Reproducible Science Project

Sara Wall

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Contents

Chapter 1

Introduction

This book is the final project for WILD6900. The book contains work and data from my MS thesis on post-fire debris flows.

Chapter 2

Research Background

Post-fire debris flows (PFDF) represent one of the most destructive and potentially hazardous consequences associated with increasing wildfire severity. While the abundance of literature has explored the initiation processes and generation of PFDFs, investigations into their downstream impacts are limited. Modeling frameworks have begun to investigate the downstream impacts of post-fire erosion by predicting where PFDF sediment is generated post-wildfire, how much of that sediment is delivered to a stream channel, and how that pulse of sediment propagates downstream through the river network. While most inputs to such modeling frameworks are available through open source datasets, a significant gap still exists regarding the grain size distributions (GSD) of PFDFs and the factors influencing these GSDs. This presents a major obstacle in developing watershed-scale wildfire risk assessment models, as GSD exerts a first-order control on the rates and modes of sediment transport through a river network. Additionally, while models exist to predict the volumes of sediment deposited by PFDFs, the most prominent volume-prediction model (Gartner et al., 2014) was calibrated using data from Southern California. We therefore have a limited understanding of how this model functions in other regions. We have compiled GSDs and volume data from previous wildfire studies and conducted new fieldwork measuring GSDs and deposit volumes in PFDF deposits to fill this critical knowledge gap. Adding to the 25 GSDs and the 13 volume measurements from previous studies spanning the Intermountain West, we measured GSDs and volumes from an additional 30 PFDFs that occurred in 10 different wildfires across Utah. Altogether this represents the largest and most spatially extensive dataset of PFDF GSDs of which we are aware. Catchments that produced these PFDFs vary in upstream burn severity, area, slope, forest type, soils, climate, and geology. These metrics were all extracted as potential predictor variables for our statistical analysis. We will analyze these data using Random Forest and Multiple Linear Regression statistical modeling and investigate which landscape metrics exert the most control on PFDF GSD and volumes in the Intermountain West. We aim to generalize the results of our GSD model and to validate existing PFDF volume models for this region.

2.1 Research Questions

1. How much variance is there in post-fire debris flow grain sizes between different fans?
2. How well do the Gartner et al. (2008; 2014) models apply to debris flows in the Intermountain West?

Chapter 3

Create Database

This document will create a database for my MS Research Data.

The database will follow the following structure:

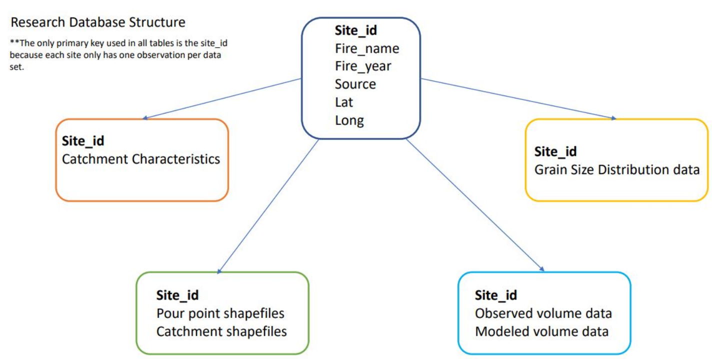


Figure 3.1: Database Structure

The data in this database is compiled from primary fieldwork and from data found in the literature. For each post-fire debris flow characterized, location, grain size, volume, and catchment characteristics are provided. Each debris flow fan is characterized once and therefore the site_id for each fan is used as the Primary Key in all data sets in the database.

3.1 Step 1. Load packages and connect to the SQL database

```
# Load packages ####

library(DBI)
library(RSQLite)
```

```
## Warning: package 'RSQLite' was built under R version 4.0.3
```

```
library(rlang)
```

```
## Warning: package 'rlang' was built under R version 4.0.3
```

```
# Establish database connection ####

debrisflow_db <- dbConnect(drv = RSQLite::SQLite(), "database/MS_research_db.db")
```

3.2 Step 2. Create DF_Locations Table

```
dbExecute(debrisflow_db, "CREATE TABLE DF_locations (
          Site_id varchar(50),
          Fire varchar(50),
          fire_year varchar(5),
          Source varchar(50),
          year_surveyed varchar(5),
          Lat double,
          long double, PRIMARY KEY (Site_id));
          ")

DF_locations <- read.csv("DF_locations.csv", header = TRUE, stringsAsFactors = FALSE)

names(DF_locations)

dbWriteTable(debrisflow_db, "DF_locations", DF_locations, append= TRUE)
```

```
#Check table
dbGetQuery(debrisflow_db, "SELECT * FROM DF_locations LIMIT 10;")
```

```
##           Site_id              Fire fire_year           Source year_surveyed
## 1     Brianhead 1         Brianhead      2017 Primary Fieldwork          2020
## 2     Brianhead 2         Brianhead      2017 Primary Fieldwork          2020
## 3     Brianhead 3         Brianhead      2017 Primary Fieldwork          2020
## 4   Brianhead 3.2         Brianhead      2017 Primary Fieldwork          2020
## 5     Brianhead 4         Brianhead      2017 Primary Fieldwork          2020
## 6  Clay Springs 1 Clay Springs Fire      2012 Primary Fieldwork          2020
## 7  Clay Springs 2 Clay Springs Fire      2012 Primary Fieldwork          2020
## 8    Dairy Fork 1  Coal Hollow Fire      2018 Primary Fieldwork          2020
## 9    Dairy Fork 2  Coal Hollow Fire      2018 Primary Fieldwork          2020
## 10 Dollar Ridge 1 Dollar Ridge Fire      2018 Primary Fieldwork          2020
##         Lat      long
## 1  37.74776 -112.7887
## 2  37.74148 -112.7932
## 3  37.72436 -112.7062
## 4        NA        NA
## 5  37.75856 -112.7941
## 6  39.35653 -112.1648
## 7  39.33334 -112.1507
## 8  39.95080 -111.3493
## 9  39.95397 -111.3477
## 10 40.12092 -110.7446
```

3.3 Step 3. Create Catchment Characteristics Table

```
dbExecute(debrisflow_db, "CREATE TABLE catchments (
          Site_id varchar(50),
          cat_area float,
          relief float,
          mean_cat_elev float,
          himod_perc float,
          himod_area float,
          slope23_perc float,
          sort_unsort char(10),
          clast_matrix char(10),
          strat char(10),
          boulder_perc float,
          dom_lith char(20),
          Lith_type char(20),
          X2yr_storm float,
          X100yr_storm float,
          Al2O3Ws float, CaOWs float, Fe2O3Ws float, K2OWs float, MgOWs float,
```

```
         Na2OWs float, NWs float, P2O5Ws float, SiO2Ws float,
         PctAlluvCoastWs float,
         PctEolFineWs float, PctCarbResidWs float, PctNonCarbResidWs float,
         PctSilicicWs float, CompStrgthWs float, HydrlCondWs float,
         AvgWetIndxWs float, ClayWs float, AgKffactWs float, PermWs float,
         RckdepWs float, OmWs float, SandWs float,PctBl2011Ws float,
         PctConif2011Ws float,
         PctDecid2011Ws float, PctGrs2011Ws float,PctHay2011Ws float,
         PctHbWet2011Ws float, PctMxFst2011Ws float, PctShrb2011Ws float,
         Precip8110Ws float, RunoffWs float, Tmean8110Ws float, WtDepWs float

         PRIMARY KEY (Site_id));
         ")

catchments <- read.csv("catchments.csv", header = TRUE, stringsAsFactors = FALSE)

names(catchments)

dbWriteTable(debrisflow_db, "catchments", catchments, append= TRUE)
```

```
#Check table
dbGetQuery(debrisflow_db, "SELECT * FROM catchments LIMIT 10;")
```

```
##           Site_id cat_area relief mean_cat_elev himod_perc himod_area
## 1     Brianhead 1     0.36    305          2631         54       0.19
## 2     Brianhead 2     2.98    744          2924         45       1.34
## 3     Brianhead 3     0.62    276          2832         81       0.50
## 4   Brianhead 3.2     0.62    276          2832         81       0.50
## 5     Brianhead 4     2.10    473          2575          8       0.17
## 6  Clay Springs 1     4.01    901          2269         36       1.44
## 7  Clay Springs 2     2.07   1029          2154          7       0.14
## 8    Dairy Fork 1     2.12    583          2141         63       1.34
## 9    Dairy Fork 2     1.01    309          1993         48       0.48
## 10 Dollar Ridge 1     0.15    225          2054         17       0.03
##    slope23_perc sort_unsort clast_matrix          strat boulder_perc GSD_Q
## 1          15.5    unsorted       clast  not stratified           10     4
## 2          14.0    unsorted       matrix not stratified            5     5
## 3          13.0     sorted        matrix    stratified            10     4
## 4          13.0                                                   NA    NA
## 5          54.0    unsorted       matrix not stratified            3     4
## 6          65.0    unsorted        clast not stratified            5     4
## 7          56.0    unsorted        clast not stratified            3     3
## 8           5.0      sorted       matrix not stratified            5     3
## 9           3.0    unsorted       matrix not stratified            2     4
## 10         26.0      sorted       matrix not stratified           10     4
```

```
##    Vol_Q  dom_lith   Lith_type X2yr_storm X100yr_storm Al2O3Ws CaOWs Fe2O3Ws
## 1      4  volcanic     igneous       5.09        15.48   12.23  9.80    4.82
## 2      5  volcanic     igneous       5.33        16.07   11.88 10.54    4.70
## 3      4  volcanic     igneous       4.92        15.10   14.86  3.73    5.62
## 4     NA  volcanic     igneous       4.92        15.10      NA    NA      NA
## 5      3 Limestone sedimentary       4.63        14.33    9.45 15.46    3.85
## 6      3 Limestone sedimentary       3.28        10.18   10.56  4.92    8.33
## 7      2 Limestone sedimentary       3.15         9.93   10.56  4.92    8.33
## 8      3  mudstone sedimentary       3.35        10.77    6.91 17.10    2.57
## 9      2  mudstone sedimentary       3.33        10.71    6.57 18.32    2.50
## 10     3 sandstone sedimentary       2.75         9.20    6.80 18.60    2.63
##    K2OWs MgOWs Na2OWs  NWs P2O5Ws   SiO2Ws PctAlluvCoastWs PctEolFineWs
## 1   2.63  2.53   2.74 0.03   0.16 55.38075            0.00            0
## 2   2.57  2.57   2.63 0.04   0.16 54.27291            0.00            0
## 3   3.17  2.03   3.60 0.03   0.18 64.69118            0.00            0
## 4     NA    NA     NA   NA     NA       NA              NA           NA
## 5   2.16  3.04   1.84 0.04   0.14 46.56477            0.00            0
## 6   2.15  2.41   1.05 0.17   0.14 54.65962           64.51            0
## 7   2.15  2.41   1.05 0.17   0.14 54.65962           64.51            0
## 8   1.54  3.12   0.93 0.12   0.18 41.36917            0.00            0
## 9   1.54  3.59   0.90 0.11   0.18 39.28827            0.00            0
## 10  1.53  3.51   1.02 0.11   0.19 39.05255            0.02            0
##    PctCarbResidWs PctNonCarbResidWs PctSilicicWs CompStrgthWs HydrlCondWs
## 1            0.00             28.13        71.87        70.24        0.03
## 2            0.00             13.77        86.23        70.42        0.03
## 3            0.00              0.00       100.00        72.66        0.04
## 4              NA                NA           NA           NA          NA
## 5            0.00             45.32        54.68        71.26        0.03
## 6           12.08             23.41         0.00        30.00        3.77
## 7           12.08             23.41         0.00        30.00        3.77
## 8            0.00            100.00         0.00        76.74        0.02
## 9            0.00            100.00         0.00        77.29        0.03
## 10           0.00             99.98         0.00        79.03        0.02
##    AvgWetIndxWs ClayWs AgKffactWs PermWs RckdepWs OmWs SandWs PctBl2011Ws
## 1        310.24  34.97          0   1.21   147.05 0.76  22.76        1.09
## 2        317.89  31.03          0   2.51   145.97 0.64  28.55        4.62
## 3        349.50  35.00          0   1.20   147.06 0.76  22.57        0.04
## 4            NA     NA         NA     NA       NA   NA     NA          NA
## 5        300.02  32.94          0   1.88   146.50 0.70  25.67        4.26
## 6        431.81  20.43          0   6.93   123.86 0.93  37.31        0.39
## 7        431.81  20.43          0   6.93   123.86 0.93  37.31        0.39
## 8        338.03  22.87          0   4.70   108.43 0.56  38.65        0.00
## 9        296.74  22.23          0   4.73   108.81 0.67  38.79        0.03
## 10       262.52  20.38          0   6.06   101.72 1.31  36.53        9.20
##    PctConif2011Ws PctDecid2011Ws PctGrs2011Ws PctHay2011Ws PctHbWet2011Ws
## 1           56.23           1.82         0.18         0.00              0
```

```
## 2          52.72          6.22        1.87        0.00            0
## 3          43.61         19.17        0.19        0.00            0
## 4             NA            NA          NA          NA           NA
## 5          62.20          3.78        1.00        0.00            0
## 6          33.24          2.27       13.81        0.42            0
## 7          33.24          2.27       13.81        0.42            0
## 8          15.68         61.01        0.00        0.00            0
## 9          43.59         34.90        0.00        0.00            0
## 10         46.11          5.33        0.06        0.11            0
##    PctMxFst2011Ws PctShrb2011Ws Precip8110Ws RunoffWs Tmean8110Ws WtDepWs
## 1           39.61          1.00       756.61    30.00        4.62  182.88
## 2           31.22          3.27       859.86    30.21        3.35  182.88
## 3           31.50          4.98       690.55    38.65        3.77  182.88
## 4              NA            NA           NA       NA          NA      NA
## 5           25.00          3.59       776.01    30.11        4.23  182.88
## 6            0.01         49.59       404.38    29.00        8.96  182.88
## 7            0.01         49.59       404.38    29.00        8.96  182.88
## 8            0.00         23.31       572.16   248.00        6.99  182.88
## 9            0.21         21.21       565.32   248.00        6.84  182.88
## 10           1.24         37.45       519.64    57.78        5.03  181.97
```

3.4 Step 4. Create Grain Size Distribution Table

```r
dbExecute(debrisflow_db, "CREATE TABLE GSD (
          Site_id varchar(50),
          subD16 float,
          subD50 float,
          subD84 float,
          D84B float,
          surD16 float,
          surD50 float,
          surD84 float,
          subD50range float,
          sub_var float,
          sur_var float,
          PRIMARY KEY (Site_id));
          ")

GSD <- read.csv("GSD_data.csv", header = TRUE, stringsAsFactors = FALSE)

names(GSD)
```

```
dbWriteTable(debrisflow_db, "GSD", GSD, append= TRUE)
```

```
#Check table
dbGetQuery(debrisflow_db, "SELECT * FROM GSD LIMIT 10;")
```

```
##           Site_id subD16 subD50 subD84   D84B surD16 surD50 surD84 subD50range
## 1     Brianhead 1   1.81  12.71  33.94 1116.0  13.67  30.08  50.59        3.72
## 2     Brianhead 2   1.00  12.40  54.62  527.0  11.58  30.29  51.53        6.82
## 3     Brianhead 3   0.33  11.85  55.86  537.5  12.15  40.99  74.31       40.22
## 4   Brianhead 3.2     NA     NA     NA     NA     NA     NA     NA          NA
## 5     Brianhead 4   1.68  21.61  58.63  820.0  19.30  31.65  53.75        5.05
## 6  Clay Springs 1   1.08  10.51  40.23  380.0  11.43  40.23  72.48        1.40
## 7  Clay Springs 2  13.15  32.95  58.78     NA  16.96  26.36  43.17          NA
## 8    Dairy Fork 1   2.62  13.97  57.36  540.0   6.63  20.95  38.26        3.37
## 9    Dairy Fork 2   0.90   4.78  13.58  490.0   2.00   8.25  19.30          NA
## 10 Dollar Ridge 1   0.53   6.88  56.88  860.0  19.21  32.26  55.90        0.43
##    sub_var sur_var
## 1     4.23    1.89
## 2     5.77    2.15
## 3     7.40    2.61
## 4       NA      NA
## 5     5.13    1.48
## 6     5.22    2.66
## 7     2.16    1.35
## 8     4.45    2.53
## 9     3.92    3.27
## 10    6.75    1.54
```

3.5 Step 5. Create Volume Data Table

```
dbExecute(debrisflow_db, "CREATE TABLE volume (
          obsVol_min varchar(50),
          obsVol float,
          obsVol_max float,
          G08_vol2yr_min float,
          G08_vol2yr float,
          G08_vol2yr_max float,
          G08_vol100yr_min float,
          G08_vol100yr float,
          G08_vol100yr_max float,
          G14_vol2yr_min float,
```

```
          G14_vol2yr float,
          G14_vol2yr_max float,
          G14_vol100yr_min float,
          G14_vol100yr float,
          G14_vol100yr_max float,
          PRIMARY KEY (Site_id));
          ")

volume <- read.csv("DF_Volume_data.csv", header = TRUE, stringsAsFactors = FALSE)

names(volume)

dbWriteTable(debrisflow_db, "volume", volume, append= TRUE)
```

```
#Check table
dbGetQuery(debrisflow_db, "SELECT * FROM volume LIMIT 10;")
```

```
##           Site_id obsVol_min  obsVol obsVol_max G08_vol2yr_min  G08_vol2yr
## 1     Brianhead 1    73.1250   97.50   131.6250      117.86806    943.4712
## 2     Brianhead 2   468.7500  625.00   843.7500      503.77232   4032.4298
## 3     Brianhead 3  1350.0000 1800.00  2430.0000      218.57784   1749.5996
## 4   Brianhead 3.2   399.0000  532.00   718.2000      711.47298   5694.9633
## 5     Brianhead 4  1141.8750 1522.50  2055.3750     1363.30468  10912.5299
## 6  Clay Springs 1   140.2500  187.00   252.4500      680.62099   5448.0095
## 7  Clay Springs 2   130.5000  174.00   234.9000      310.77948   2487.6247
## 8    Dairy Fork 1    27.1875   36.25    48.9375      204.96535   1640.6388
## 9    Dairy Fork 2   993.7500 1325.00  1788.7500       78.84295    631.0960
## 10 Dollar Ridge 1  5250.0000 7000.00  9450.0000    13357.70775 106921.3564
##    G08_vol2yr_max G08_vol100yr_min G08_vol100yr G08_vol100yr_max G14_vol2yr_min
## 1        7551.986         76.98279     616.2063         4932.404      110.01438
## 2       32277.459        324.97765    2601.2735        20821.813      805.88558
## 3       14004.615        142.36557    1139.5608         9121.579      136.56922
## 4       45585.157        477.27337    3820.3199        30579.632      174.91993
## 5       87349.007       1027.20720    8222.2481        65814.729      973.26510
## 6       43608.423        518.32663    4148.9294        33209.976      548.34744
## 7       19912.115        229.43772    1836.5271        14700.424      444.47567
## 8       13132.442        151.40054    1211.8810         9700.463      131.13507
## 9        5051.588         60.46193     483.9656         3873.888       30.44355
## 10     855848.674       9922.14946   79421.5369       635727.224     5614.71204
##    G14_vol2yr G14_vol2yr_max G14_vol100yr_min G14_vol100yr G14_vol100yr_max
## 1    880.6066       7048.789        211.70029    1694.5484        13563.960
## 2   6450.6861      51634.316       1563.94325   12518.5351       100204.225
## 3   1093.1641       8750.198        261.71595    2094.8972        16768.540
## 4   1400.1411      11207.386        330.79300    2647.8223        21194.411
## 5   7790.4703      62358.577       1666.82324   13342.0348       106795.903
```

```
## 6   4389.2300      35133.455         937.94561    7507.7565         60095.604
## 7   3557.7917      28478.233         782.87071    6266.4642         50159.718
## 8   1049.6666       8402.024         230.64137    1846.1617         14777.544
## 9    243.6845       1950.565          52.04251     416.5727          3334.443
## 10 44942.7880     359743.149        9598.77383   76833.0868        615008.054
```

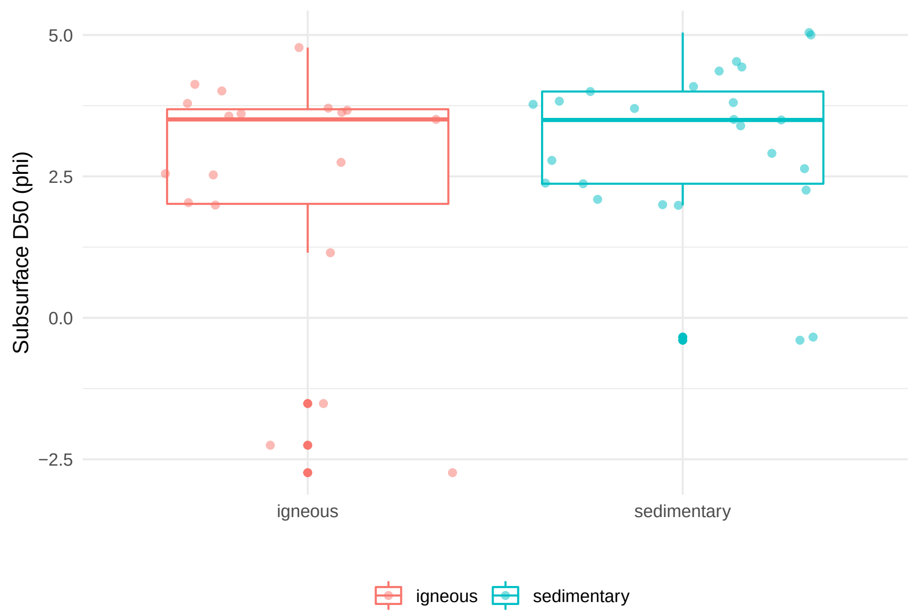
Chapter 4

Investigating Grain Size Variance

First, we will look at a boxplot of the distributions of the median grain size for all debris flow fans broken down by lithology.

Plotting boxplot of median grain size:

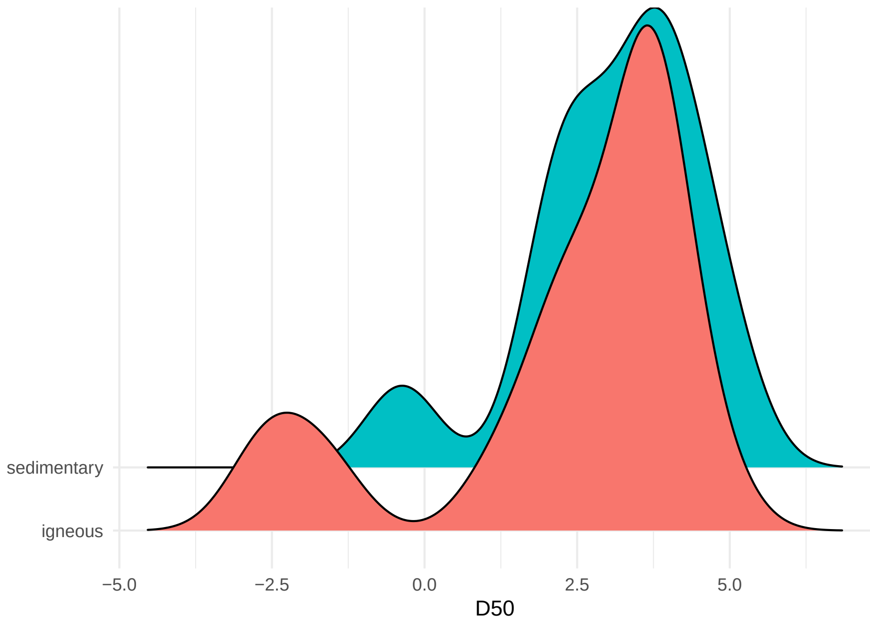
```
GSD %>%
  filter(complete.cases(subD50),
         (Lith_type == "igneous" | Lith_type == "sedimentary")) %>%
  mutate(subD50_phi = log2(subD50)) %>%
  relocate(subD50_phi, .after = subD50) %>%
  ggplot(aes(x = Lith_type, y= subD50_phi, color = Lith_type))+
  geom_boxplot() +
  geom_jitter(alpha = 0.5) +
  labs(y = "Subsurface D50 (phi)", x = "", color = "") +
  theme_minimal() +
  theme(legend.position = "bottom")
```



It is surpising that there is not much of a discernible difference in median grain size distributions between the sedimentary and igneous rocks.

Density plot of median grain size by lithology:

```
GSD %>%
  filter(
         (Lith_type == "igneous" | Lith_type == "sedimentary")) %>%
  mutate(subD50_phi = log2(subD50),
         surD50_phi = log2(surD50)) %>%
  ggplot(aes(x = subD50_phi, y = Lith_type, fill = Lith_type)) +
  geom_density_ridges(scale = 8) +
  theme_minimal() +
  labs(y = "", x = "D50") +
  theme(legend.position = "none")
```



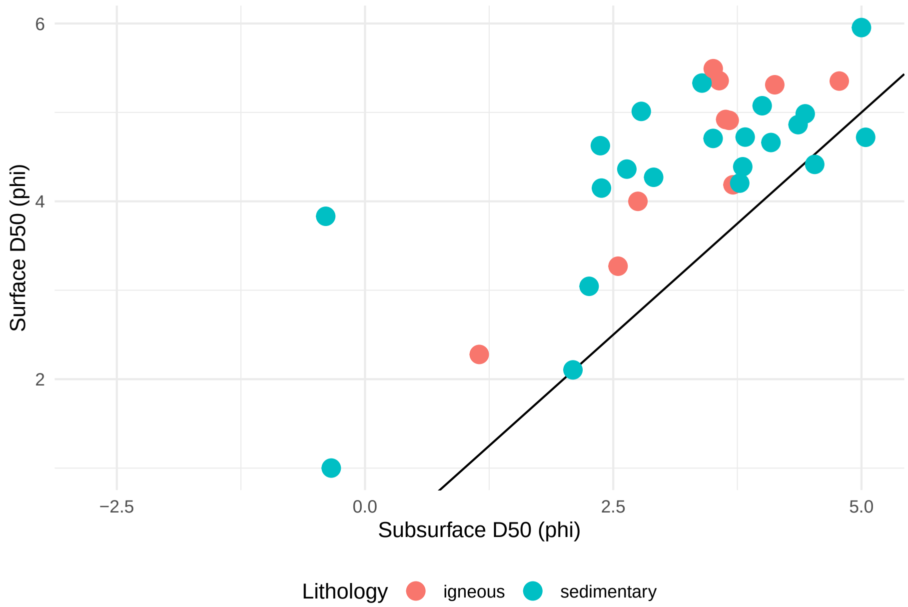
We can see that the igneous distribution is narrower than that of the sedimentary rocks.

Chapter 5

Subsurface vs Surface Grain Size Distribution

Scatter plot of the surface vs subsurface median grain size

```
GSD %>%
  filter(complete.cases(subD50),
         (Lith_type == "igneous" | Lith_type == "sedimentary")) %>%
  mutate(subD50_phi = log2(subD50),
         surD50_phi = log2(surD50)) %>%
  ggplot(aes(x = subD50_phi, y = surD50_phi, color = Lith_type))+
  geom_abline(aes(slope = 1, intercept = 0),
              size = 0.5) +
  geom_point(size = 4) +
  guides(color = guide_legend(), size = guide_legend()) +
  theme_minimal() +
  labs(x = "Subsurface D50 (phi)", y = "Surface D50 (phi)",
       color = "Lithology") +
  theme(legend.position = "bottom")
```



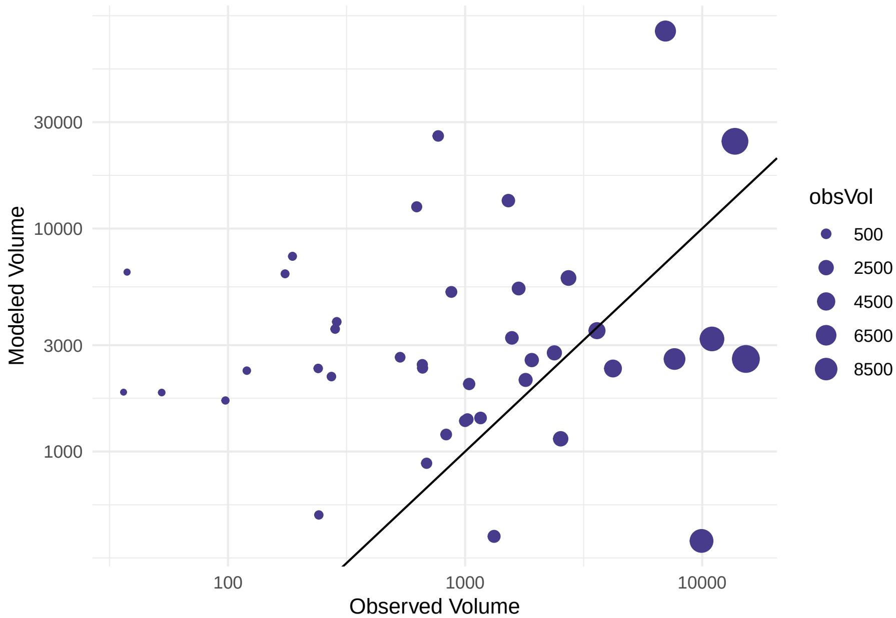
The line in the plot represents the 1 to 1. The data would follow the line if the subsurface and surface distributions were the same. However, majority of the points are on the left of the line, indicating that the surface distribution is coarser than the subsurface distribution.

Chapter 6

Evaluating the Gartner et al., 2014 model

Plotting the Observed Volume vs predicted volume:

```
volume %>%
  ggplot(aes(x = obsVol, size = obsVol))+
  geom_point(aes(y = G14_vol100yr), color = "slateblue4", label = "100 year storm") +
  geom_abline(intercept = 0, slope = 1)+
  scale_size_continuous(breaks=seq(500, 10000, by=2000))+
  scale_x_continuous(trans = 'log10') +
  scale_y_continuous(trans = 'log10')+
  guides(size = guide_legend()) +
  labs(x = "Observed Volume", y = "Modeled Volume"  )+
  theme_minimal()
```



We can see that the model does not do a good job of estimating post-fire debris flow volumes in the Intermountain West, especially for smaller volume debris flows.