scale_colour_brewer(palette = "Dark2") +
  theme_classic() +
  labs(x="", colour="Raw material")


# joint and rescale plots

small_theme <- theme(
  axis.title = element_text(size = 9),
  axis.text  = element_text(size = 8),
  legend.title = element_text(size = 9),
  legend.text  = element_text(size = 8)
)

p8   <- p8   + small_theme
p9 <- p9 + small_theme
p10 <- p10 + small_theme
p11  <- p11  + small_theme
p12  <- p12  + small_theme
p13  <- p13  + small_theme

ggarrange(
  p9, p10, p11, p12, p13,
  common.legend = TRUE,
  legend = "bottom"
)
```




```
ggsave("analysis/plots/confostatsvolume_boxplots.png")
```

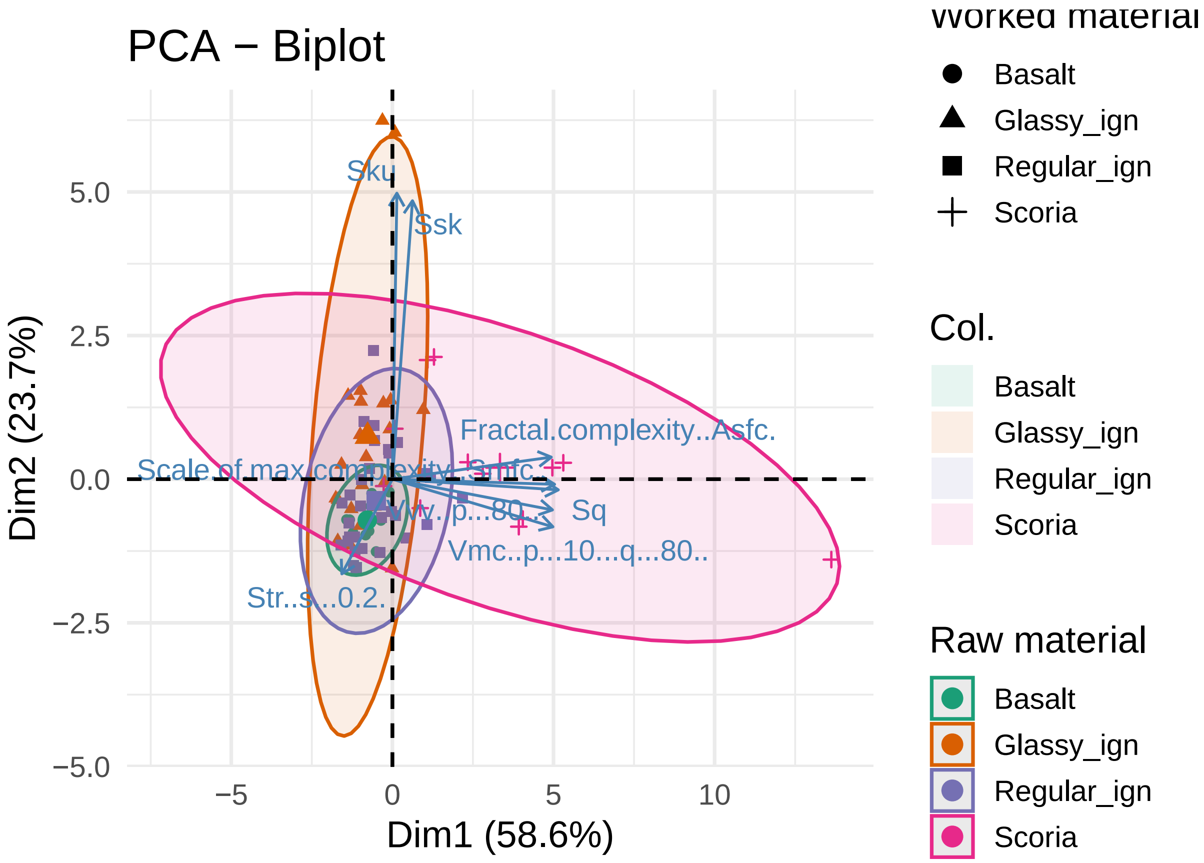
```
## Saving 6.5 x 4.5 in image
```

Multivariate pattern exploration, PCA biplot

```
pca_vars <- c(
  "Sq", "Ssk", "Sku",
  "Vmc..p...10...q...80..", "Vvv..p...80..",
  "Fractal.complexity..Asfc.", "Scale.of.max.complexity..Smfc.",
  "Str..s...0.2."
)

pca_data <- confocaldata %>%
  dplyr::select(all_of(c("Raw_material", "Worked_material", pca_vars))) %>%
  drop_na()

pca_data_clean <- pca_data %>%
  mutate(
    across(
      all_of(pca_vars),
      ~ suppressWarnings(as.numeric(.))
    )
  )
```

```r
pca_data_clean <- pca_data_clean %>%
  drop_na(all_of(pca_vars))
pca_res <- PCA(
  pca_data_clean %>% dplyr::select(all_of(pca_vars)),
  scale.unit = TRUE,
  graph = FALSE
)

pca_res <- PCA(
  pca_data_clean %>% dplyr::select(all_of(pca_vars)),
  scale.unit = TRUE,
  graph = FALSE
)

fviz_pca_biplot(
  pca_res,
  geom.ind = "point",
  col.ind = pca_data_clean$Raw_material,
  shape.ind = as.factor(pca_data_clean$Worked_material),
  palette = "Dark2",
  addEllipses = TRUE,
  ellipse.level = 0.95,
  label = "var",
  repel = TRUE,
  legend.title = list(
    col = "Raw material",
    shape = "Worked material"
  )
) +
  theme_minimal(base_size = 14)
```

```
## Warning: Using ‘size‘ aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use ‘linewidth‘ instead.
## i The deprecated feature was likely used in the ggpubr package.
##   Please report the issue at <https://github.com/kassambara/ggpubr/issues>.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```



End and Session info

```r
sessionInfo()
```

```
## R version 4.3.0 (2023-04-21)
## Platform: aarch64-apple-darwin20 (64-bit)
## Running under: macOS 26.2
##
## Matrix products: default
## BLAS:   /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/lib/libRblas.0.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/lib/libRlapack.dylib;  LAPACK ve
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## time zone: Europe/Berlin
## tzcode source: internal
##
## attached base packages:
## [1] tools     stats     graphics  grDevices utils     datasets  methods
## [8] base
##
## other attached packages:
```

```
##  [1] factoextra_1.0.7 FactoMineR_2.11  ggthemes_5.1.0   ggpubr_0.6.2
##  [5] doBy_4.7.0       GGally_2.4.0     kableExtra_1.4.0 janitor_2.2.1
##  [9] knitr_1.50       lubridate_1.9.4  forcats_1.0.1    stringr_1.6.0
## [13] dplyr_1.1.4      purrr_1.2.0      readr_2.1.6      tidyr_1.3.1
## [17] tibble_3.3.0     ggplot2_4.0.1    tidyverse_2.0.0
##
## loaded via a namespace (and not attached):
##  [1] tidyselect_1.2.1     viridisLite_0.4.2    farver_2.1.2
##  [4] S7_0.2.1             fastmap_1.2.0        TH.data_1.1-5
##  [7] digest_0.6.39        timechange_0.3.0     estimability_1.5.1
## [10] lifecycle_1.0.4      cluster_2.1.8.1      Deriv_4.2.0
## [13] multcompView_0.1-10  survival_3.8-3       magrittr_2.0.4
## [16] compiler_4.3.0       rlang_1.1.6          yaml_2.3.10
## [19] ggsignif_0.6.4       labeling_0.4.3       htmlwidgets_1.6.4
## [22] bit_4.6.0            scatterplot3d_0.3-44 xml2_1.3.8
## [25] RColorBrewer_1.1-3   abind_1.4-8          multcomp_1.4-29
## [28] withr_3.0.2          grid_4.3.0           xtable_1.8-4
## [31] emmeans_2.0.0        scales_1.4.0         MASS_7.3-60.0.1
## [34] tinytex_0.58         flashClust_1.01-2    cli_3.6.5
## [37] mvtnorm_1.3-3        crayon_1.5.3         rmarkdown_2.30
## [40] ragg_1.5.0           generics_0.1.4       rstudioapi_0.17.1
## [43] modelr_0.1.11        tzdb_0.5.0           splines_4.3.0
## [46] parallel_4.3.0       vctrs_0.6.5          boot_1.3-32
## [49] Matrix_1.6-5         sandwich_3.1-1       carData_3.0-5
## [52] car_3.1-3            hms_1.1.4            bit64_4.6.0-1
## [55] rstatix_0.7.3        ggrepel_0.9.6        Formula_1.2-5
## [58] systemfonts_1.3.1    glue_1.8.0           ggstats_0.11.0
## [61] codetools_0.2-20     DT_0.33              cowplot_1.2.0
## [64] stringi_1.8.7        gtable_0.3.6         pillar_1.11.1
## [67] htmltools_0.5.8.1    R6_2.6.1             microbenchmark_1.5.0
## [70] textshaping_1.0.4    vroom_1.6.5          evaluate_1.0.5
## [73] lattice_0.22-7       backports_1.5.0      leaps_3.2
## [76] broom_1.0.8          snakecase_0.11.1     Rcpp_1.1.0
## [79] gridExtra_2.3        svglite_2.2.1        xfun_0.54
## [82] zoo_1.8-14           pkgconfig_2.0.3
```