Brady

April 16, 2021

0.1 Geothermal machine learning analysis: Brady site, Nevada

This notebook is a part of the GeoThermalCloud.jl: Machine Learning framework for Geothermal Exploration.

<img src="../../logos/geothermalcloud-small.png" alt="geothermalcloud" width=25% max-width=125

Machine learning analyses are performed using the **SmartTensors** machine learning framework.

<img src="../../logos/SmartTensorsNewSmaller.png" alt="SmartTensors" width=25% max-width=125p

This notebook demonstrates how the **NMFk** module of **SmartTensors** can be applied to perform unsupervised geothermal machine-learning analyses.

More information on how the ML results are interpreted to provide geothermal insights is discussed in our research paper.

0.2 GeoThermalCloud installation

If **GeoThermalCloud** is not installed, first execute in the Julia REPL `import Pkg; Pkg.add("GeoThermalCloud"); import Pkg; Pkg.add("NMFk"); Pkg.add("Mads"); Pkg.add("DelimitedFiles"); Pkg.add("JLD"); Pkg.add("Gadfly"); Pkg.add("Cairo"); Pkg.add("Fontconfig")`.

[1]:
```
import GeoThermalCloud
import NMFk
import Mads
import DelimitedFiles
import JLD
import Gadfly
import Cairo
import Fontconfig
```

0.3 Load and pre-process the dataset

0.3.1 Setup the working directory containing the Brady site data

[2]:
```
cd(joinpath(GeoThermalCloud.dir, "Brady"));
```

0.3.2 Load the data file

[3]:
```
d, h = DelimitedFiles.readdlm("data/AllBradyWells_LANL_ML_9.txt", ',';␣
↪header=true);
```

0.3.3 Populate the missing well names

[4]:
```
global wellname = ""
for i = 1:size(d, 1)
        if d[i, 1] != ""
                global wellname = d[i, 1]
        else
                d[i, 1] = wellname
        end
end
```

0.3.4 Set up missing entries to be equal to zero

[5]:
```
d[d[:, 24] .== "", 24] .= 0;
```

0.3.5 Define names of the data attributes (matrix columns)

[6]:
```
attributes_short = ["ID", "D", "azimuth", "incline", "x", "y", "z", "casing",␣
↪"fluids", "use", "production", "use2", "lt750mstatus", "normal", "coulomb",␣
↪"dilation", "faults", "td", "ts", "curve", "modeltemp", "faultdense",␣
↪"faultintdense", "inv_distcontacts", "inv_distfaults", "unitthickness",␣
↪"goodlith", "confidence"]
attributes_order = ["ID", "D", "azimuth", "incline", "x", "y", "z", "casing",␣
↪"fluids", "use", "production", "use2", "lt750mstatus", "faults", "curve",␣
↪"td", "ts", "inv_distfaults", "faultdense", "faultintdense", "dilation",␣
↪"normal", "coulomb", "inv_distcontacts", "unitthickness", "goodlith",␣
↪"modeltemp", "confidence"]
attributes_long = ["ID", "Depth", "Azimuth", "Inclination", "X", "Y", "Z",␣
↪"Casing", "Fluids", "use", "Production", "use2", "Status", "Normal stress",␣
↪"Coulomb shear stress", "Dilation", "Faulting", "Fault dilation tendency",␣
↪"Fault slip tendency", "Fault curvature", "Modeled temperature", "Fault␣
↪density", "Fault intersection density", "Inverse distance from contacts",␣
↪"Inverse distance from faults", "Unit thickness", "Good lithology",␣
↪"Confidence"];
```

Short attribute names are used for coding.

Long attribute names are used for plotting and visualization.

0.3.6 Define the attributes that will be processed

[7]:
```
attributes_process = ["normal", "coulomb", "dilation", "faults", "td", "ts",␣
↪"curve", "modeltemp", "faultdense", "faultintdense", "inv_distcontacts",␣
↪"inv_distfaults", "unitthickness", "goodlith"];
```

0.3.7 Index the attributes that will be processed

[8]:
```
Aorder = indexin(attributes_order, attributes_process)
Aorder = Aorder[Aorder.!==nothing]
ai = indexin(attributes_process, attributes_short)
pr = indexin(["production"], attributes_short)
attributes_process_long = attributes_long[ai]

attributes_col = vec(permutedims(h))
attributes = attributes_col[ai];
```

0.3.8 Display information about the processed data (min, max, count):

[9]:
```
for i=1:length(attributes_col); println("$(attributes_col[i]): Column $i Min␣
↪$(minimum(d[:,i])) Max $(maximum(d[:,i]))"); end
for i=1:length(attributes_col); println("$(attributes_col[i]): Column $i Unique␣
↪entries:"); display(unique(sort(d[:,i]))); end
```

```
wellid: Column 1 Min 15-12 Max MGI-2
md: Column 2 Min 0.0 Max 2213.723
azimuth: Column 3 Min 0.0 Max 359.991
inclination: Column 4 Min 0.0 Max 359.963
x: Column 5 Min 326859.34 Max 328813.04
y: Column 6 Min 4.4051245e6 Max 4.40887416e6
z: Column 7 Min -923.476 Max 1277.29
casing: Column 8 Min Cased Max Slotted
fluids: Column 9 Min Flowing Max NotFlowing
use: Column 10 Min Dry Max Production
production: Column 11 Min InjectionZone Max SecondaryProductionZone
use2: Column 12 Min Dry Max Production
lt750mstatus: Column 13 Min Dry Max Production
normal: Column 14 Min -100.6743850708 Max 156.40034484863
dilation: Column 15 Min -0.000240148059675 Max 0.0002483890857548
coulomb: Column 16 Min -44.226177215576 Max 105.31118774414
shear: Column 17 Min -104.33931732178 Max 87.588310241699
faults: Column 18 Min 0 Max 1
td: Column 19 Min 0.0 Max 1.0
ts: Column 20 Min 0.0 Max 0.4
curve: Column 21 Min 0.0 Max 0.0028201111126691
```

```
47-element Array{Any,1}:
 "15-12"
```

```
 "17-31"
 "18-1"
 "18-31"
 "18A-1"
 "18B-31"
 "18D-31"
 "22-13"
 "26-12"
 "27-1"
 "46-1"
 "46A-1"
 "47A-1"

 "B5A"
 "B6"
 "B7"
 "B8"
 "BCH-1"
 "BCH-2"
 "BCH-3"
 "EE-1"
 "MG-1(SP-1)"
 "MG-2(SP-2)"
 "MGI-1"
 "MGI-2"
```

```
modeltemp: Column 22 Min 19.935361862183 Max 211.10404968262
faultdense: Column 23 Min 0.2445030361414 Max 68.830604553223
faultintdense: Column 24 Min 0.0004273319500498 Max 26.058692932129
inv_distfaults: Column 25 Min 0.0 Max 524.44979986751
inv_distcontacts: Column 26 Min 0.0 Max 788.70471191407
unitthick: Column 27 Min 0.0 Max 829.723
goodlith: Column 28 Min 0 Max 1
wellid: Column 1 Unique entries:
```

```
2482-element Array{Any,1}:
    0
    1
    2
    3
    4
    5
    6
    7
    8
    9
   10
   11
   12
```

```
 2203
 2204
 2205.001
 2206
 2207
 2208
 2209
 2210.001
 2211
 2212
 2213
 2213.723
```

```
md: Column 2 Unique entries:
```

```
5965-element Array{Any,1}:
   0
   0.001
   0.002
   0.003
   0.005
   0.009
   0.01
   0.011
   0.012
   0.013
   0.014
   0.015
   0.016

 359.663
 359.702
 359.705
 359.746
 359.794
 359.836
 359.877
 359.902
 359.916
 359.954
 359.969
 359.991
```

```
7680-element Array{Any,1}:
   0
   0.035
   0.103
   0.163
```

```
   0.176
   0.216
   0.22
   0.275
   0.336
   0.382
   0.398
   0.451
   0.462

 359.348
 359.358
 359.44
 359.458
 359.521
 359.533
 359.538
 359.598
 359.616
 359.798
 359.89
 359.963
```

```
9381-element Array{Any,1}:
 326859.34
 326889
 326907.12
 326907.121
 326907.122
 326907.123
 326907.124
 326907.126
 326907.128
 326907.13
 326907.133
 326907.136
 326907.139

 328194.089
 328194.09
 328214.13
 328229.72
 328398.2
 328528.63
 328567.28
 328598.76
 328751.91
 328791.32
```

```
 328801.97
 328813.04

9349-element Array{Any,1}:
 4.4051245e6
 4.40544507e6
 4.40579963e6
 4.40596877e6
 4.40600409e6
 4.406004091e6
 4.406004092e6
 4.406004093e6
 4.406004094e6
 4.406004095e6
 4.406004096e6
 4.406004097e6
 4.406004098e6

 4.407754196e6
 4.407754581e6
 4.40795433e6
 4.40800628e6
 4.40843124e6
 4.40851194e6
 4.40855648e6
 4.40862911e6
 4.40871144e6
 4.40871725e6
 4.40882204e6
 4.40887416e6

32247-element Array{Any,1}:
 -923.476
 -922.98
 -922.689
 -922.45
 -921.846
 -920.943
 -920.04
 -919.137
 -918.235
 -917.333
 -916.43
 -915.527
 -914.625

 1274.81
 1274.94
 1275.12
```

```
 1275.29
 1275.75
 1275.81
 1275.94
 1276.12
 1276.29
 1276.75
 1276.81
 1277.29

azimuth: Column 3 Unique entries:
inclination: Column 4 Unique entries:
x: Column 5 Unique entries:
y: Column 6 Unique entries:
z: Column 7 Unique entries:

3-element Array{Any,1}:
 "Cased"
 "Open"
 "Slotted"

3-element Array{Any,1}:
 "Flowing"
 "NoFlow"
 "NotFlowing"

4-element Array{Any,1}:
 "Dry"
 "Injection"
 "PrimaryProduction"
 "Production"

4-element Array{Any,1}:
 "InjectionZone"
 "NoFlow"
 "PrimaryProductionZone"
 "SecondaryProductionZone"

casing: Column 8 Unique entries:
fluids: Column 9 Unique entries:
use: Column 10 Unique entries:
production: Column 11 Unique entries:

3-element Array{Any,1}:
 "Dry"
 "Injection"
 "Production"

3-element Array{Any,1}:
 "Dry"
 "Injection"
 "Production"
```

```
34981-element Array{Any,1}:
 -100.6743850708
 -100.673828125
 -100.67253875732
 -100.67088317871
 -100.66828155518
 -100.66556549072
 -100.66159057617
 -100.65789031982
 -100.65245819092
 -100.6478729248
 -100.64087677002
 -100.63552856445
 -100.62683105469

  153.09405517578
  153.41345214844
  153.7287902832
  154.04025268555
  154.34797668457
  154.6520690918
  154.95252990723
  155.24934387207
  155.54254150391
  155.83210754395
  156.11804199219
  156.40034484863
```

```
34987-element Array{Any,1}:
 -0.000240148059675
 -0.000240147914155
 -0.000240147172008
 -0.000240146750002
 -0.000240145280259
 -0.000240144552663
 -0.000240142355324
 -0.00024014133669
 -0.000240138397203
 -0.000240137116634
 -0.000240133435
 -0.000240131863393
 -0.000240127439611

  0.0002447074803058
  0.0002447261067573
  0.0002451444452163
  0.0002452681073919
  0.0002455763460603
```

```
  0.0002458038507029
  0.0002460031828377
  0.0002463333948981
  0.0002468566817697
  0.0002473737113178
  0.00024788454175
  0.0002483890857548
```

```
use2: Column 12 Unique entries:
lt750mstatus: Column 13 Unique entries:
normal: Column 14 Unique entries:
dilation: Column 15 Unique entries:
```

```
34967-element Array{Any,1}:
 -44.226177215576
 -44.060958862305
 -44.040775299072
 -44.040149688721
 -44.039539337158
 -44.037845611572
 -44.036636352539
 -44.033767700195
 -44.031883239746
 -44.028003692627
 -44.025279998779
 -44.020561218262
 -44.016845703125

 104.53256225586
 104.54156494141
 104.55010986328
 104.55821228027
 104.56585693359
 104.57305145264
 104.63977813721
 104.77731323242
 104.9132232666
 105.04750061035
 105.18015289307
 105.31118774414
```

```
34981-element Array{Any,1}:
 -104.33931732178
 -104.33917236328
 -104.33711242676
 -104.33673095703
 -104.33235168457
 -104.33205413818
 -104.32529449463
```

```
 -104.32475280762
 -104.31578826904
 -104.31571960449
 -104.30475616455
 -104.30313110352
 -104.2912902832

   87.164611816406
   87.209342956543
   87.252738952637
   87.294860839844
   87.335746765137
   87.375434875488
   87.413917541504
   87.451202392578
   87.487281799316
   87.522155761719
   87.55583190918
   87.588310241699

2-element Array{Any,1}:
 0
 1

10676-element Array{Any,1}:
 0
 0.11799113452435
 0.14923796057701
 0.15205390751362
 0.15496139228344
 0.16140922904015
 0.16673655807972
 0.17388172447681
 0.17679633200169
 0.17838226258755
 0.18031936883926
 0.18279492855072
 0.18584255874157

 0.95848602056503
 0.95974713563919
 0.96373718976974
 0.96613895893097
 0.96952033042908
 0.97369962930679
 0.97621542215347
 0.98268735408783
 0.9892275929451
 0.9904550909996
```

```
 0.99557024240494
 1

9007-element Array{Any,1}:
 0
 0.087840177118778
 0.091098383069038
 0.092407882213593
 0.096477940678596
 0.096891812980175
 0.097081169486046
 0.097131200134754
 0.098372466862202
 0.10165121406317
 0.10244186967611
 0.10283876210451
 0.10295303165913

 0.3998741209507
 0.39990851283073
 0.3999188542366
 0.39992380142212
 0.39993488788605
 0.39998385310173
 0.39998802542686
 0.39999052882195
 0.39999303221703
 0.39999756217003
 0.39999777078629
 0.4

10157-element Array{Any,1}:
 0
 1.377035459882e-6
 2.060575752694e-6
 2.769769935185e-6
 3.423073621889e-6
 3.490062226774e-6
 3.515589924064e-6
 4.223607902532e-6
 4.990432898921e-6
 5.854992650711e-6
 6.867431238788e-6
 7.028957497823e-6
 7.064185865602e-6

 0.0027199159376323
 0.0027221064083278
 0.0027268228586763
```

```
 0.0027273003943264
 0.0027362606488168
 0.0027496886905283
 0.0027521136216819
 0.0027580843307078
 0.0027634077705443
 0.0027840670663863
 0.0028071003034711
 0.0028201111126691

coulomb: Column 16 Unique entries:
shear: Column 17 Unique entries:
faults: Column 18 Unique entries:
td: Column 19 Unique entries:
ts: Column 20 Unique entries:
curve: Column 21 Unique entries:

34051-element Array{Any,1}:
  19.935361862183
  20.744554519653
  20.875152587891
  20.880397796631
  21.007032394409
  21.1403465271
  21.274843215942
  21.409343719482
  21.542518615723
  21.674077987671
  21.804132461548
  21.932481765747
  21.953189849854

 211.03363037109
 211.0478515625
 211.05171203613
 211.05932617188
 211.06907653809
 211.07919311523
 211.08502197266
 211.08833312988
 211.09809875488
 211.09963989258
 211.10243225098
 211.10404968262

34942-element Array{Any,1}:
  0.2445030361414
  0.24515467882156
  0.2453466206789
```

```
  0.24580323696136
  0.24644432961941
  0.24707356095314
  0.24749314785004
  0.24769507348537
  0.24831020832062
  0.24891456961632
  0.24949039518833
  0.24951182305813
  0.24985438585281

 68.820022583008
 68.823181152344
 68.823387145996
 68.82585144043
 68.826110839844
 68.827896118164
 68.828178405762
 68.829360961914
 68.829605102539
 68.830253601074
 68.830406188965
 68.830604553223

34973-element Array{Any,1}:
  0.0004273319500498
  0.0004274636157788
  0.0004287812043913
  0.0004294518730603
  0.0004297314735595
  0.0004349886439741
  0.0004404290521052
  0.0004457517934497
  0.0004509270656854
  0.0004559562075883
  0.0004608305171132
  0.0004655292141251
  0.0004700521240011

 26.052576065063
 26.054138183594
 26.054559707642
 26.055700302124
 26.056158065796
 26.056926727295
 26.057367324829
 26.05782699585
 26.058187484741
```

```
 26.058418273926
 26.058624267578
 26.058692932129

34998-element Array{Any,1}:
   0
   0.14923977940998
   0.25690020147999
   0.29942775276993
   0.44978606032998
   0.59949898028003
   0.74969664421997
   0.86202767783993
   0.90060913749994
   1.05094159304
   1.20164921508
   1.35305688951
   1.42706153879
 ⋮
 524.43178380321
 524.43272050194
 524.43458434838
 524.43461689776
 524.43469630614
 524.43844968037
 524.43903237114
 524.44025173764
 524.44131276638
 524.44259000193
 524.44683307473
 524.44979986751

modeltemp: Column 22 Unique entries:
faultdense: Column 23 Unique entries:
faultintdense: Column 24 Unique entries:
inv_distfaults: Column 25 Unique entries:

34698-element Array{Any,1}:
   0
   0.43933105469
   0.62432861329
   0.75549316407
   1.27478027344
   2.1298828125
   2.98522949219
   3.84057617188
   4.69488525391
   5.5492553711
   6.40478515625
```

```
   7.26013183594
   8.11462402344
   ⋮
 788.69079589844
 788.69274902344
 788.69555664063
 788.69580078126
 788.69665527344
 788.69879150391
 788.70031738282
 788.70166015626
 788.70178222657
 788.70275878907
 788.70385742188
 788.70471191407

7470-element Array{Any,1}:
   0
   0.4139404296875
   1.0655517578125
   1.2747802734375
   1.365478515625
   1.6517333984375
   1.803955078125
   2.0863037109375
   2.7310791015625
   2.7896728515625
   2.972412109375
   3.065185546875
   3.13037109375
   ⋮
 519.43890380859
 519.45367431641
 519.46875
 519.48352050781
 519.49862670898
 519.51354980469
 545.82562255859
 545.82563781738
 558.01470947266
 632.88
 642.688
 829.723

2-element Array{Any,1}:
 0
 1

inv_distcontacts: Column 26 Unique entries:
```

```
unitthick: Column 27 Unique entries:
goodlith: Column 28 Unique entries:
```

0.3.9 Get well locations and production

[10]:
```
locations = unique(sort(d[:,1]))
ii = convert.(Int64, round.(d[:,2]))
zi = unique(sort(ii))

xcoord = Vector{Float64}(undef, length(locations))
ycoord = Vector{Float64}(undef, length(locations))
production = Vector{String}(undef, length(locations))
for (j, w) in enumerate(locations)
        iw = d[:, 1] .== w
        i = findmin(d[iw, 2])[2]
        xcoord[j] = d[iw, 5][i]
        ycoord[j] = d[iw, 6][i]
        production[j] = unique(d[iw, pr])[end]
end
```

0.3.10 Define well types

[11]:
```
welltype = Vector{Symbol}(undef, length(locations))
for (j, w) in enumerate(locations)
        iw = d[:, 1] .== w
        welltype[j] = Symbol(unique(d[iw, indexin(["lt750mstatus"],␣
↪attributes_short)])[1])
end
```

0.3.11 Display information about processed well attributes

[12]:
```
for i = ai
        println("$(attributes_col[i]): $i")
        display(unique(sort(convert.(Float64, d[:,i]))))
end
```

```
34981-element Array{Float64,1}:
 -100.6743850708
 -100.673828125
 -100.67253875732
 -100.67088317871
 -100.66828155518
 -100.66556549072
 -100.66159057617
 -100.65789031982
 -100.65245819092
 -100.6478729248
 -100.64087677002
```

```
 -100.63552856445
 -100.62683105469
  
  153.09405517578
  153.41345214844
  153.7287902832
  154.04025268555
  154.34797668457
  154.6520690918
  154.95252990723
  155.24934387207
  155.54254150391
  155.83210754395
  156.11804199219
  156.40034484863
```

```
normal: 14
```

```
34987-element Array{Float64,1}:
 -0.000240148059675
 -0.000240147914155
 -0.000240147172008
 -0.000240146750002
 -0.000240145280259
 -0.000240144552663
 -0.000240142355324
 -0.00024014133669
 -0.000240138397203
 -0.000240137116634
 -0.000240133435
 -0.000240131863393
 -0.000240127439611
  
  0.0002447074803058
  0.0002447261067573
  0.0002451444452163
  0.0002452681073919
  0.0002455763460603
  0.0002458038507029
  0.0002460031828377
  0.0002463333948981
  0.0002468566817697
  0.0002473737113178
  0.00024788454175
  0.0002483890857548
```

```
34967-element Array{Float64,1}:
 -44.226177215576
 -44.060958862305
```

```
 -44.040775299072
 -44.040149688721
 -44.039539337158
 -44.037845611572
 -44.036636352539
 -44.033767700195
 -44.031883239746
 -44.028003692627
 -44.025279998779
 -44.020561218262
 -44.016845703125

 104.53256225586
 104.54156494141
 104.55010986328
 104.55821228027
 104.56585693359
 104.57305145264
 104.63977813721
 104.77731323242
 104.9132232666
 105.04750061035
 105.18015289307
 105.31118774414

34981-element Array{Float64,1}:
 -104.33931732178
 -104.33917236328
 -104.33711242676
 -104.33673095703
 -104.33235168457
 -104.33205413818
 -104.32529449463
 -104.32475280762
 -104.31578826904
 -104.31571960449
 -104.30475616455
 -104.30313110352
 -104.2912902832

   87.164611816406
   87.209342956543
   87.252738952637
   87.294860839844
   87.335746765137
   87.375434875488
   87.413917541504
   87.451202392578
```

```
   87.487281799316
   87.522155761719
   87.55583190918
   87.588310241699

2-element Array{Float64,1}:
 0.0
 1.0

10676-element Array{Float64,1}:
 0.0
 0.11799113452435
 0.14923796057701
 0.15205390751362
 0.15496139228344
 0.16140922904015
 0.16673655807972
 0.17388172447681
 0.17679633200169
 0.17838226258755
 0.18031936883926
 0.18279492855072
 0.18584255874157

 0.95848602056503
 0.95974713563919
 0.96373718976974
 0.96613895893097
 0.96952033042908
 0.97369962930679
 0.97621542215347
 0.98268735408783
 0.9892275929451
 0.9904550909996
 0.99557024240494
 1.0

9007-element Array{Float64,1}:
 0.0
 0.087840177118778
 0.091098383069038
 0.092407882213593
 0.096477940678596
 0.096891812980175
 0.097081169486046
 0.097131200134754
 0.098372466862202
 0.10165121406317
 0.10244186967611
```

```
 0.10283876210451
 0.10295303165913
 ⋮
 0.3998741209507
 0.39990851283073
 0.3999188542366
 0.39992380142212
 0.39993488788605
 0.39998385310173
 0.39998802542686
 0.39999052882195
 0.39999303221703
 0.39999756217003
 0.39999777078629
 0.4
10157-element Array{Float64,1}:
 0.0
 1.377035459882e-6
 2.060575752694e-6
 2.769769935185e-6
 3.423073621889e-6
 3.490062226774e-6
 3.515589924064e-6
 4.223607902532e-6
 4.990432898921e-6
 5.854992650711e-6
 6.867431238788e-6
 7.028957497823e-6
 7.064185865602e-6
 ⋮
 0.0027199159376323
 0.0027221064083278
 0.0027268228586763
 0.0027273003943264
 0.0027362606488168
 0.0027496886905283
 0.0027521136216819
 0.0027580843307078
 0.0027634077705443
 0.0027840670663863
 0.0028071003034711
 0.0028201111126691
34051-element Array{Float64,1}:
  19.935361862183
  20.744554519653
  20.875152587891
  20.880397796631
```

```
  21.007032394409
  21.1403465271
  21.274843215942
  21.409343719482
  21.542518615723
  21.674077987671
  21.804132461548
  21.932481765747
  21.953189849854

 211.03363037109
 211.0478515625
 211.05171203613
 211.05932617188
 211.06907653809
 211.07919311523
 211.08502197266
 211.08833312988
 211.09809875488
 211.09963989258
 211.10243225098
 211.10404968262
34942-element Array{Float64,1}:
  0.2445030361414
  0.24515467882156
  0.2453466206789
  0.24580323696136
  0.24644432961941
  0.24707356095314
  0.24749314785004
  0.24769507348537
  0.24831020832062
  0.24891456961632
  0.24949039518833
  0.24951182305813
  0.24985438585281

 68.820022583008
 68.823181152344
 68.823387145996
 68.82585144043
 68.826110839844
 68.827896118164
 68.828178405762
 68.829360961914
 68.829605102539
 68.830253601074
```

```
 68.830406188965
 68.830604553223

dilation: 15
coulomb: 16
shear: 17
faults: 18
td: 19
ts: 20
curve: 21
modeltemp: 22
faultdense: 23

34973-element Array{Float64,1}:
  0.0004273319500498
  0.0004274636157788
  0.0004287812043913
  0.0004294518730603
  0.0004297314735595
  0.0004349886439741
  0.0004404290521052
  0.0004457517934497
  0.0004509270656854
  0.0004559562075883
  0.0004608305171132
  0.0004655292141251
  0.0004700521240011

 26.052576065063
 26.054138183594
 26.054559707642
 26.055700302124
 26.056158065796
 26.056926727295
 26.057367324829
 26.05782699585
 26.058187484741
 26.058418273926
 26.058624267578
 26.058692932129

34998-element Array{Float64,1}:
   0.0
   0.14923977940998
   0.25690020147999
   0.29942775276993
   0.44978606032998
   0.59949898028003
   0.74969664421997
```

```
   0.86202767783993
   0.90060913749994
   1.05094159304
   1.20164921508
   1.35305688951
   1.42706153879
 ⋮
 524.43178380321
 524.43272050194
 524.43458434838
 524.43461689776
 524.43469630614
 524.43844968037
 524.43903237114
 524.44025173764
 524.44131276638
 524.44259000193
 524.44683307473
 524.44979986751

34698-element Array{Float64,1}:
   0.0
   0.43933105469
   0.62432861329
   0.75549316407
   1.27478027344
   2.1298828125
   2.98522949219
   3.84057617188
   4.69488525391
   5.5492553711
   6.40478515625
   7.26013183594
   8.11462402344
 ⋮
 788.69079589844
 788.69274902344
 788.69555664063
 788.69580078126
 788.69665527344
 788.69879150391
 788.70031738282
 788.70166015626
 788.70178222657
 788.70275878907
 788.70385742188
 788.70471191407

7470-element Array{Float64,1}:
```

```
  0.0
  0.4139404296875
  1.0655517578125
  1.2747802734375
  1.365478515625
  1.6517333984375
  1.803955078125
  2.0863037109375
  2.7310791015625
  2.7896728515625
  2.972412109375
  3.065185546875
  3.13037109375

519.43890380859
519.45367431641
519.46875
519.48352050781
519.49862670898
519.51354980469
545.82562255859
545.82563781738
558.01470947266
632.88
642.688
829.723

faultintdense: 24
inv_distfaults: 25
inv_distcontacts: 26
unitthick: 27
```

0.3.12 Collect the well data into a 3D tensor

Tensor indices (dimensions) define depths, attributes, and wells.

[13]:
```
T = Array{Float64}(undef, length(zi), length(ai), length(locations))
T .= NaN

for w = 1:length(locations)
        iw = d[:, 1] .== locations[w]
        m = d[iw, ai]
        zw = ii[iw]
        for z = 1:length(zw)
                a = vec(m[z, :])
                s = length(a)
                if s == 0
                        continue
```

```
                end
                T[zw[z] + 1, 1:s, w] .= a
        end
end
```

0.3.13 Define the maximum depth

The maximum depth limits the depth of the data included in the analyses.

The maximum depth is set to 750 m.

[14]:
```
depth = 750;
```

0.3.14 Normalize tensor slices associated with each attribute

[15]:
```
Tn = deepcopy(T[1:depth,:,:])
for a = 1:length(ai)
        Tn[:,a,:], _, _ = NMFk.normalize!(Tn[:,a,:])
end
```

0.3.15 Define problem setup variables

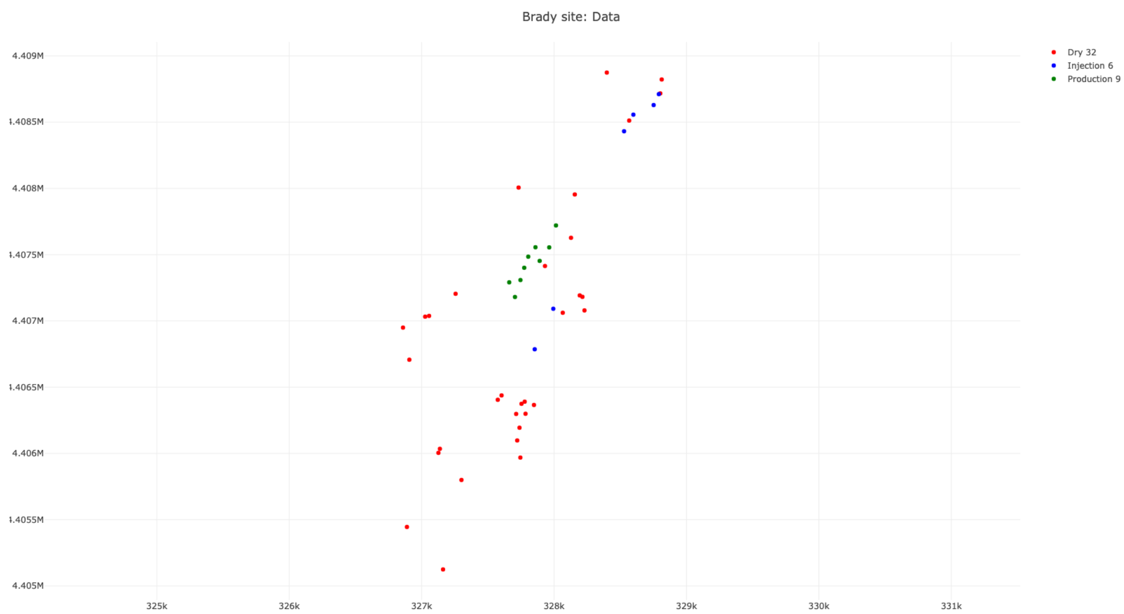
[16]:
```
nruns = 1000 # number of random NMF runs
nkrange = 2:8 # range of k values explored by the NMFk algorithm

casename = "set00-v9-inv" # casename of the performed ML analyses
figuredir = "figures-$(casename)-$(depth)" # directory to store figures␣
 ↪associated with the performed ML analyses
resultdir = "results-$(casename)-$(depth)"; # directory to store obtained␣
 ↪results associated with the performed ML analyses
```

0.3.16 Plot well data

[17]:
```
nlocations = length(locations)
hovertext = Vector{String}(undef, nlocations)
for i = 1:nlocations
        hovertext[i] = join(map(j->("$(attributes_process_long[j]):␣
 ↪$(round(float.(NMFk.meannan(T[:,j,i])); sigdigits=3))<br>"), 1:
 ↪length(attributes_process_long)))
end

NMFk.plot_wells("map/dataset-$(casename).html", xcoord, ycoord, String.
 ↪(welltype); hover=locations .* "<br>" .* String.(welltype) .* "<br>" .*␣
 ↪production .* "<br>" .* hovertext, title="Brady site: Data")
```

A HTML file named `../map/dataset-set00-v9-inv.html` is generated mapping the site data. The map provides interactive visualization of the site data (it can also be opened with any browser).

The map below shows the location of the `Dry`, `Injection` and `Production` wells.



0.4 Perform ML analyses

For the ML analyses, the data tensor can be flattened into a data matrix by using two different approaches:

- Type 1: Merge depth and attribute tensor dimensions; in this way, the focus of the ML analysis is on finding the features associated with the well locations
- Type 2: Merge depth and location tensor dimensions; in this way, the focus of the ML analysis is on finding the features associated with the well attributes

After that the **NMFk** algorithm will factorize the data matrix `X` into `W` and `H` matrices. For more information, check out the **NMFk** website

0.4.1 Type 1 flattening: Focus on well locations

Flatten the tensor into a matrix

[18]:
```
Xdaln = reshape(Tn, (depth * length(attributes_process)), length(locations));
```

Matrix rows merge the depth and attribute dimensions.

Matrix columns represent the well locations.

Perform NMFk analyses

[19]:
```
W, H, fitquality, robustness, aic = NMFk.execute(Xdaln, nkrange, nruns;␣
↪resultdir=resultdir, casefilename="nmfk-daln-$(join(size(Xdaln), '_'))",␣
↪load=true)
W, H, fitquality, robustness, aic = NMFk.load(nkrange, nruns;␣
↪resultdir=resultdir, casefilename="nmfk-daln-$(join(size(Xdaln), '_'))");
```

```
Signals:  2 Fit:     17906.11 Silhouette:    0.6571116 AIC:    -944054.7
Signals:  3 Fit:     15067.48 Silhouette:    0.2121185 AIC:    -981003.7
```

```
Signals:  4 Fit:     12811.86 Silhouette:  -0.03854946 AIC:     -1014443
Signals:  5 Fit:     10966.81 Silhouette:    0.4108927 AIC:     -1045640
Signals:  6 Fit:     9570.522 Silhouette:    0.4704617 AIC:     -1070343
Signals:  7 Fit:     8398.009 Silhouette:   -0.2070509 AIC:     -1093198
Signals:  8 Fit:     7428.398 Silhouette:   -0.2601539 AIC:     -1113361
Signals:  2 Fit:     17906.11 Silhouette:    0.6571116 AIC:    -944054.7
Signals:  3 Fit:     15067.48 Silhouette:    0.2121185 AIC:    -981003.7
Signals:  4 Fit:     12811.86 Silhouette:  -0.03854946 AIC:     -1014443
Signals:  5 Fit:     10966.81 Silhouette:    0.4108927 AIC:     -1045640
Signals:  6 Fit:     9570.522 Silhouette:    0.4704617 AIC:     -1070343
Signals:  7 Fit:     8398.009 Silhouette:   -0.2070509 AIC:     -1093198
Signals:  8 Fit:     7428.398 Silhouette:   -0.2601539 AIC:     -1113361
```

```
 Info: Results
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:15
 Info: Optimal solution: 6 signals
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:20
```

```
Signals:  2 Fit:     17906.11 Silhouette:    0.6571116 AIC:    -944054.7
Signals:  3 Fit:     15067.48 Silhouette:    0.2121185 AIC:    -981003.7
Signals:  4 Fit:     12811.86 Silhouette:  -0.03854946 AIC:     -1014443
Signals:  5 Fit:     10966.81 Silhouette:    0.4108927 AIC:     -1045640
Signals:  6 Fit:     9570.522 Silhouette:    0.4704617 AIC:     -1070343
Signals:  7 Fit:     8398.009 Silhouette:   -0.2070509 AIC:     -1093198
Signals:  8 Fit:     7428.398 Silhouette:   -0.2601539 AIC:     -1113361
```

```
 Info: Optimal solution: 6 signals
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkIO.jl:30
```

Here, the **NMFk** results are loaded from a prior ML run.

As seen from the output above, the **NMFk** analyses identified that the optimal number of geothermal signatures in the dataset **6**.

Solutions with a number of signatures less than **6** are underfitting.

Solutions with a number of signatures greater than **6** are overfitting and unacceptable.

The set of acceptable solutions are defined by the **NMFk** algorithm as follows:

[20]:
```
NMFk.getks(nkrange, robustness[nkrange])
```

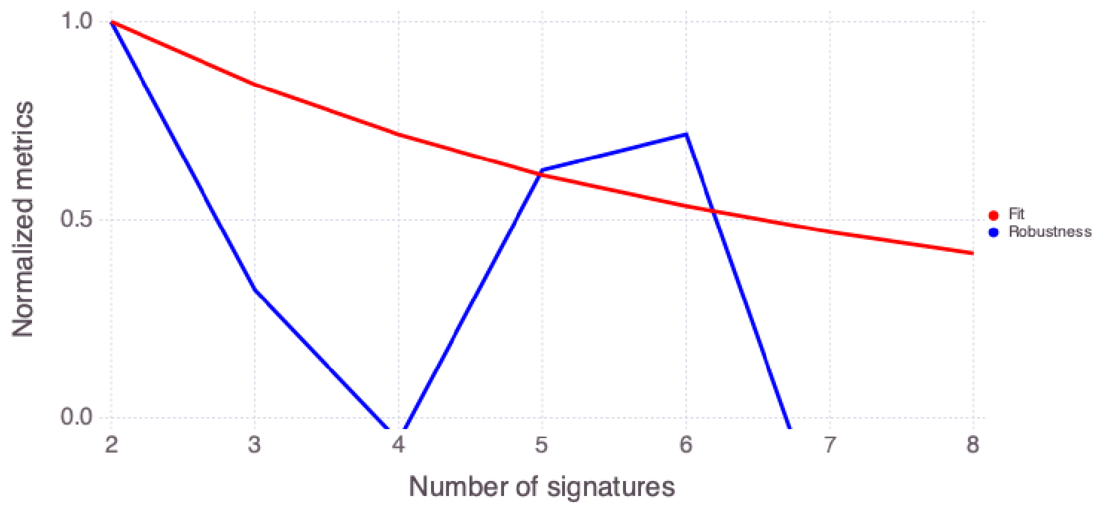
[20]:
```
3-element Array{Int64,1}:
 2
 5
 6
```

The acceptable solutions contain 2, 5 and 6 signatures.

Post-process NMFk results

Number of signatures Below is a plot representing solution quality (fit) and silhouette width (robustness) for different numbers of signatures k:

[21]:
```
NMFk.plot_signal_selecton(nkrange, fitquality, robustness;␣
↪figuredir="$figuredir-$(nruns)-daln", xtitle="Number of signatures")
```



The plot above also demonstrates that the acceptable solutions contain 2, 5 and 6 signatures.

Analysis of all the acceptable solutions The ML solutions containing an acceptable number of signatures are further analyzed as follows:

[22]:
```
NMFk.clusterresults(NMFk.getks(nkrange, robustness[nkrange]; ks=[3,4]), W, H,␣
↪attributes_process_long, locations; loadassignements=true, lon=xcoord,␣
↪lat=ycoord, Wsize=depth, Worder=Worder, Wcasefilename="attributes",␣
↪Hcasefilename="locations", resultdir=resultdir * "-$(nruns)-daln",␣
↪figuredir=figuredir * "-$(nruns)-daln", hover="Well: " .* locations .*␣
↪"<br>" .* "WellType: " .* String.(welltype) .* "<br>" .* production,␣
↪Wmatrix_font_size=4Gadfly.pt, biplotcolor=:WH, biplotlabel=:WH)
```

```
Info: Number of signals: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144

Signal importance (high->low): [2, 1]

Info: Locations (signals=2)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
```

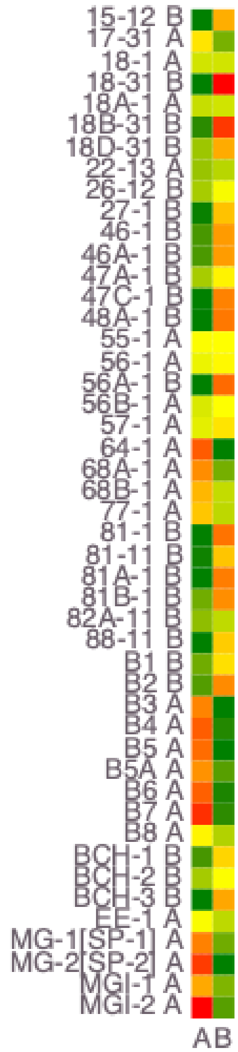
```
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Hmatrix-2-2_47-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Wmatrix-2-2_14-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Info: Signal A -> A Count: 24
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
```

```
24×2 Array{Any,2}:
 "MGI-2"       1.0
 "B7"          0.971874
 "MG-2(SP-2)"  0.957147
 "64-1"        0.906381
 "B4"          0.902571
 "B6"          0.897107
 "B5"          0.874384
 "MG-1(SP-1)"  0.828417
 "B3"          0.82034
 "68A-1"       0.80013
 "B5A"         0.78864
 "MGI-1"       0.732217
 "68B-1"       0.696522
 "77-1"        0.655878
 "17-31"       0.57376
 "B8"          0.528089
 "55-1"        0.491206
 "EE-1"        0.487324
 "56-1"        0.455524
 "57-1"        0.43842
 "56B-1"       0.413443
 "18-1"        0.395716
 "18A-1"       0.370733
 "22-13"       0.269227
```

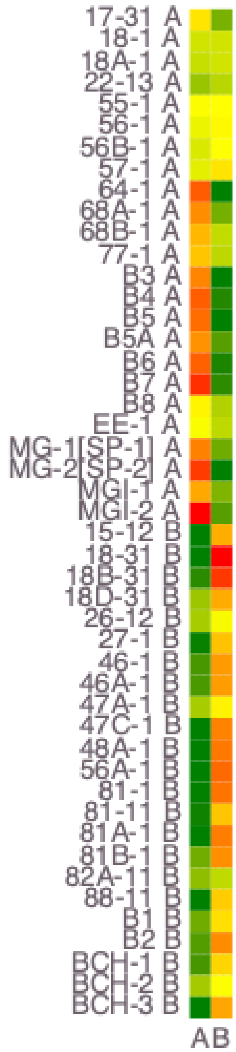
```
 Info: Signal B -> B Count: 23
```

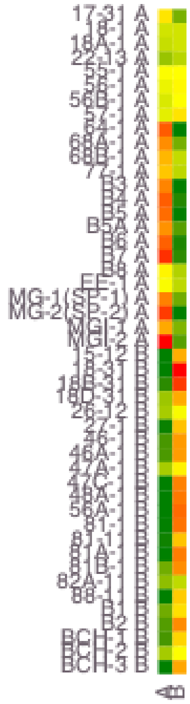
```
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal A (S1) (k-means clustering)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```

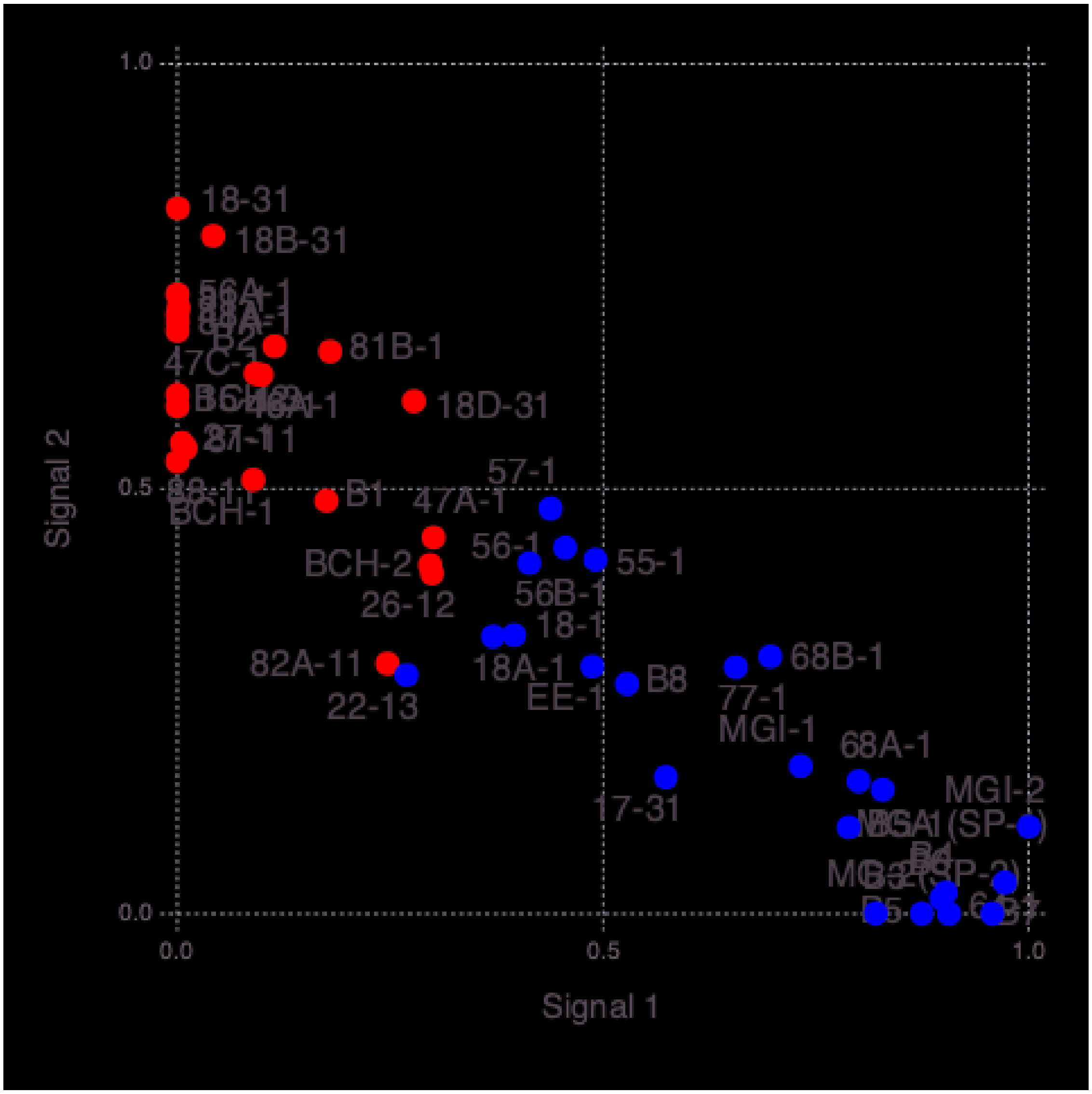
```
23×2 Array{Any,2}:
 "18-31"   1.0
 "18B-31"  0.960836
 "56A-1"   0.878124
 "81-1"    0.859001
 "48A-1"   0.849051
 "81A-1"   0.838298
 "47C-1"   0.826181
 "B2"      0.804453
 "81B-1"   0.796872
 "46-1"    0.765556
 "46A-1"   0.763833
 "BCH-3"   0.735382
 "18D-31"  0.726398
 "15-12"   0.719203
 "27-1"    0.66714
 "81-11"   0.659873
 "88-11"   0.641011
 "BCH-1"   0.61491
 "B1"      0.58518
 "47A-1"   0.533141
 "BCH-2"   0.494268
 "26-12"   0.482354
 "82A-11"  0.354477
```



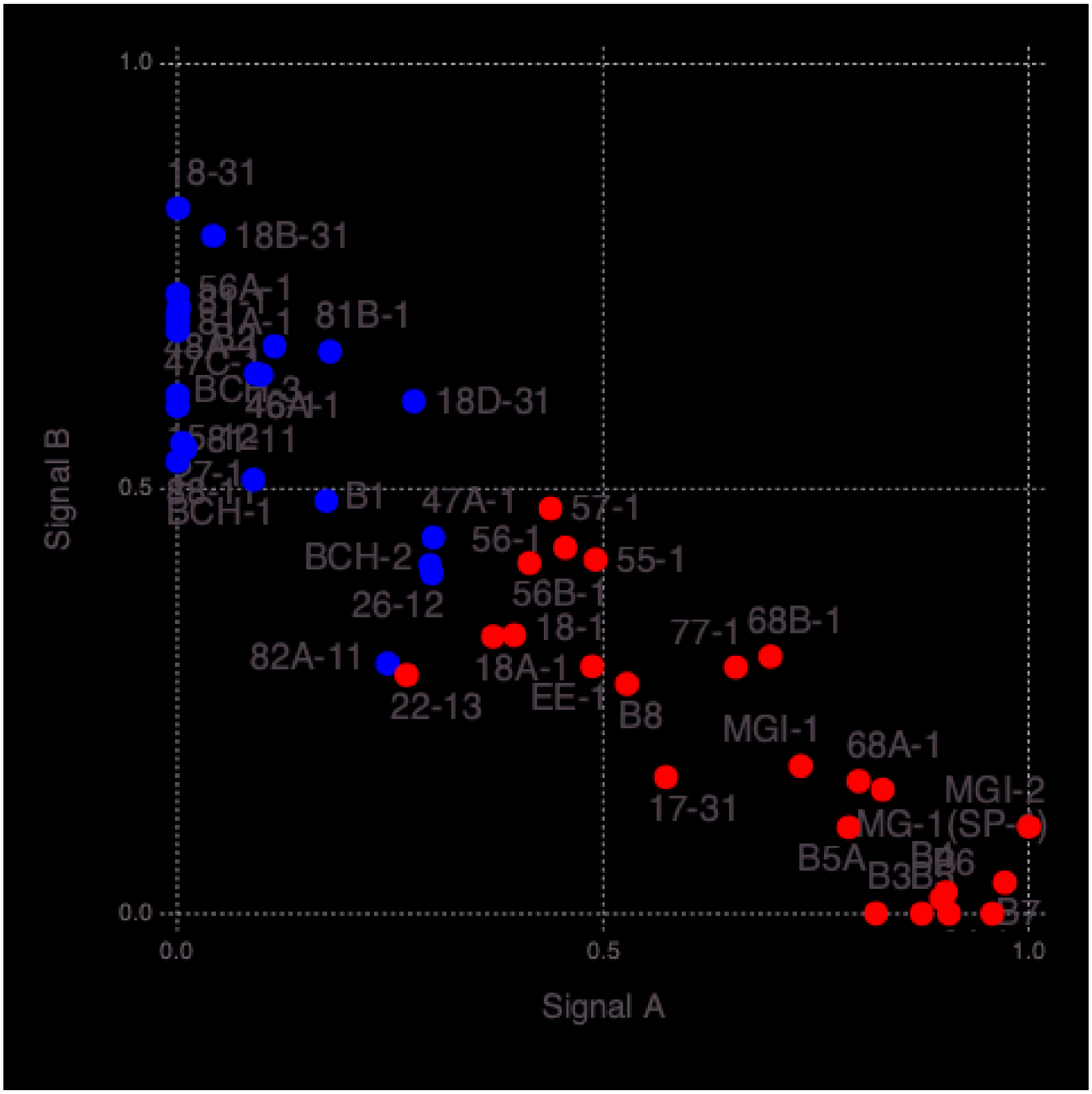

```
Info: Signal B (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```


17-31 A
18-1 A
18A-1 A
22-13 A
55-1 A
56-1 A
56B-1 A
57-1 A
64-1 A
68A-1 A
68B-1 A
77-1 A
B3 A
B4 A
B5 A
B5A A
B6 A
B7 A
B8 A
EE-1 A
MG-1[SP-1] A
MG-2[SP-2] A
MGI-1 A
MGI-2 A
15-12 B
18-31 B
18B-31 B
18D-31 B
26-12 B
27-1 B
46-1 B
46A-1 B
47A-1 B
47C-1 B
48A-1 B
56A-1 B
81-1 B
81-11 B
81A-1 B
81B-1 B
82A-11 B
88-11 B
B1 B
B2 B
BCH-1 B
BCH-2 B
BCH-3 B
A
B



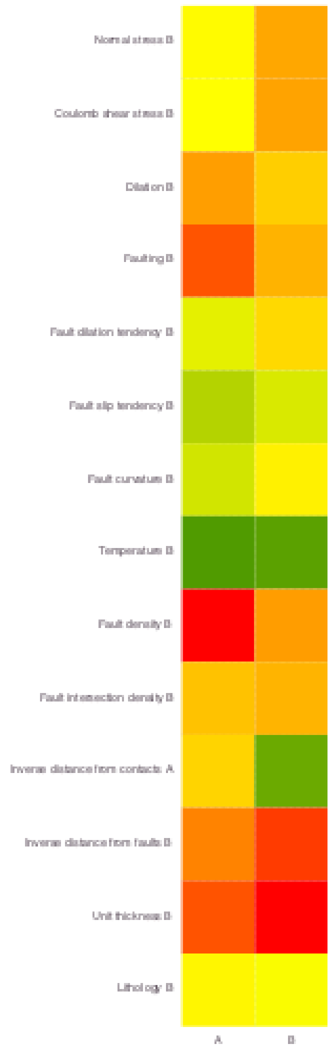


Signal 2
Signal 1
1.0
0.5
0.0
0.0
0.5
1.0
18-31
18B-31
81B-1
18D-31
47C-1
B1
BCH-1
47A-1
BCH-2
26-12
82A-11
22-13
57-1
56-1
55-1
56B-1
18-1
18A-1
EE-1
B8
68B-1
77-1
MGI-1
68A-1
17-31
MGI-2



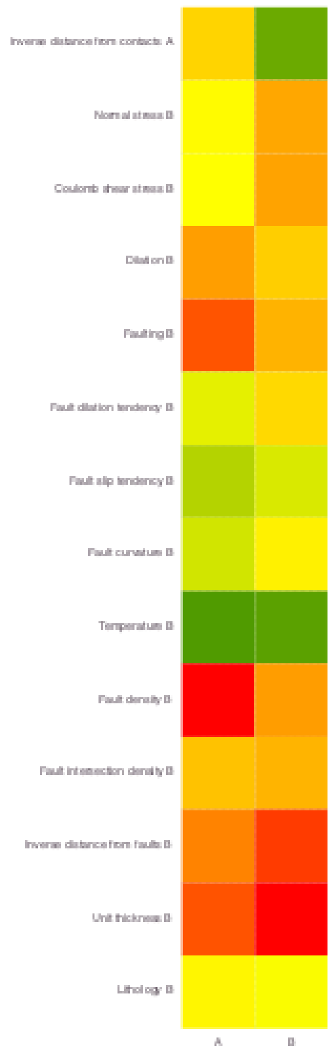

```
1×2 Array{Any,2}:
 "Inverse distance from contacts"  0.619519

13×2 Array{Any,2}:
 "Unit thickness"                1.0
 "Inverse distance from faults"  0.957468
 "Fault density"                 0.761708
 "Coulomb shear stress"          0.74607
 "Normal stress"                 0.737061
 "Faulting"                      0.706576
 "Fault intersection density"    0.702918
 "Dilation"                      0.635119
```

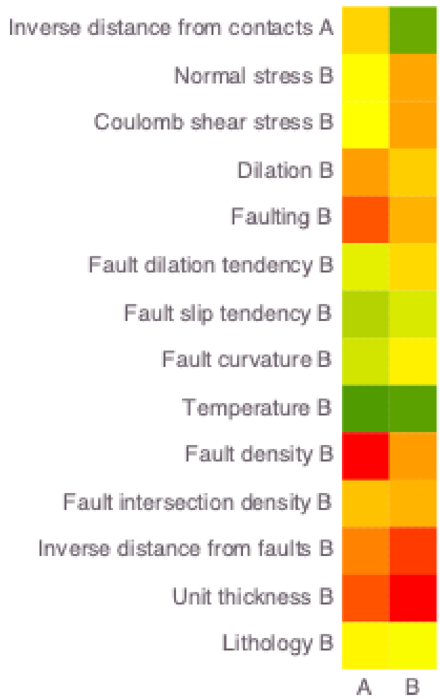
```
"Fault dilation tendency"       0.605243
"Fault curvature"               0.538705
"Lithology"                     0.488473
"Fault slip tendency"           0.41415
"Temperature"                   0.131901
```

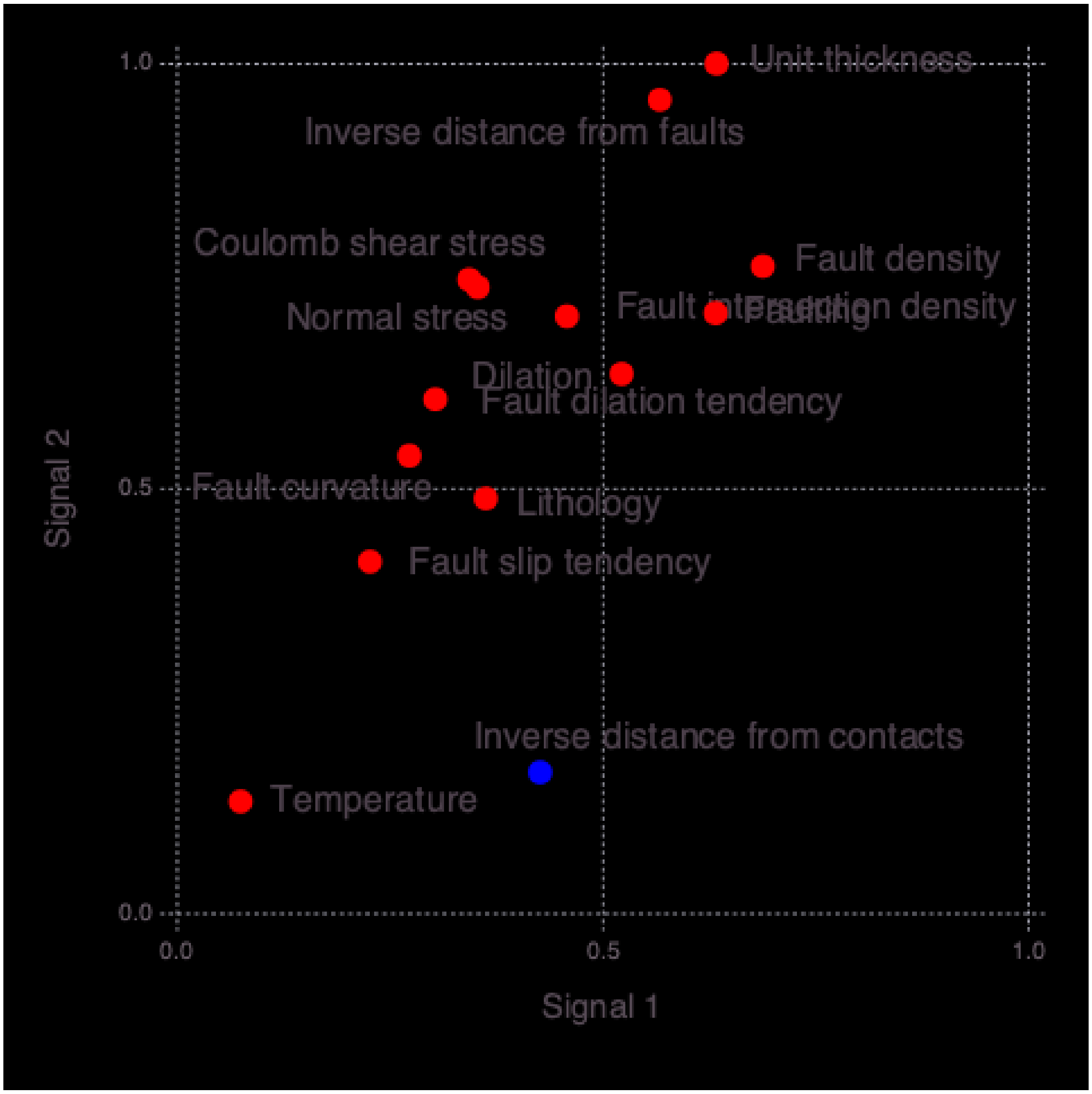


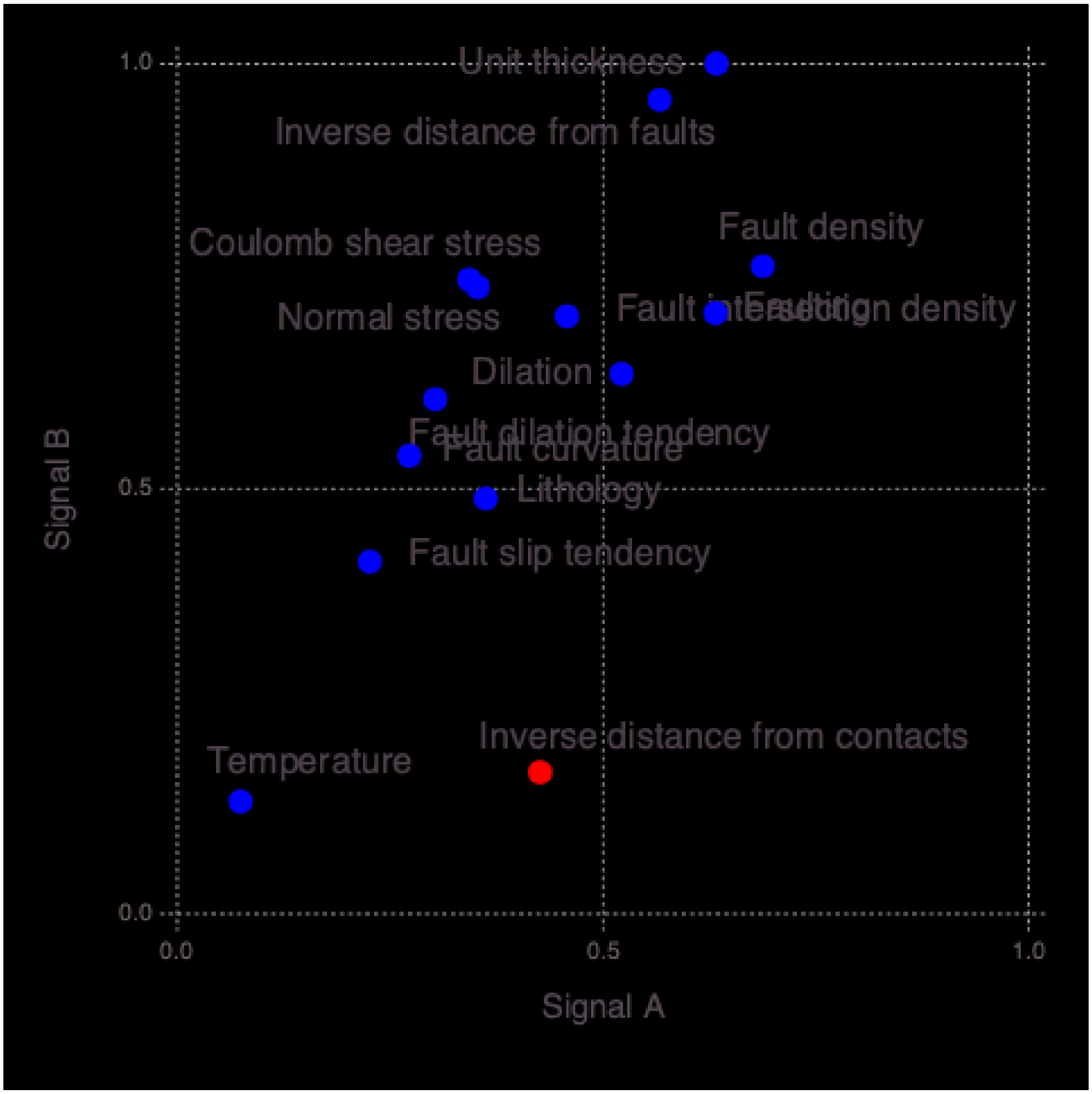

```
Info: Attributes (signals=2)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S2) Count: 13
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S1) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B -> A Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
```

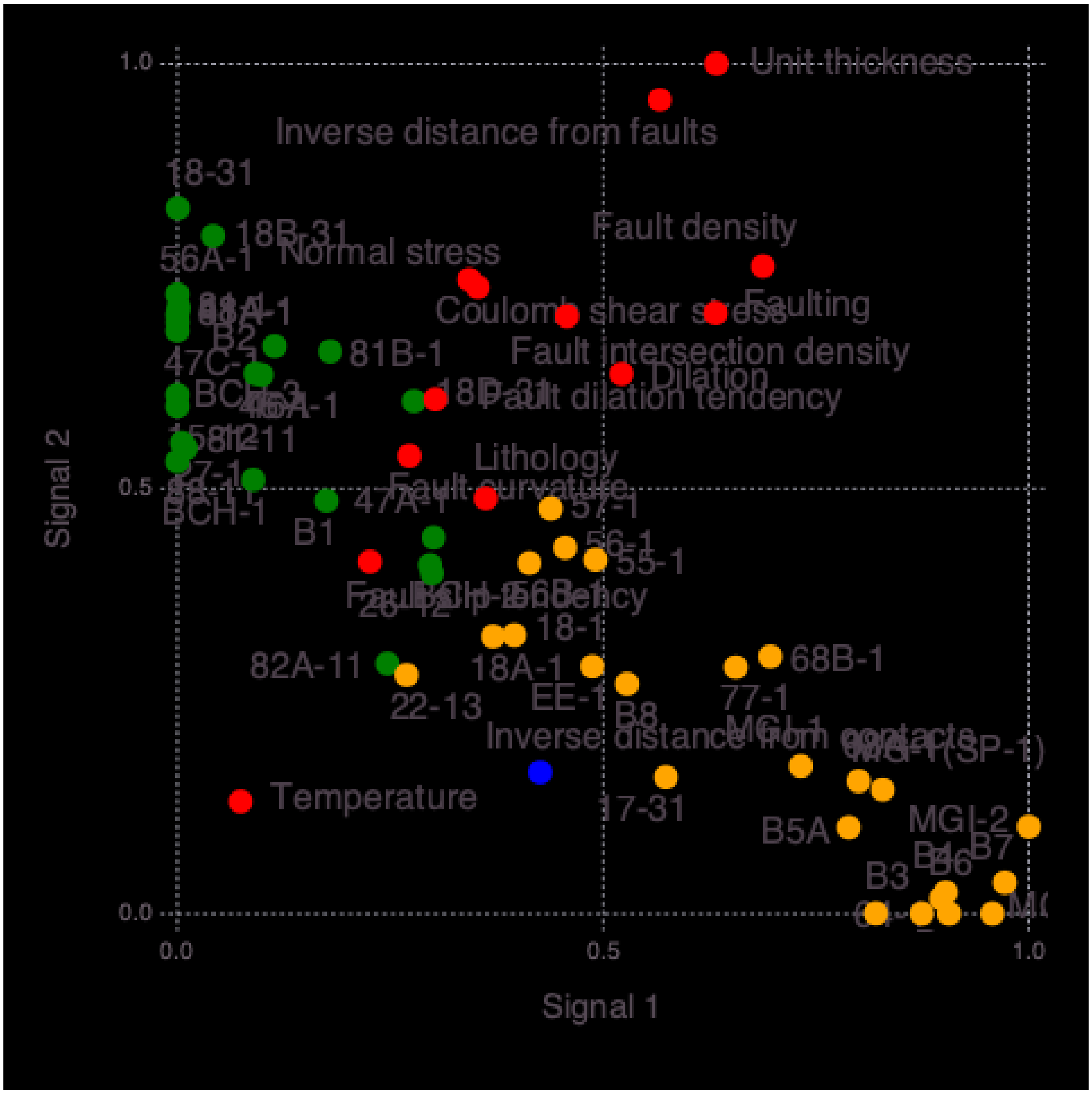
```
Info: Signal A -> B Count: 13
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

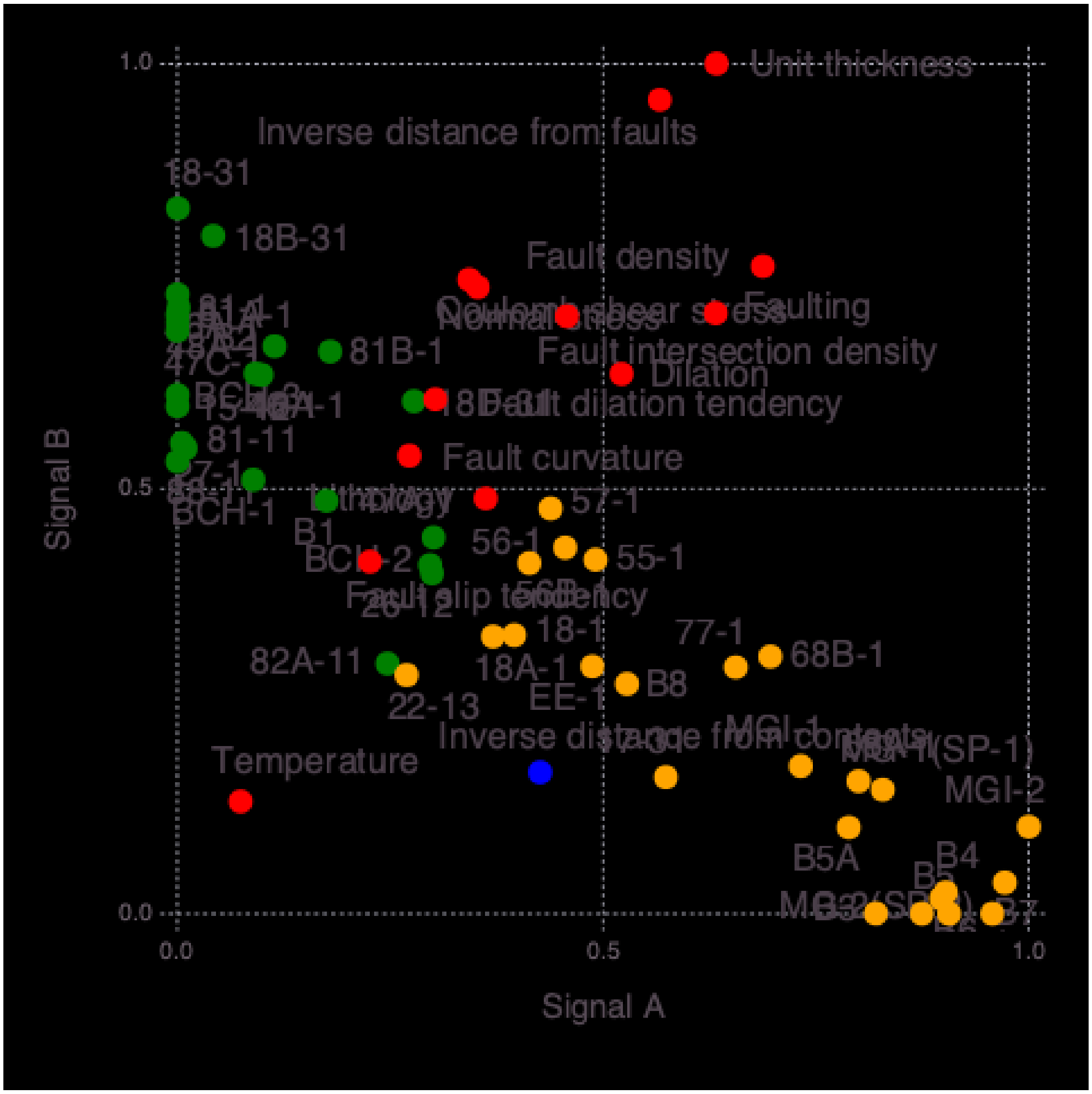



Inverse distance from contacts A
Normal stress B
Coulomb shear stress B
Dilation B
Faulting B
Fault dilation tendency B
Fault slip tendency B
Fault curvature B
Temperature B
Fault density B
Fault intersection density B
Inverse distance from faults B
Unit thickness B
Lithology B
A
B


Unit thickness
Inverse distance from faults
Coulomb shear stress
Fault density
Normal stress
Fault intersection density
Faulting
Dilation
Fault dilation tendency
Fault curvature
Lithology
Fault slip tendency
Inverse distance from contacts
Temperature
Signal 2
Signal 1
0.0
0.5
1.0


Unit thickness
Inverse distance from faults
Fault density
Coulomb shear stress
Normal stress
Fault intersection density
Erodibility
Dilation
Fault dilation tendency
Fault curvature
Lithology
Fault slip tendency
Inverse distance from contacts
Temperature
Signal B
Signal A
0.0
0.5
1.0

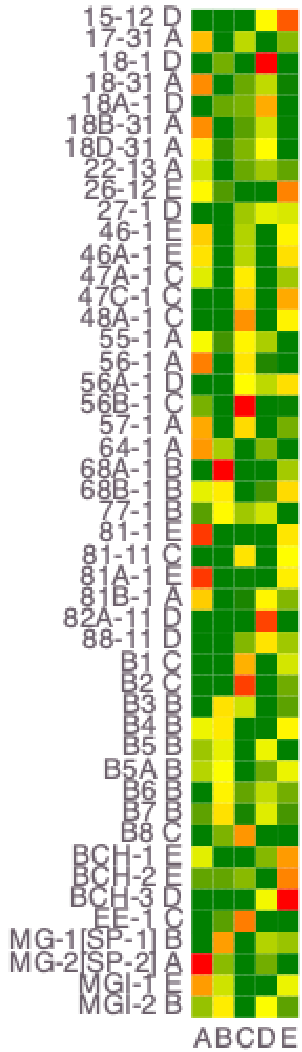

Signal 1
Signal 2
0.0
0.5
1.0
Unit thickness
Inverse distance from faults
18-31
18B-31
Normal stress
56A-1
Fault density
Faulting
81B-1
Fault intersection density
Dilation
Fault dilation tendency
Lithology
Fault curvature
47A-1
B1
BCH-1
57-1
55-1
18-1
82A-11
22-13
18A-1
EE-1
68B-1
77-1
B8
Inverse distance from contacts
Temperature
17-31
B5A
MGI-2
B3
B7




```
Signal importance (high->low): [1, 3, 5, 4, 2]
 Info: Number of signals: 5
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
 Info: Locations (signals=5)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Hmatrix-5-5_47-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
```

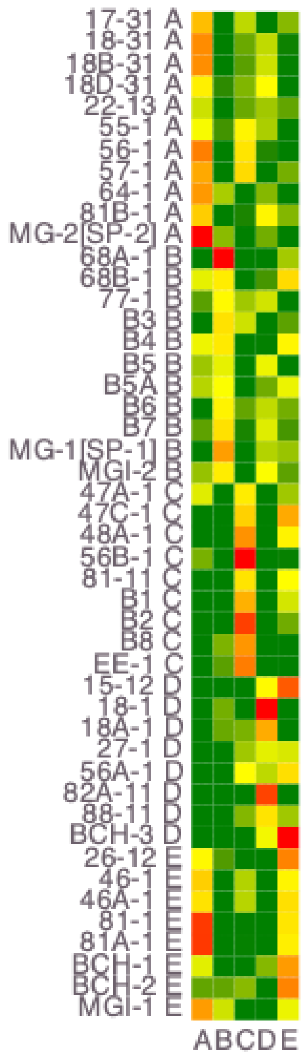
```
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Wmatrix-5-5_14-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67

11×2 Array{Any,2}:
 "MG-2(SP-2)"  1.0
 "56-1"        0.833071
 "18-31"       0.803582
 "18B-31"      0.79762
 "64-1"        0.771609
 "57-1"        0.731212
 "17-31"       0.675958
 "81B-1"       0.638129
 "18D-31"      0.542359
 "55-1"        0.482608
 "22-13"       0.384279

11×2 Array{Any,2}:
 "68A-1"       1.0
 "MG-1(SP-1)"  0.760228
 "B7"          0.583165
 "B3"          0.579901
 "B4"          0.559561
 "MGI-2"       0.550751
 "68B-1"       0.549639
 "B6"          0.533677
 "77-1"        0.51494
 "B5A"         0.492662
 "B5"          0.444441

9×2 Array{Any,2}:
 "56B-1"  1.0
 "B2"     0.952516
 "EE-1"   0.837563
 "48A-1"  0.787595
 "B8"     0.779397
```

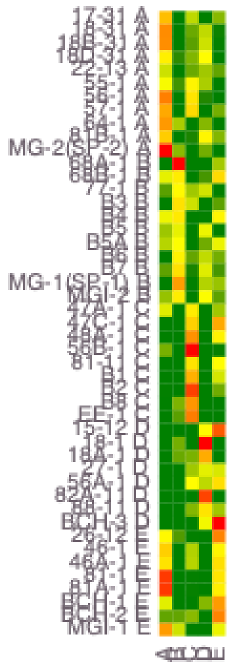
```
 "B1"     0.711321
 "47C-1"  0.625562
 "81-11"  0.574423
 "47A-1"  0.549964

8×2 Array{Any,2}:
 "18-1"    1.0
 "82A-11"  0.947022
 "18A-1"   0.723864
 "88-11"   0.57605
 "15-12"   0.515703
 "BCH-3"   0.472471
 "27-1"    0.439353
 "56A-1"   0.3504

8×2 Array{Any,2}:
 "26-12"  0.82344
 "BCH-2"  0.822391
 "BCH-1"  0.766974
 "46A-1"  0.586862
 "81-1"   0.570404
 "81A-1"  0.545145
 "46-1"   0.529248
 "MGI-1"  0.456212
```

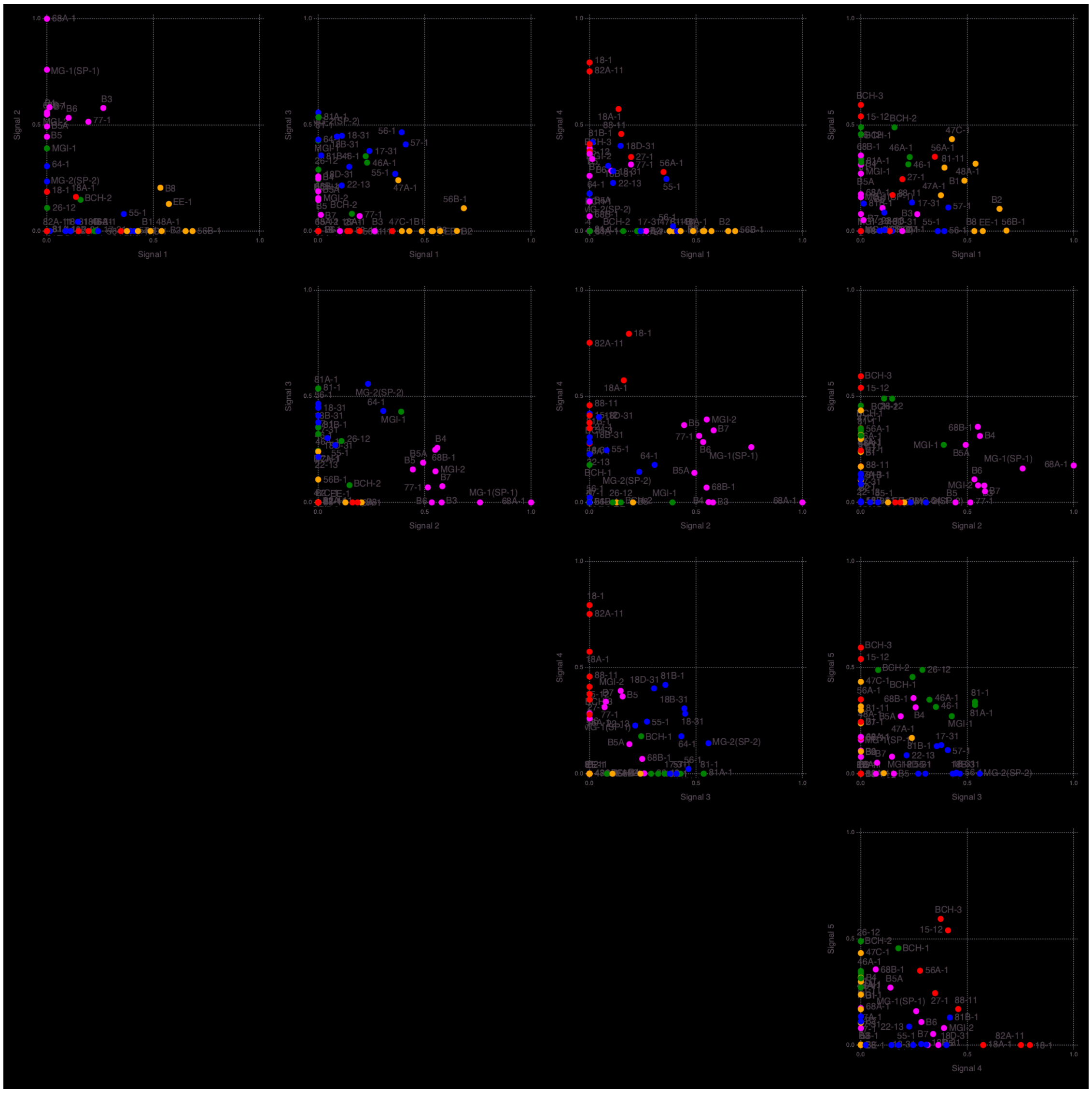


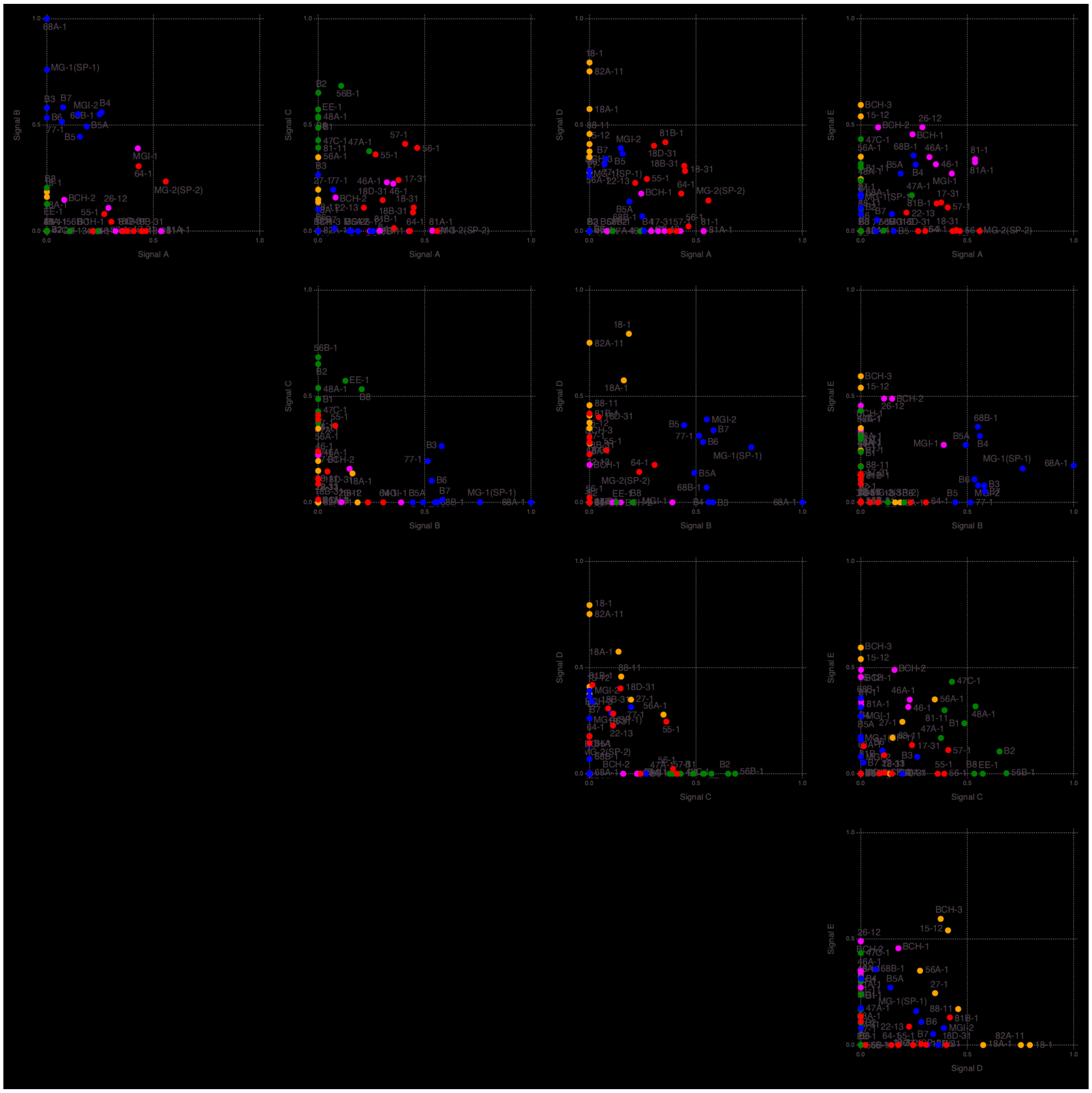

```
Warning: Procedure to find unique signals could not identify a solution …
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
Warning: Procedure to find unique signals could not identify a solution …
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
Warning: Procedure to find unique signals could not identify a solution …
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
Info: Signal A -> A Count: 11
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal B -> B Count: 11
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal C -> C Count: 9
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal D -> D Count: 8
```

```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal E -> E Count: 8
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal A (S3) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal B (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal C (S1) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal D (S4) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal E (S5) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```



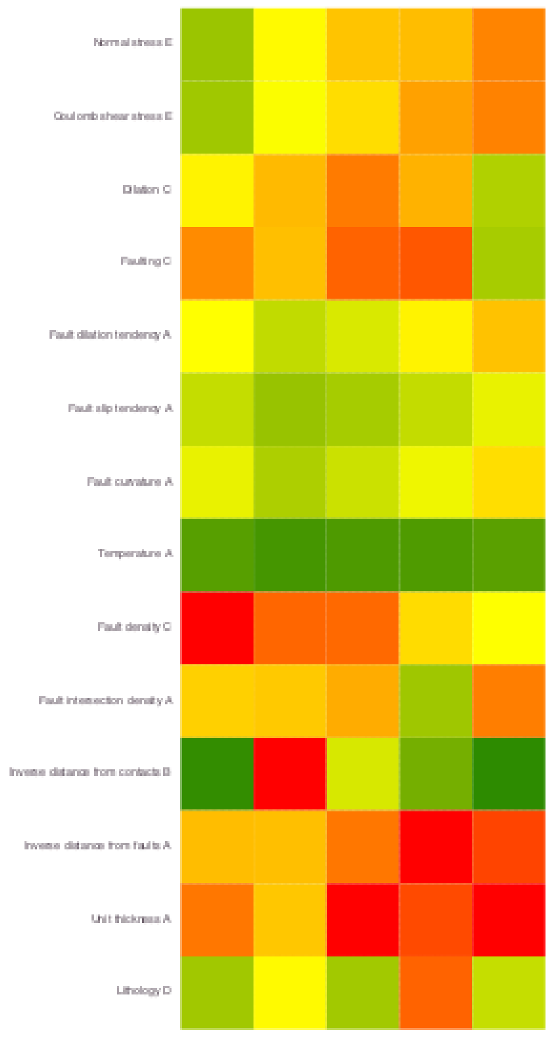






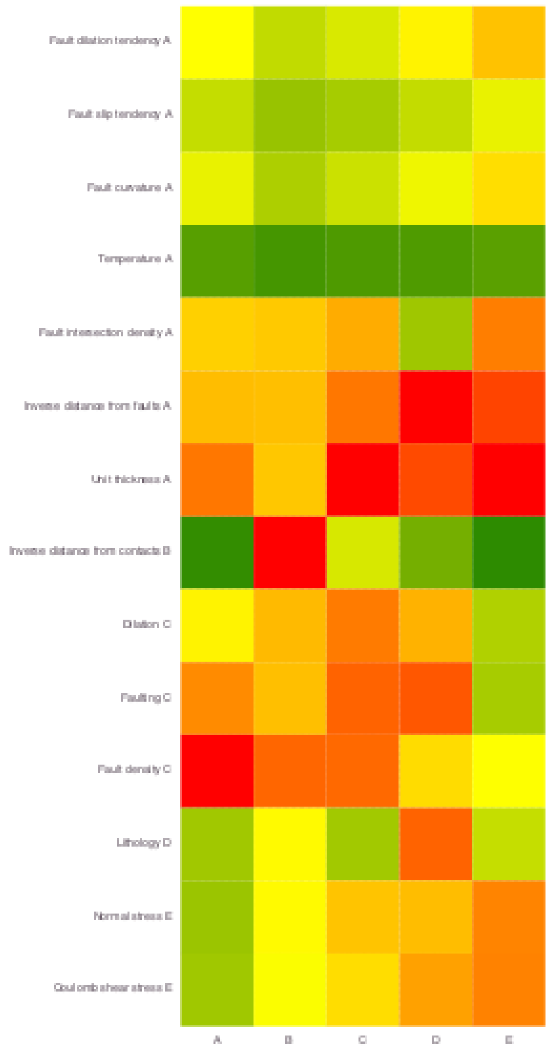
```
7×2 Array{Any,2}:
 "Unit thickness"                   0.849937
 "Inverse distance from faults"     0.680541
 "Fault intersection density"       0.629292
 "Fault dilation tendency"          0.501789
 "Fault curvature"                  0.449738
 "Fault slip tendency"              0.365781
 "Temperature"                      0.123165

1×2 Array{Any,2}:
 "Inverse distance from contacts"  1.0

3×2 Array{Any,2}:
```

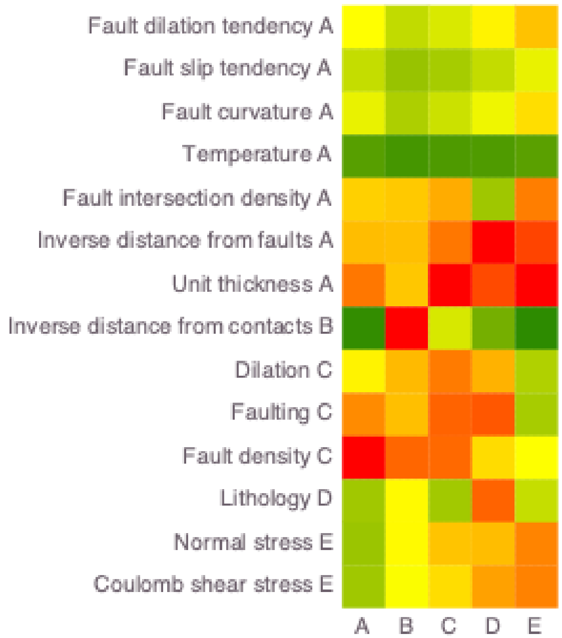
```
 "Faulting"       0.892846
 "Fault density"  0.880551
 "Dilation"       0.841464

1×2 Array{Any,2}:
 "Lithology"  0.89235

2×2 Array{Any,2}:
 "Coulomb shear stress"  0.826886
 "Normal stress"         0.820471
```

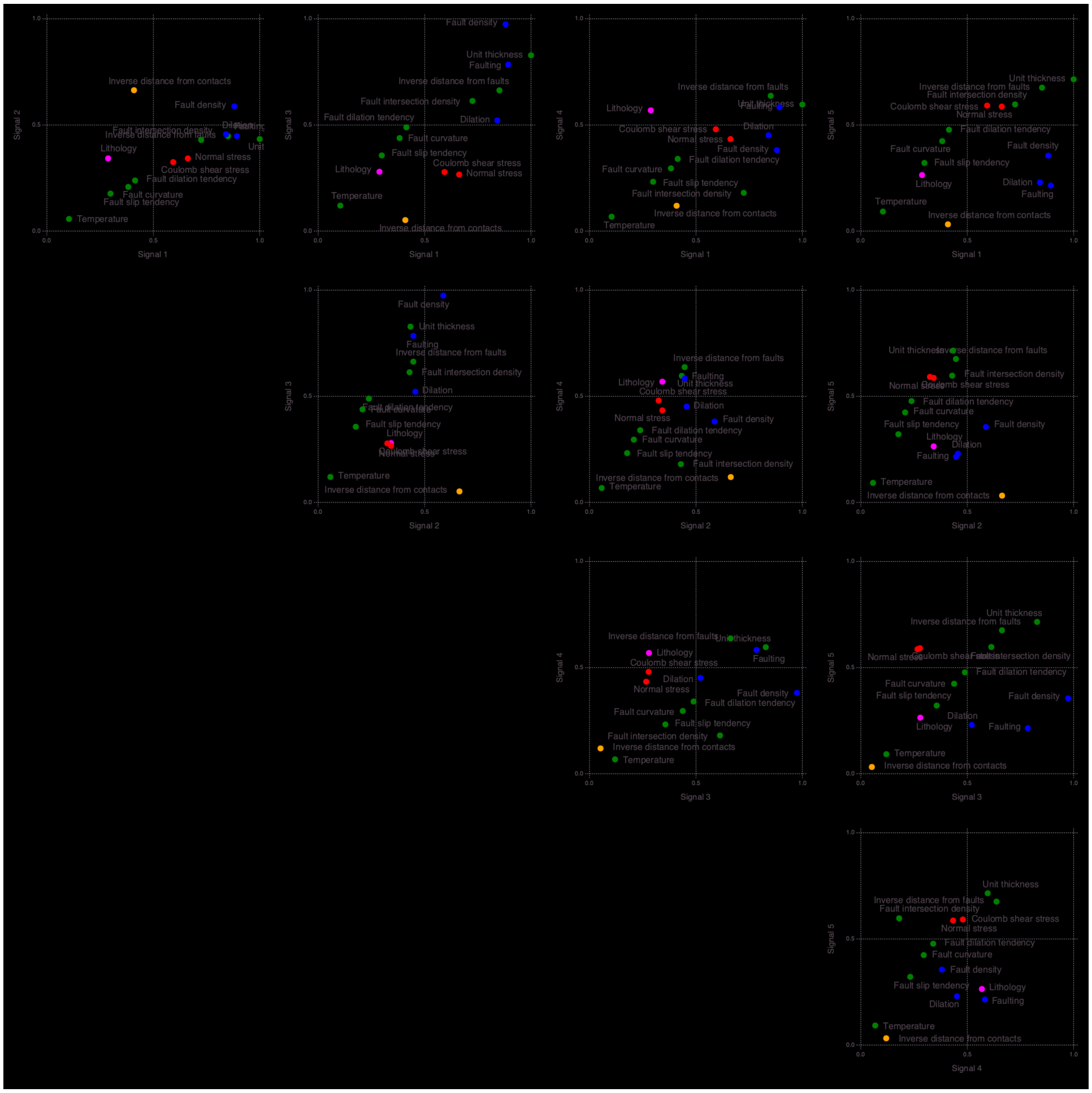


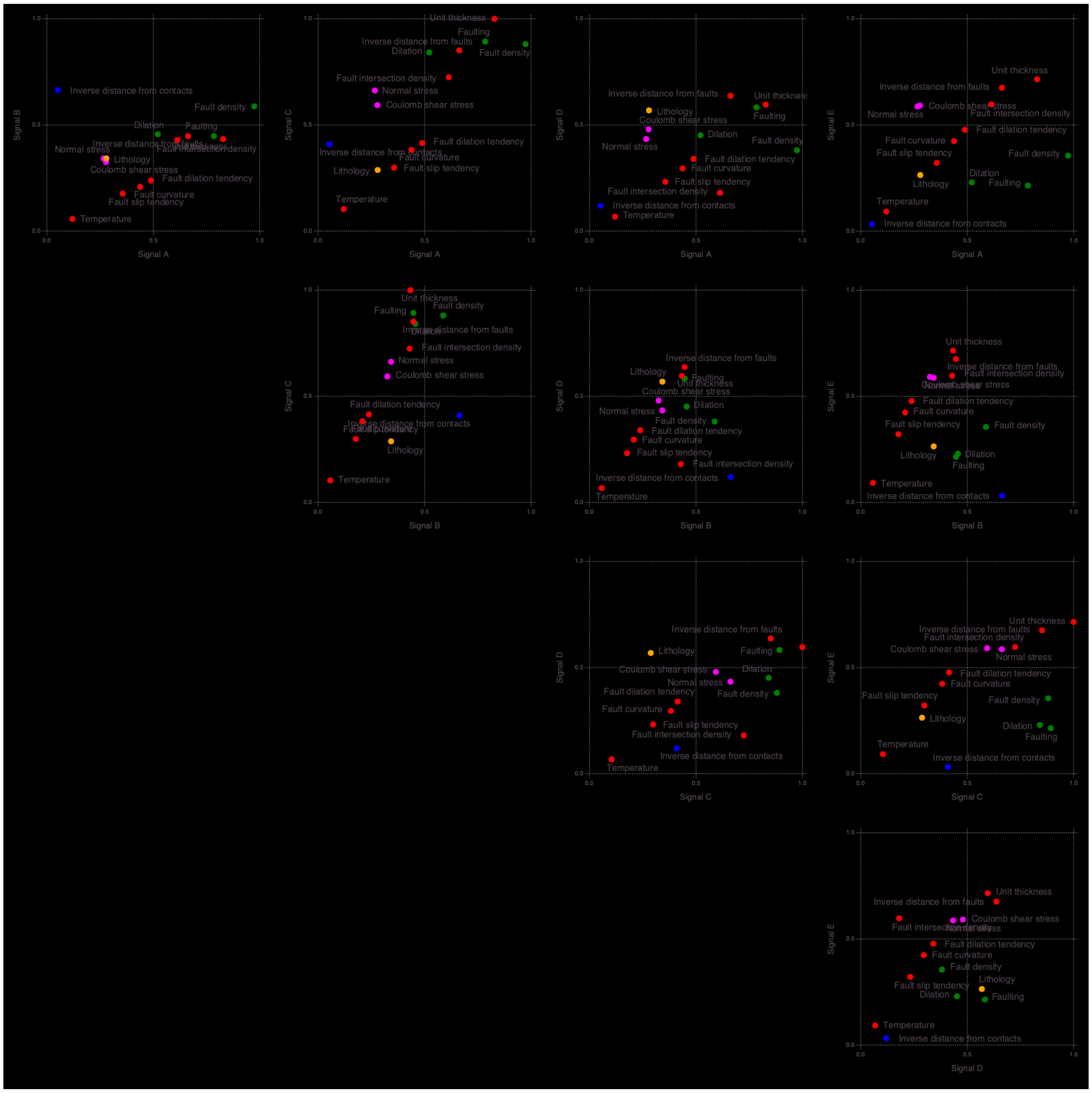

```
Info: Attributes (signals=5)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S3) Count: 7
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
```

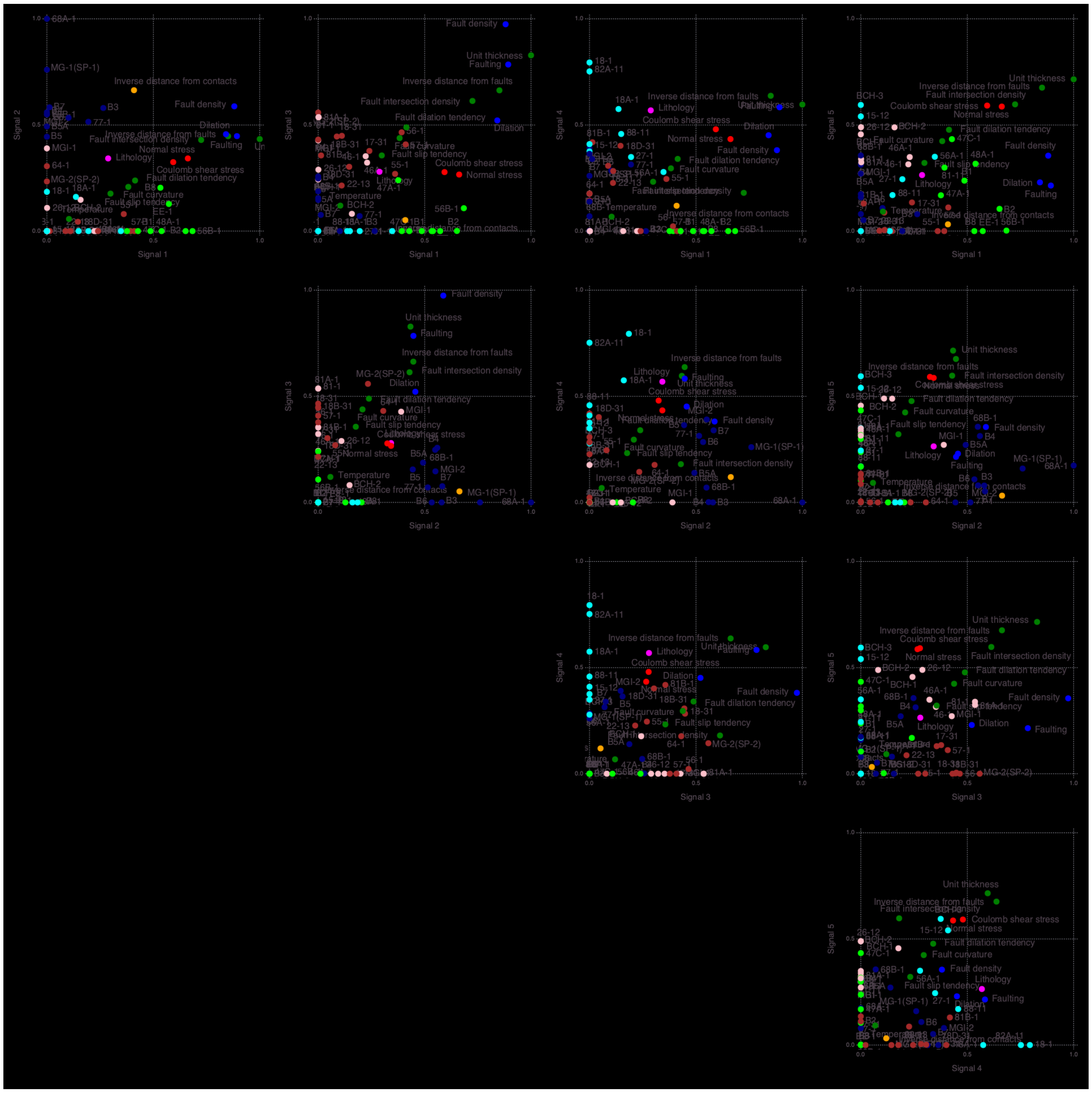
```
Info: Signal B (S1) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S5) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D (S2) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E (S4) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal A -> A Count: 7
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal D -> B Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> C Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal E -> D Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal C -> E Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal D (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal E (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

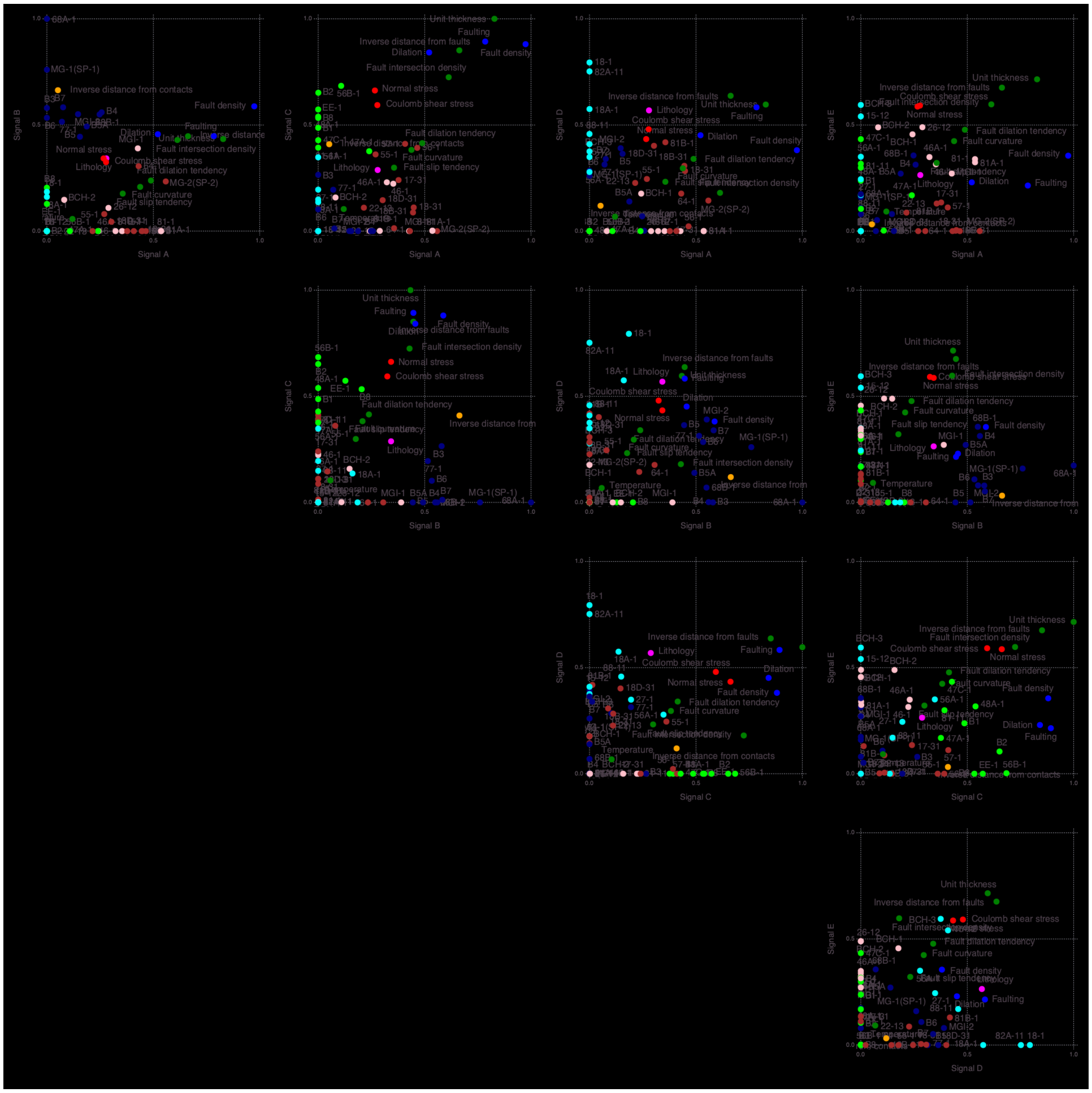

Fault dilation tendency A
Fault slip tendency A
Fault curvature A
Temperature A
Fault intersection density A
Inverse distance from faults A
Unit thickness A
Inverse distance from contacts B
Dilation C
Faulting C
Fault density C
Lithology D
Normal stress E
Coulomb shear stress E
A
B
C
D
E


Fault dilation tendency A
Fault slip tendency A
Fault curvature A
Temperature A
Fault intersection density A
Inverse distance from faults A
Unit thickness A
Inverse distance from contacts B
Dilation C
Faulting C
Fault density C
Lithology D
Normal stress E
Coulomb shear stress E
A
B
C
D
E









```
Signal importance (high->low): [1, 5, 2, 6, 4, 3]
 Info: Number of signals: 6
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
 Info: Locations (signals=6)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Hmatrix-6-6_47-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
```

```
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
```

```
11×2 Array{Any,2}:
 "MG-1(SP-1)"  1.0
 "68B-1"       0.917059
 "77-1"        0.81018
 "B5A"         0.794163
 "68A-1"       0.771571
 "B5"          0.751175
 "B6"          0.726543
 "MGI-2"       0.712331
 "B7"          0.71064
 "B4"          0.671091
 "B3"          0.643308
```

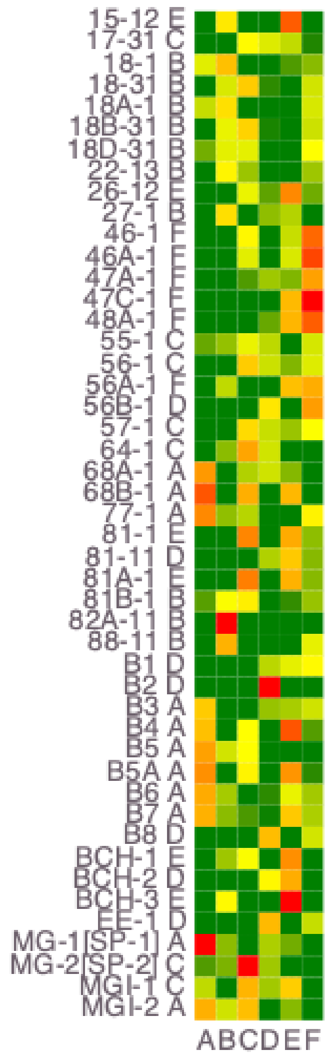
```
10×2 Array{Any,2}:
 "82A-11"  1.0
 "88-11"   0.708797
 "18-1"    0.670833
 "27-1"    0.588465
 "18A-1"   0.586851
 "22-13"   0.530055
 "81B-1"   0.490522
 "18B-31"  0.450915
 "18D-31"  0.439487
 "18-31"   0.413683
```

```
7×2 Array{Any,2}:
 "MG-2(SP-2)"  1.0
 "64-1"        0.741999
 "MGI-1"       0.701663
 "56-1"        0.640372
 "57-1"        0.600702
 "17-31"       0.512659
 "55-1"        0.453248
```

```
7×2 Array{Any,2}:
 "B2"     1.0
 "EE-1"   0.68867
 "B8"     0.679526
 "56B-1"  0.56822
 "BCH-2"  0.521776
 "B1"     0.342468
 "81-11"  0.320946
```

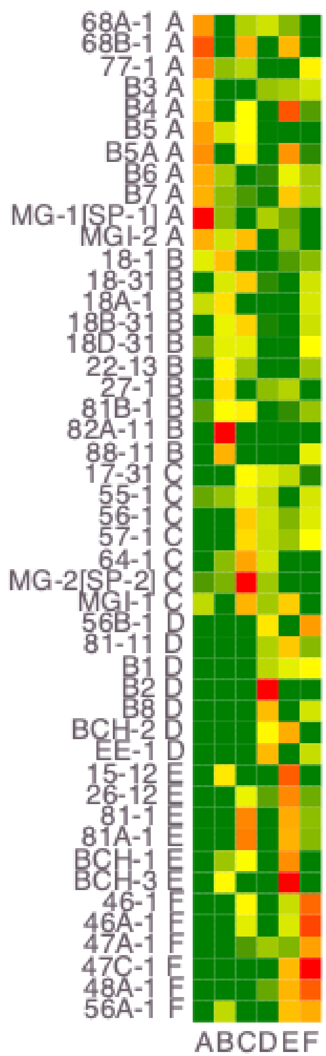
```
6×2 Array{Any,2}:
 "BCH-3"  1.0
 "15-12"  0.904396
 "26-12"  0.808831
 "BCH-1"  0.795303
 "81-1"   0.7272
 "81A-1"  0.707665
```

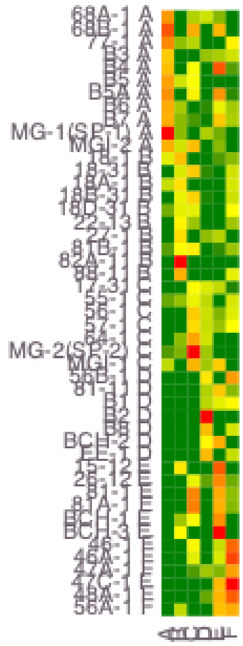
```
6×2 Array{Any,2}:
 "47C-1"  1.0
 "46A-1"  0.943298
 "48A-1"  0.903309
 "46-1"   0.882457
 "47A-1"  0.751523
 "56A-1"  0.720315
```



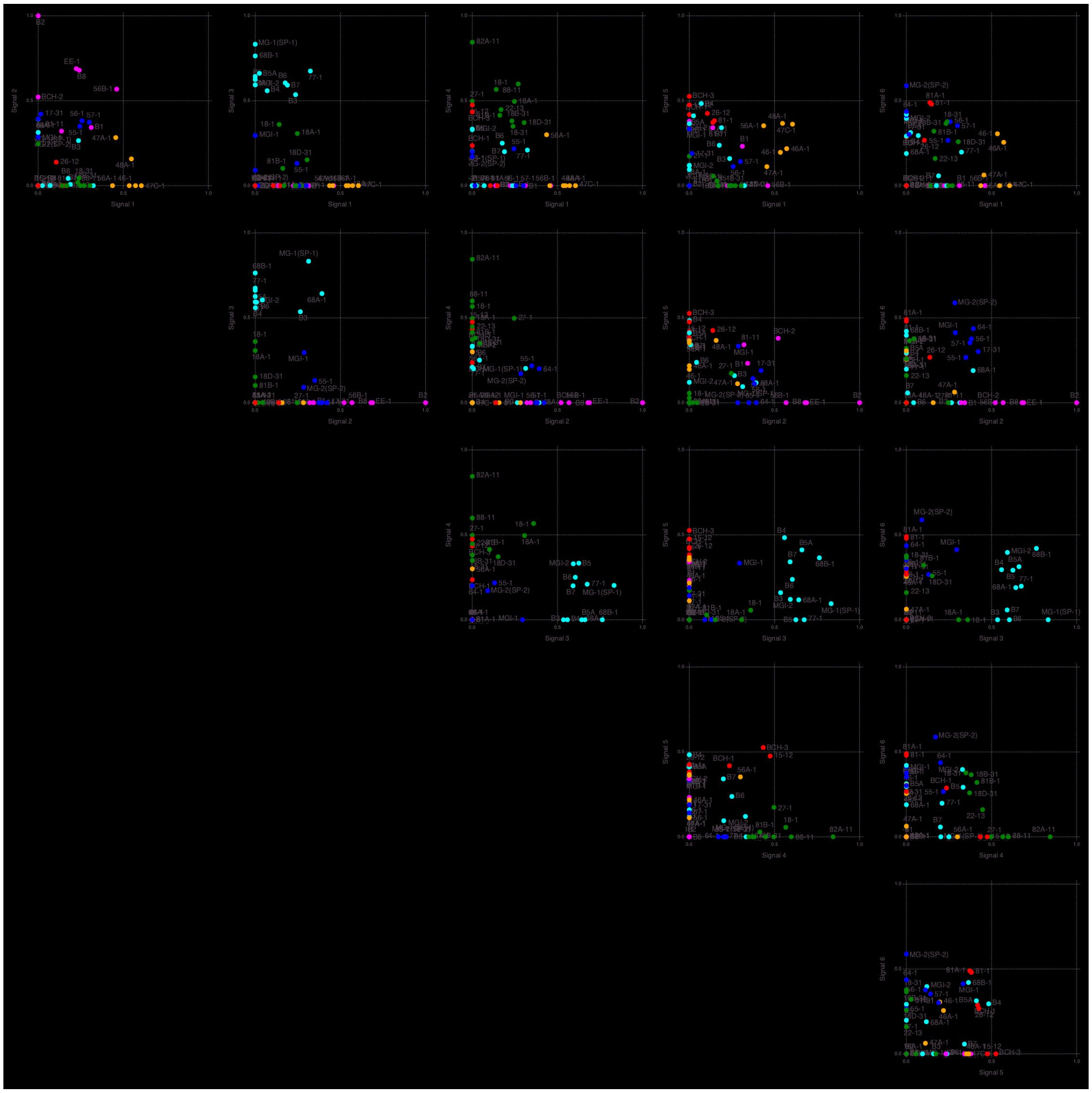

```
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-daln/Wmatrix-6-6_14-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Info: Signal A -> A Count: 11
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal B -> B Count: 10
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal C -> C Count: 7
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal D -> D Count: 7
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
```

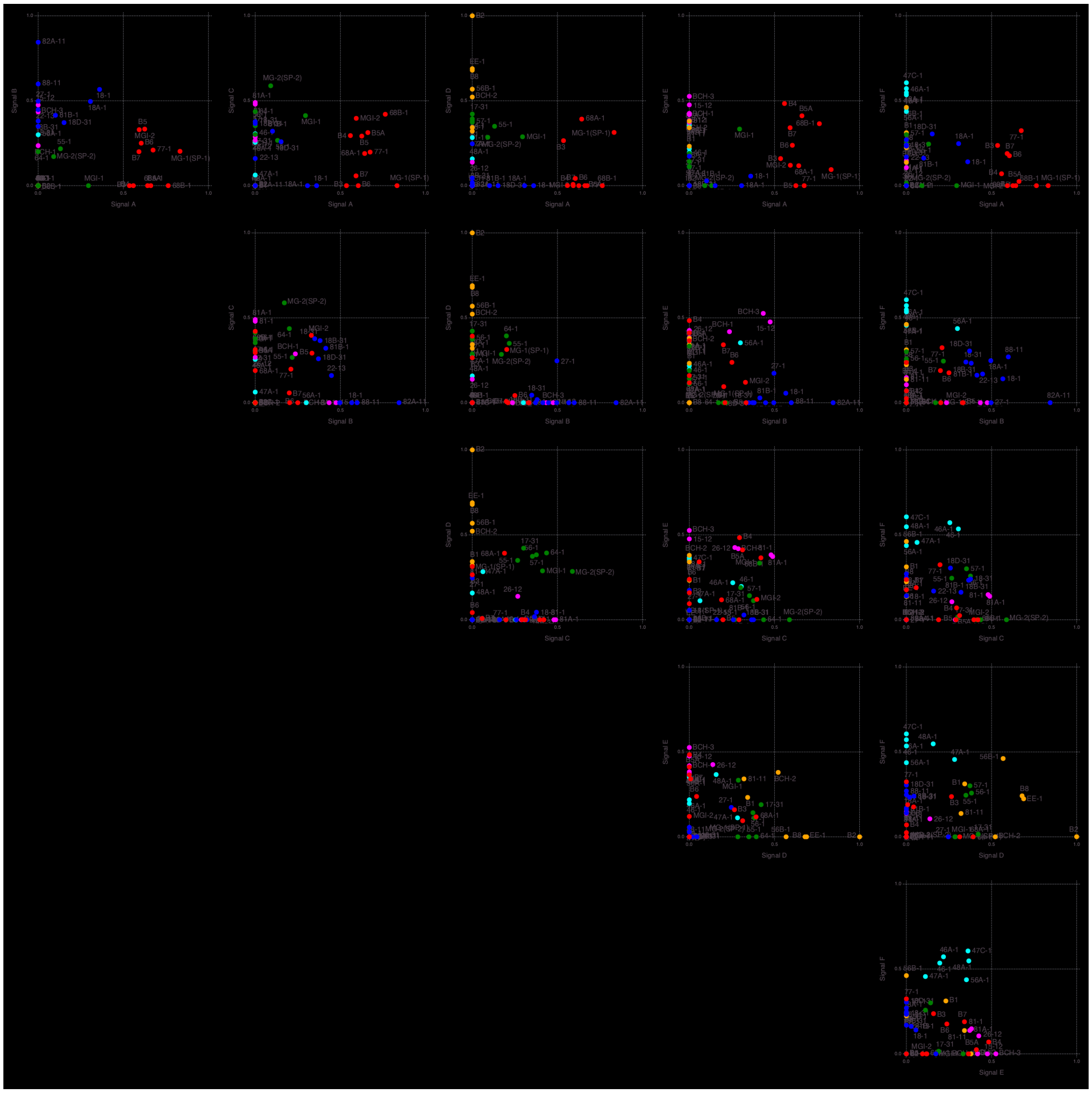
```
Info: Signal E -> E Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal F -> F Count: 6
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal A (S3) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal B (S4) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal C (S6) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal D (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal E (S5) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal F (S1) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```





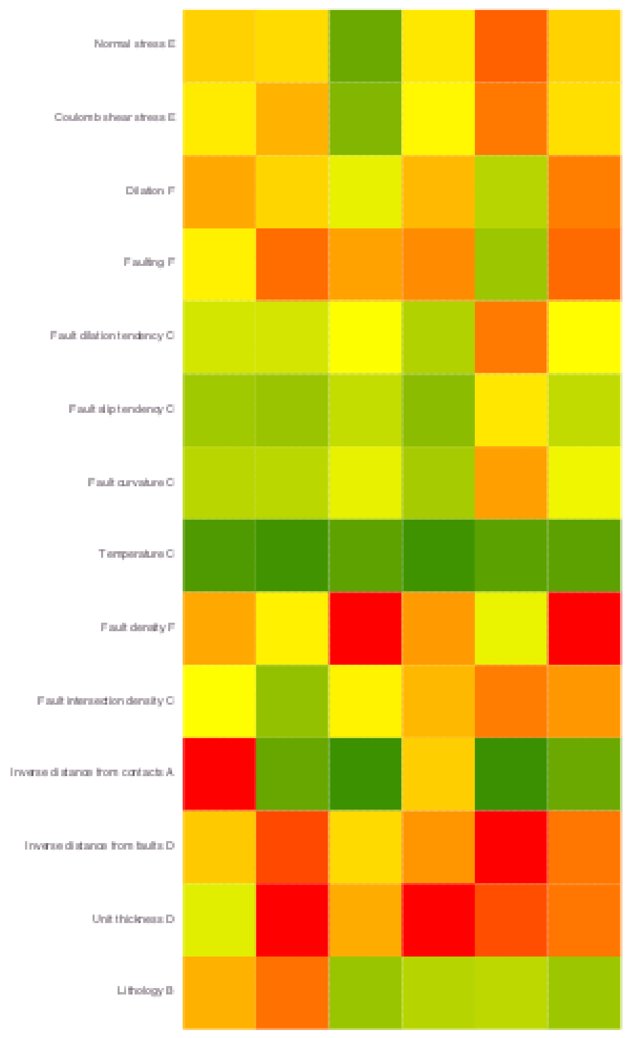
68A-1 A
B5A A
MG-1(SP-1) A
MG-2(SP-2) C
BCH-2 D
56A-1 F





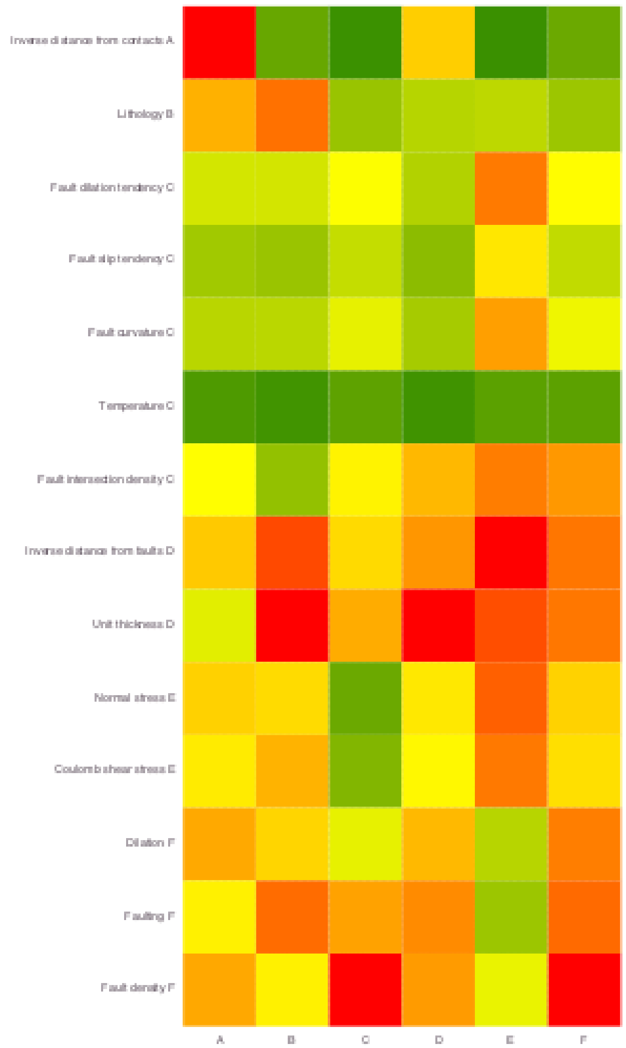
```
1×2 Array{Any,2}:
 "Inverse distance from contacts"  1.0

1×2 Array{Any,2}:
 "Lithology"  0.864227

5×2 Array{Any,2}:
 "Fault intersection density"  0.534767
 "Fault dilation tendency"     0.494983
 "Fault curvature"             0.444422
 "Fault slip tendency"         0.367193
 "Temperature"                 0.136511
```

```
2×2 Array{Any,2}:
 "Unit thickness"                 1.0
 "Inverse distance from faults"  0.778501

2×2 Array{Any,2}:
 "Normal stress"          0.896801
 "Coulomb shear stress"  0.845105

3×2 Array{Any,2}:
 "Fault density"  1.0
 "Faulting"       0.877916
 "Dilation"       0.834909
```

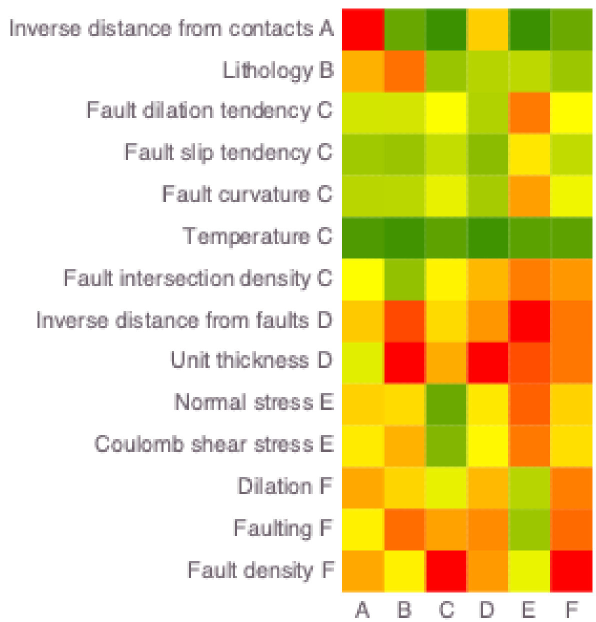


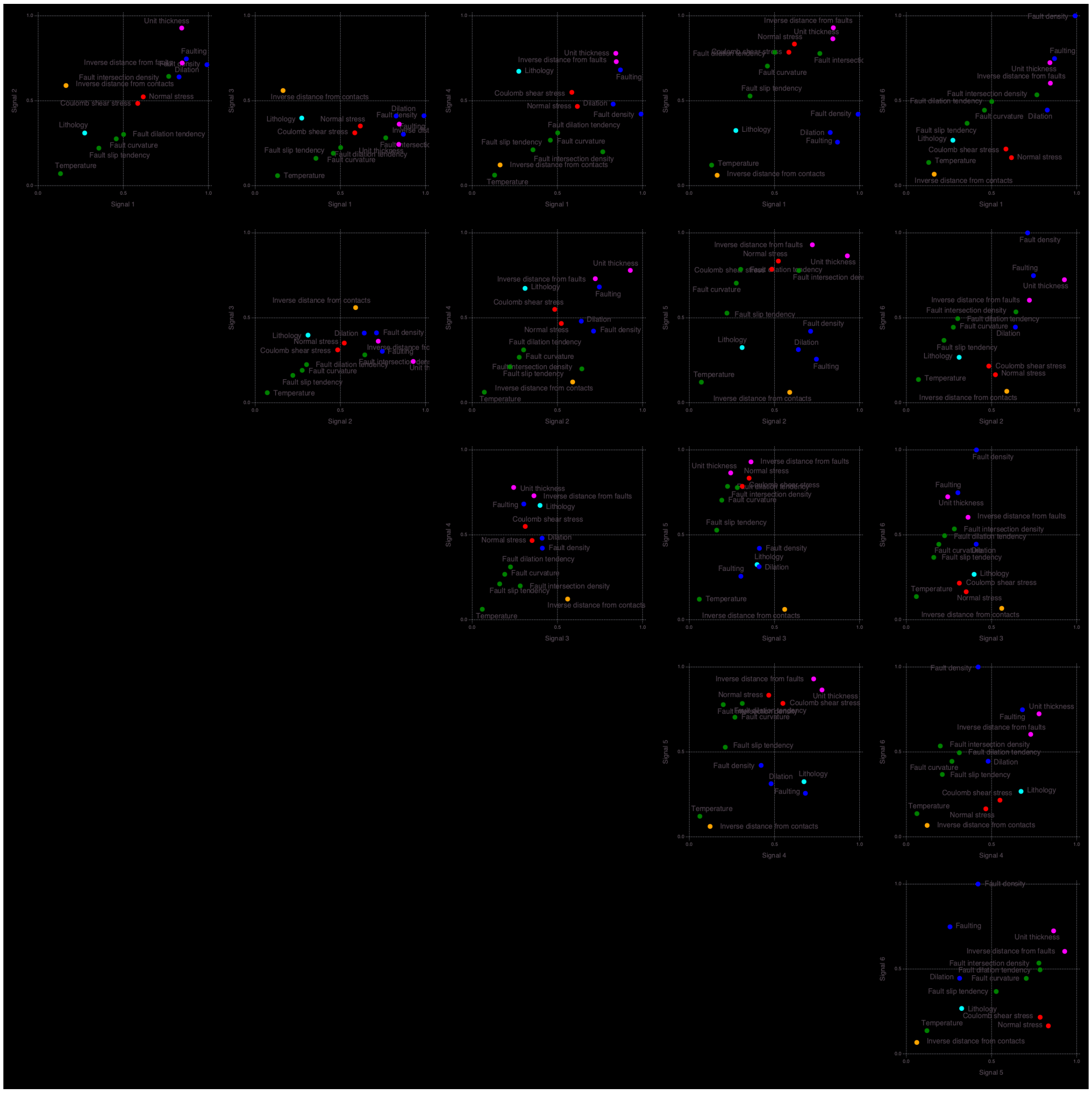

```
Info: Attributes (signals=6)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
```

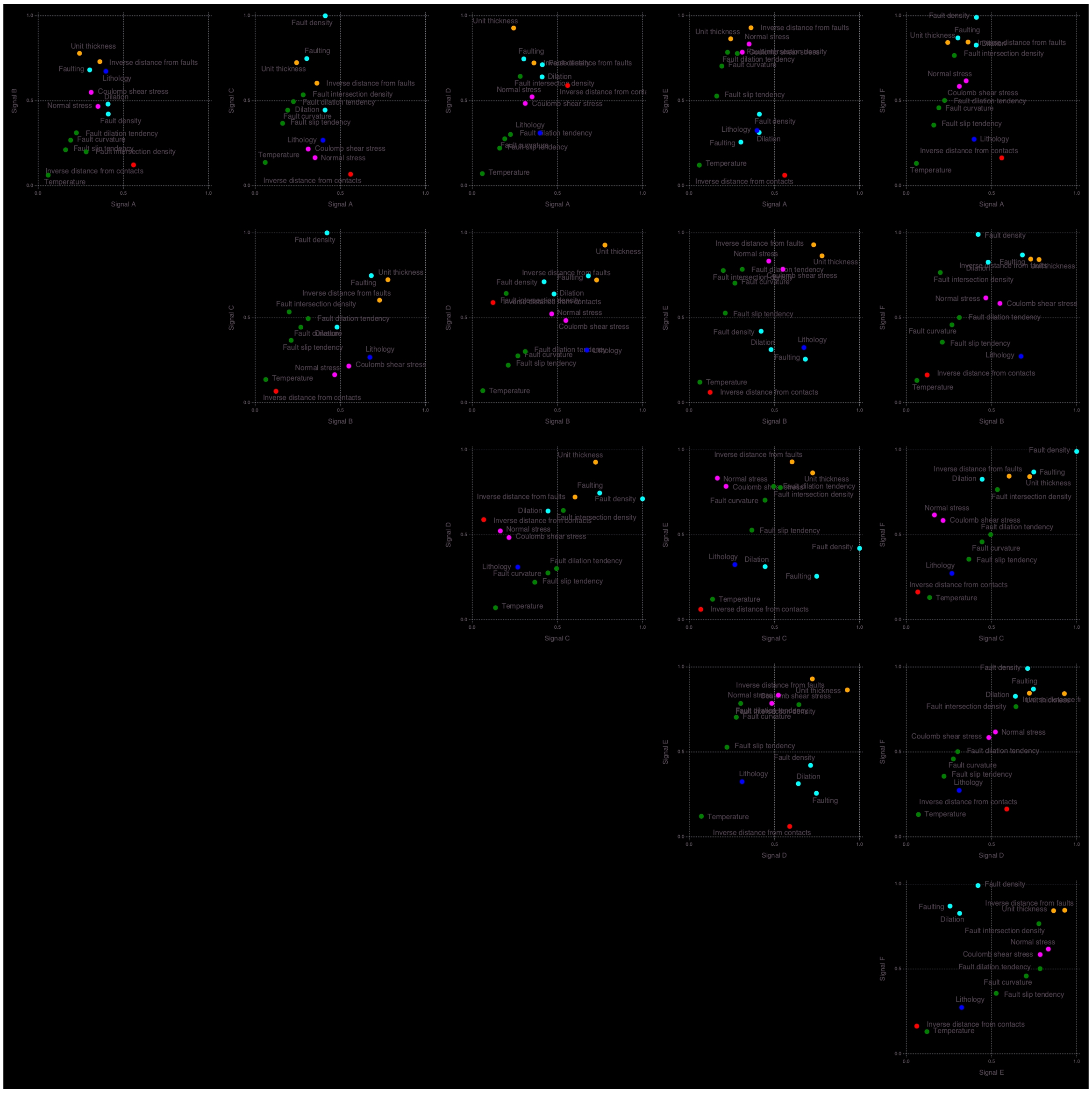
```
Info: Signal A (S6) Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S1) Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S5) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal D (S2) Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E (S3) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal F (S4) Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal E -> A Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal F -> B Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> C Count: 5
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal D -> D Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal C -> E Count: 2
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> F Count: 3
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal D (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal E (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal F (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

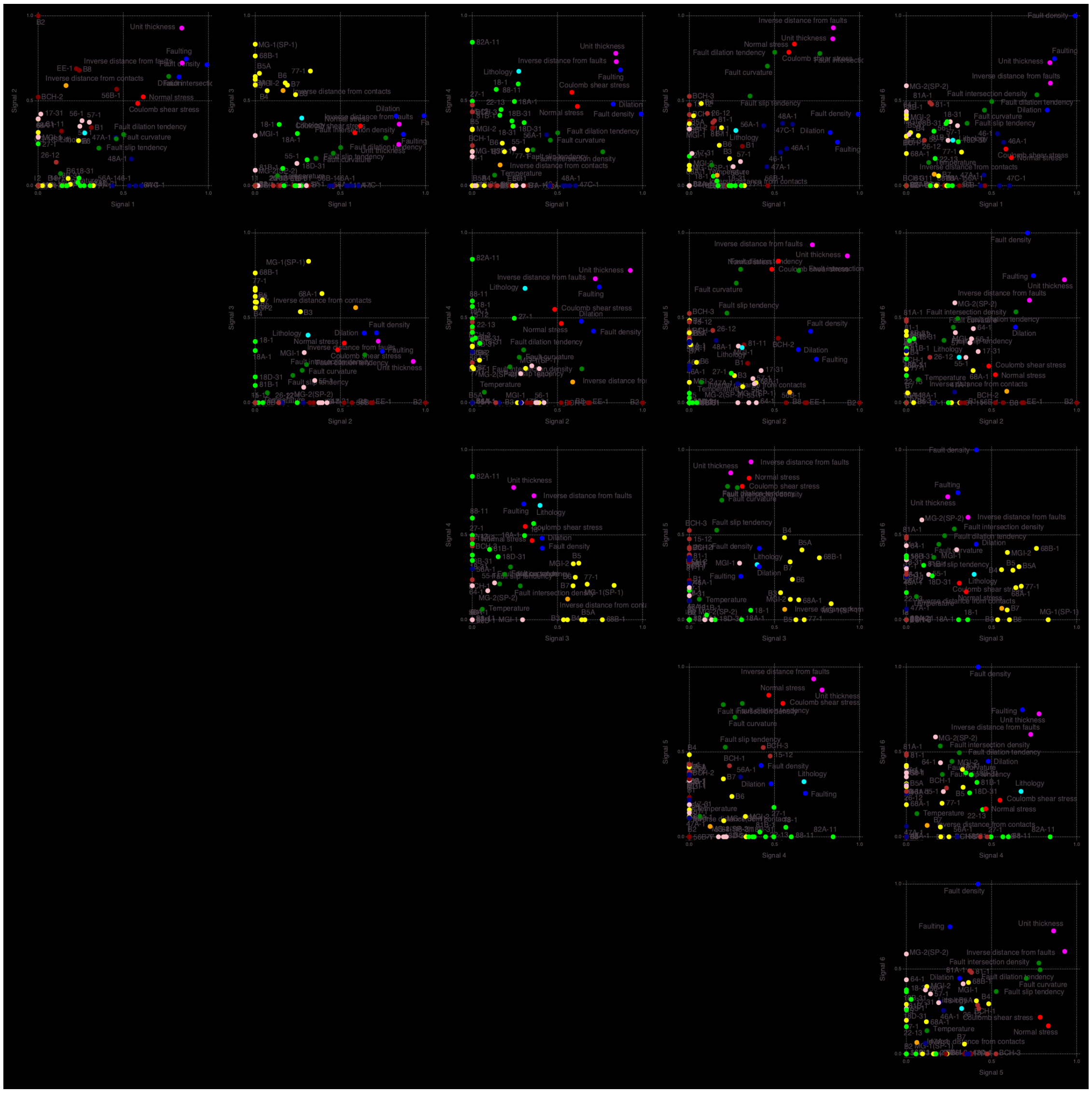


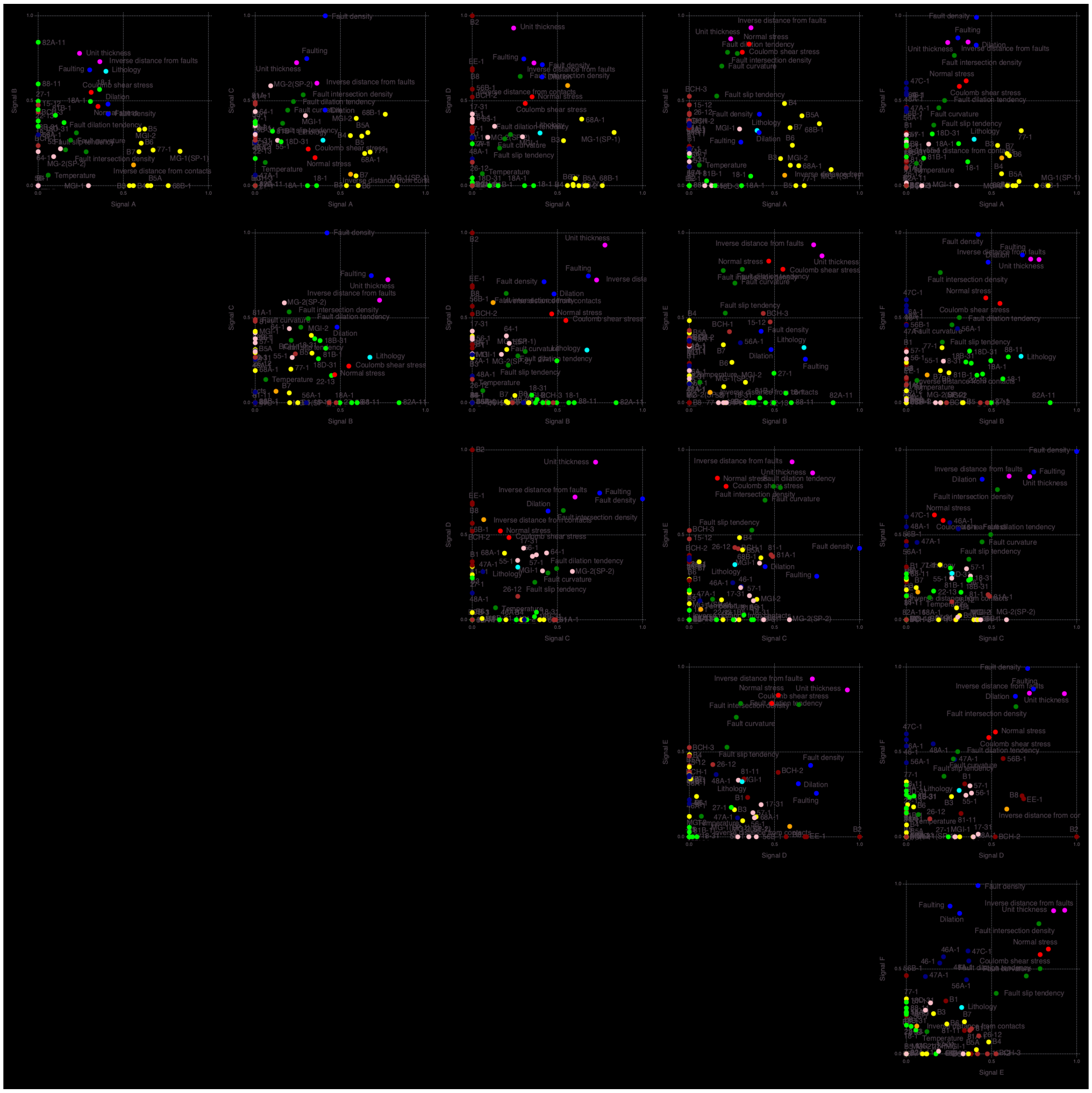
Inverse distance from contacts A
Lithology B
Fault dilation tendency C
Fault slip tendency C
Fault curvature C
Temperature C
Fault intersection density C
Inverse distance from faults D
Unit thickness D
Normal stress E
Coulomb shear stress E
Dilation F
Faulting F
Fault density F
A
B
C
D
E
F


Inverse distance from contacts A
Lithology B
Fault dilation tendency C
Fault slip tendency C
Fault curvature C
Temperature C
Fault intersection density C
Inverse distance from faults D
Unit thickness D
Normal stress E
Coulomb shear stress E
Dilation F
Faulting F
Fault density F
A B C D E F









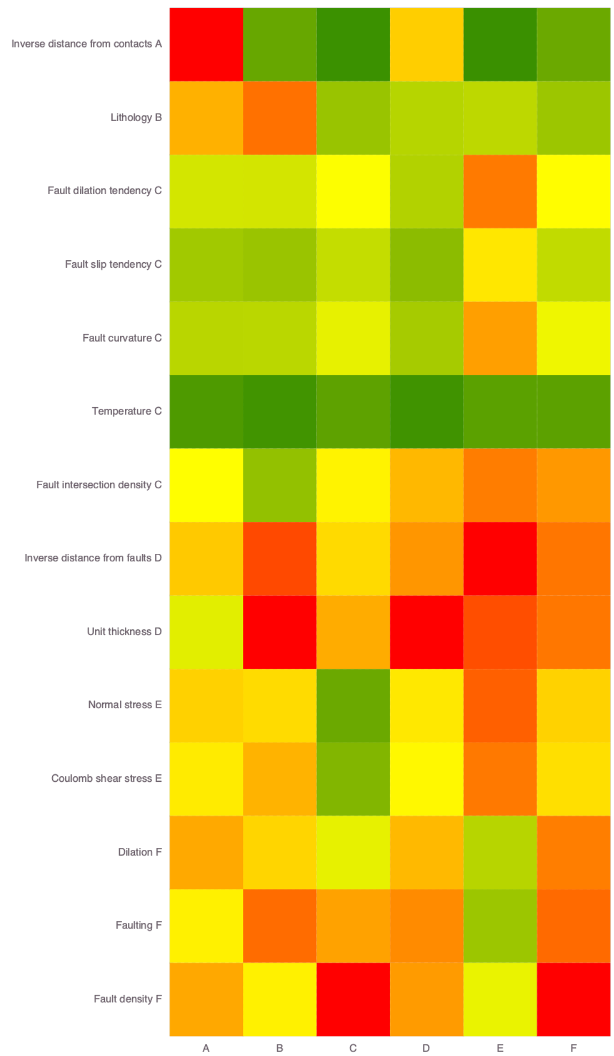
[22]: ([[1, 2], [3, 2, 1, 4, 5], [3, 4, 6, 2, 5, 1]], [['B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'A', 'B', 'B', 'B'], ['E', 'E', 'C', 'C', 'A', 'A', 'A', 'A', 'C', 'A', 'B', 'A', 'A', 'D'], ['E', 'E', 'F', 'F', 'C', 'C', 'C', 'C', 'F', 'C', 'A', 'D', 'D', 'B']], [['B', 'A', 'A', 'B', 'A', 'B', 'B', 'A', 'B', 'B' … 'A', 'A', 'B', 'B', 'B', 'A', 'A', 'A', 'A', 'A'], ['D', 'A', 'D', 'A', 'D', 'A', 'A', 'A', 'E', 'D' … 'B', 'C', 'E', 'E', 'D', 'C', 'B', 'A', 'E', 'B'], ['E', 'C', 'B', 'B', 'B', 'B', 'B', 'B', 'E', 'B' … 'A', 'D', 'E', 'D', 'E', 'D', 'A', 'C', 'C', 'A']])

The results for a solution with **6** signatures presented above will be further discussed here.

The well attributes are clustered into **6** groups:

```
[ ]: Mads.display("results-set00-v9-inv-750-1000-daln/attributes-6-groups.txt")
```

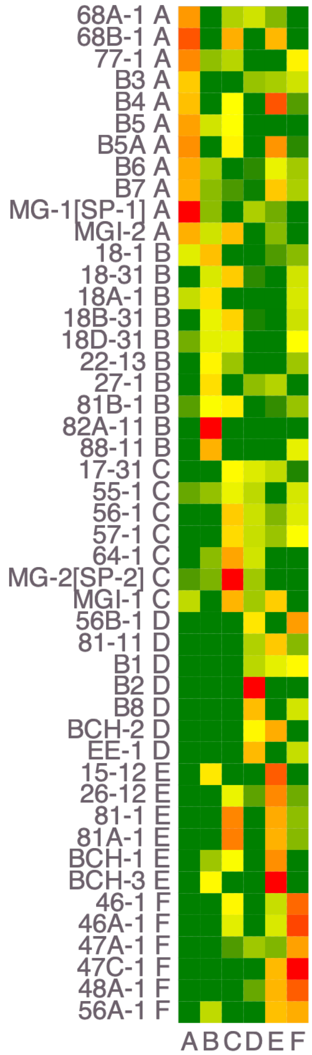
This grouping is based on analyses of the attribute matrix `W`:



Note that the attribute matrix `W` is automatically modified to account that a range of vertical depths is applied in characterizing the site wells.

The well locations are also clustered into **6** groups:

This grouping is based on analyses of the location matrix `H`:



The map `../figures-set00-v9-inv-750-1000-daln/locations-6-map.html` provides interactive visualization of the extracted well location groups (the html file can also be opened with any browser).

<iframe src="../figures-set00-v9-inv-750-1000-daln/locations-6-map.html" frameborder="0" heigh

More information on how the ML results are interpreted to provide geothermal insights is discussed in our research paper.

0.4.2 Type 2 flattening: Focus on well attributes

Flatten the tensor into a matrix

[23]:
```
Xdlan = reshape(permutedims(Tn, (1,3,2)), (depth * length(locations)),␣
↪length(attributes_process));
```

Matrix rows merge the depth and well locations dimensions.

Matrix columns represent the well attributes.

Perform NMFk analyses

[24]:
```
W, H, fitquality, robustness, aic = NMFk.execute(Xdlan, nkrange, nruns;␣
↪resultdir=resultdir, casefilename="nmfk-dlan-$(join(size(Xdlan), '_'))",␣
↪load=true)
W, H, fitquality, robustness, aic = NMFk.load(nkrange, nruns;␣
↪resultdir=resultdir, casefilename="nmfk-dlan-$(join(size(Xdlan), '_'))");
```

```
Signals:  2 Fit:     8717.101 Silhouette:    0.9918721 AIC:     -1087260
Signals:  3 Fit:     6319.428 Silhouette:    0.5782437 AIC:     -1124899
Signals:  4 Fit:     4843.099 Silhouette:   -0.2086358 AIC:     -1143846
Signals:  5 Fit:     3526.994 Silhouette:   0.03306949 AIC:     -1179956
Signals:  6 Fit:     2430.352 Silhouette:   -0.5717948 AIC:     -1234661
Signals:  7 Fit:     1649.869 Silhouette:   -0.4817311 AIC:     -1294388
Signals:  8 Fit:     1182.794 Silhouette:    0.1610176 AIC:     -1335780
Signals:  2 Fit:     8717.101 Silhouette:    0.9918721 AIC:     -1087260
Signals:  3 Fit:     6319.428 Silhouette:    0.5782437 AIC:     -1124899
Signals:  4 Fit:     4843.099 Silhouette:   -0.2086358 AIC:     -1143846
Signals:  5 Fit:     3526.994 Silhouette:   0.03306949 AIC:     -1179956
Signals:  6 Fit:     2430.352 Silhouette:   -0.5717948 AIC:     -1234661
Signals:  7 Fit:     1649.869 Silhouette:   -0.4817311 AIC:     -1294388
Signals:  8 Fit:     1182.794 Silhouette:    0.1610176 AIC:     -1335780
Signals:  2 Fit:     8717.101 Silhouette:    0.9918721 AIC:     -1087260
Signals:  3 Fit:     6319.428 Silhouette:    0.5782437 AIC:     -1124899
Signals:  4 Fit:     4843.099 Silhouette:   -0.2086358 AIC:     -1143846
Signals:  5 Fit:     3526.994 Silhouette:   0.03306949 AIC:     -1179956
Signals:  6 Fit:     2430.352 Silhouette:   -0.5717948 AIC:     -1234661
Signals:  7 Fit:     1649.869 Silhouette:   -0.4817311 AIC:     -1294388
Signals:  8 Fit:     1182.794 Silhouette:    0.1610176 AIC:     -1335780
  Info: Results
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:15
  Info: Optimal solution: 3 signals
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkExecute.jl:20
  Info: Optimal solution: 3 signals
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkIO.jl:30
```

Here the **NMFk** results are loaded from a prior ML run.

As seen from the output above, the **NMFk** analyses identified that the optimal number of geothermal signatures in the dataset **3**.

Solutions with a number of signatures less than **3** are underfitting.

Solutions with a number of signatures greater than **3** are overfitting and unacceptable.

The set of acceptable solutions are defined by the **NMFk** algorithm as follows:

[25]:
```
NMFk.getks(nkrange, robustness[nkrange])
```

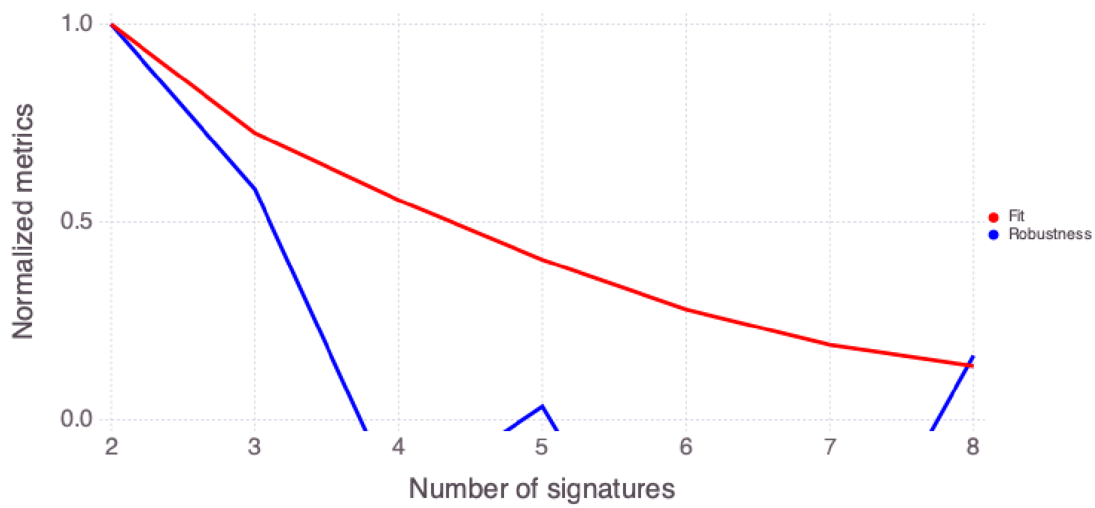
[25]: 2-element Array{Int64,1}:
 2
 3

The acceptable solutions contain 2 and 3 signatures.

Post-process NMFk results

Number of signatures Below is a plot representing solution quality (fit) and silhouette width (robustness) for different numbers of signatures k:

[26]:
```
NMFk.plot_signal_selecton(nkrange, fitquality, robustness;␣
↪figuredir="$figuredir-$(nruns)-dlan", xtitle="Number of signatures")
```

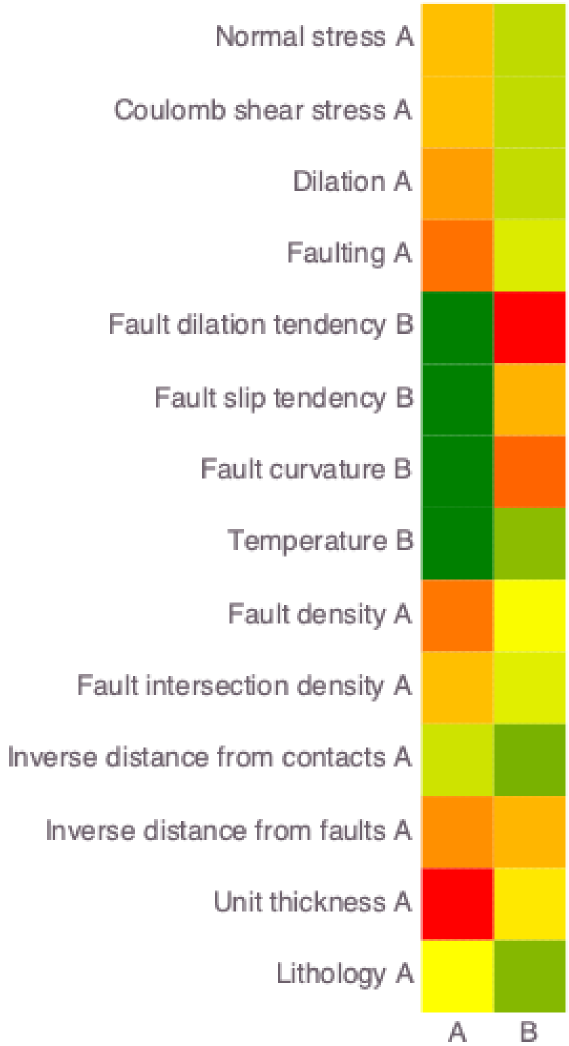


The plot above also demonstrates that the acceptable solutions contain 2 and 3 signatures.

Analysis of all the acceptable solutions The ML solutions containing an acceptable number of signatures are further analyzed as follows:

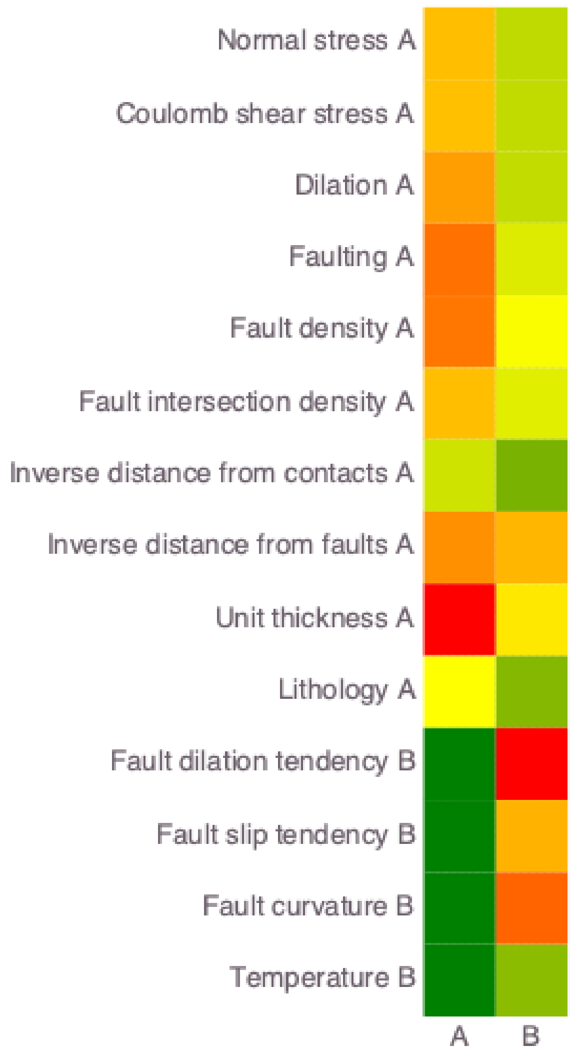
[27]:
```
NMFk.clusterresults(NMFk.getks(nkrange, robustness[nkrange]; ks=4), W, H,␣
↪locations, attributes_process_long; loadassignements=true, lon=xcoord,␣
↪lat=ycoord, Horder=Aorder, Wsize=depth, Wcasefilename="locations",␣
↪Hcasefilename="attributes", resultdir=resultdir * "-$(nruns)-dlan",␣
↪figuredir=figuredir * "-$(nruns)-dlan", hover="Well: " .* locations .*␣
↪"<br>" .* "WellType: " .* String.(welltype) .* "<br>" .* production,␣
↪Wmatrix_font_size=4Gadfly.pt, biplotcolor=:WH, biplotlabel=:WH)
```

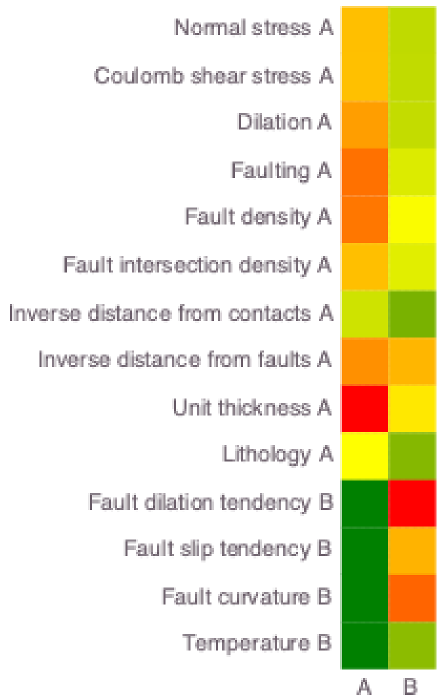
```
Signal importance (high->low): [2, 1]
 Info: Number of signals: 2
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
 Info: Attributes (signals=2)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-dlan/Hmatrix-2-2_14-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
 @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697

10×2 Array{Any,2}:
 "Unit thickness"                   1.0
 "Faulting"                         0.863986
 "Fault density"                    0.849999
 "Inverse distance from faults"     0.792619
 "Dilation"                         0.75876
 "Normal stress"                    0.674322
 "Fault intersection density"       0.673763
 "Coulomb shear stress"             0.672813
 "Lithology"                        0.501336
 "Inverse distance from contacts"   0.388519

4×2 Array{Any,2}:
 "Fault dilation tendency"  1.0
 "Fault curvature"          0.89069
 "Fault slip tendency"      0.706146
 "Temperature"              0.239306
```

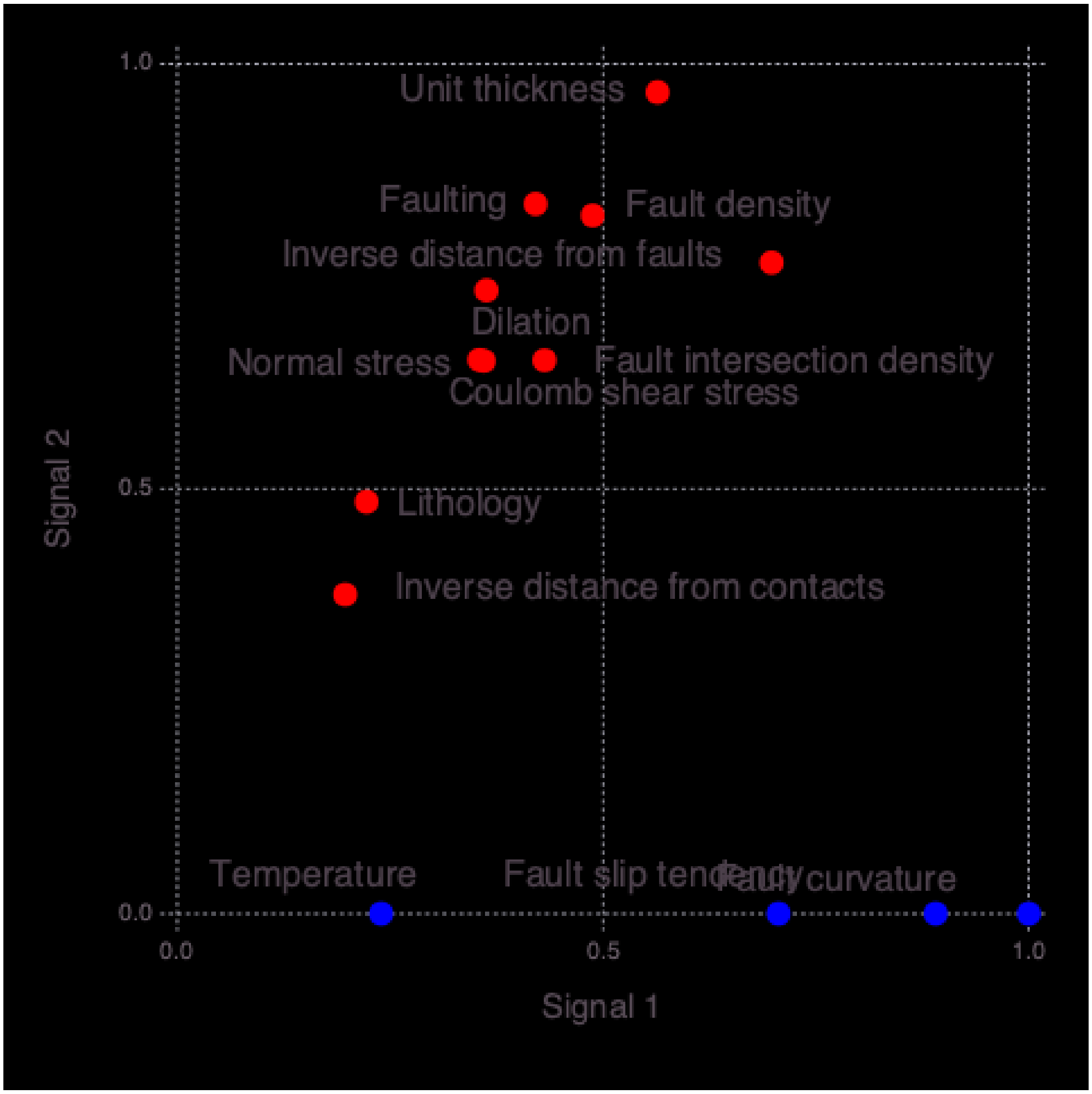


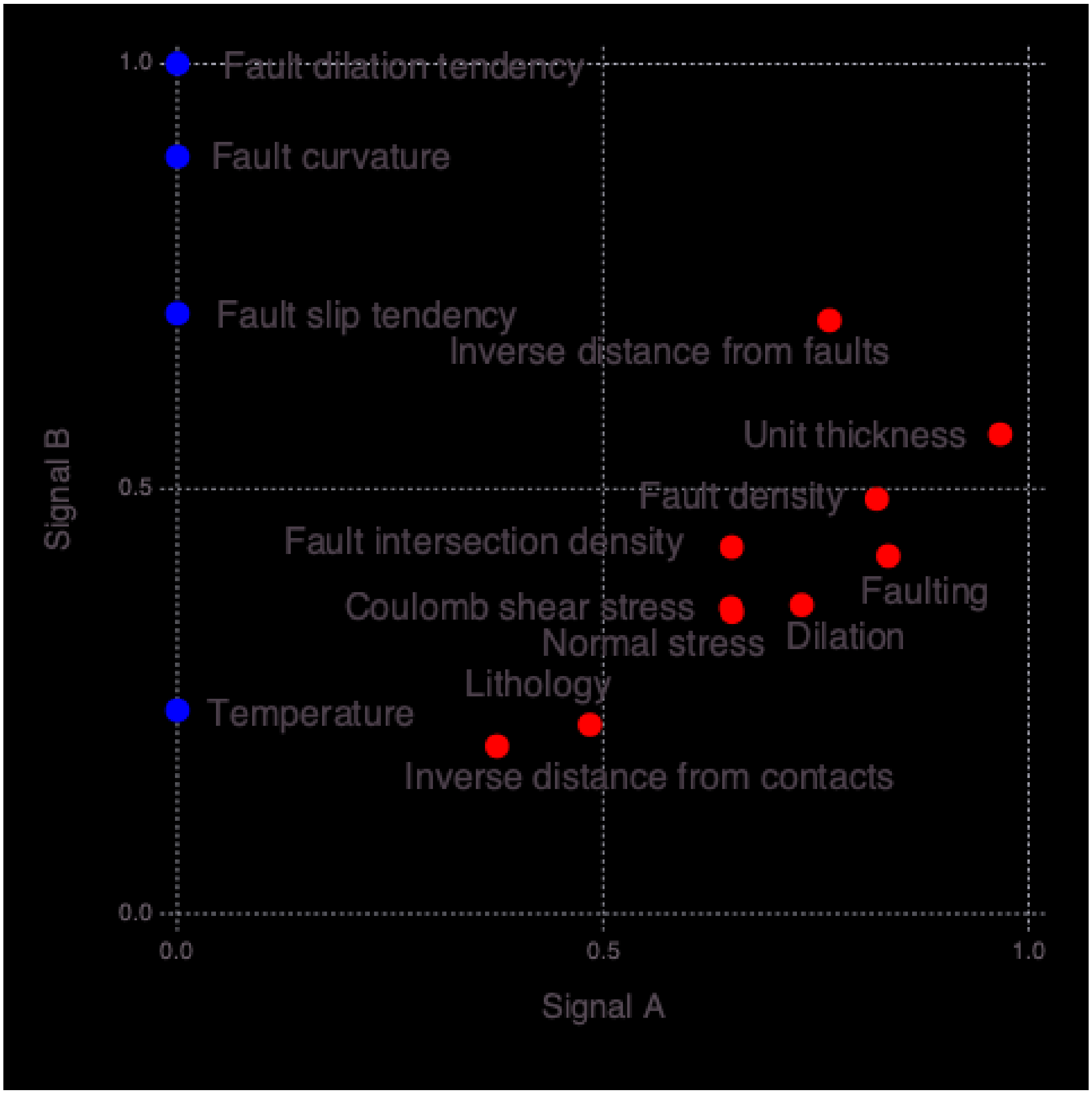

```
 Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-dlan/Wmatrix-2-2_47-1000.jld!
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Warning: Procedure to find unique signals could not identify a solution …
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
 Info: Signal A -> A Count: 10
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal B -> B Count: 4
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
 Info: Signal A (S2) (k-means clustering)
 @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```

```
Info: Signal B (S1) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```



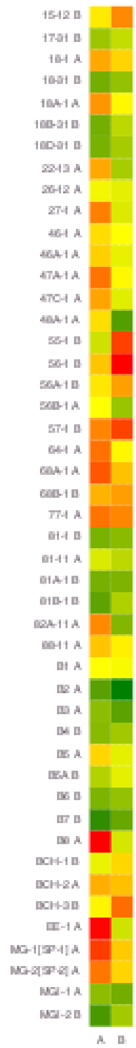

Normal stress A
Coulomb shear stress A
Dilation A
Faulting A
Fault density A
Fault intersection density A
Inverse distance from contacts A
Inverse distance from faults A
Unit thickness A
Lithology A
Fault dilation tendency B
Fault slip tendency B
Fault curvature B
Temperature B
A
B


Unit thickness
Faulting
Fault density
Inverse distance from faults
Dilation
Normal stress
Fault intersection density
Coulomb shear stress
Lithology
Inverse distance from contacts
Temperature
Fault slip tendency
Fault curvature
Signal 1
Signal 2
0.0
0.5
1.0



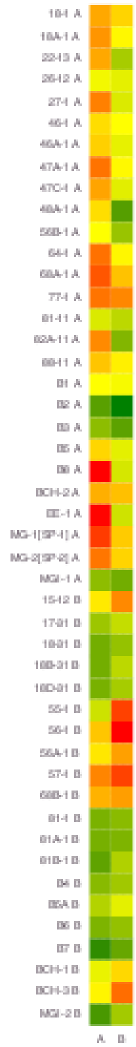

```
27×2 Array{Any,2}:
 "B8"           1.0
 "EE-1"         0.998613
 "MG-1(SP-1)"   0.956943
 "68A-1"        0.916159
 "64-1"         0.864026
 "47A-1"        0.859446
 "77-1"         0.857345
 "MG-2(SP-2)"   0.853707
 "27-1"         0.829554
 "82A-11"       0.807563
 "18A-1"        0.782265
 "47C-1"        0.745002
```

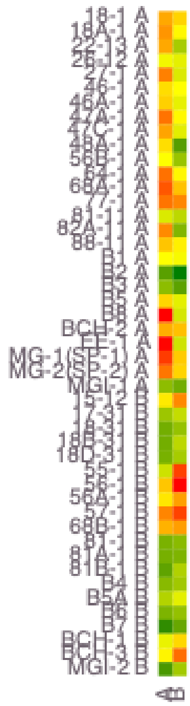
```
 "22-13"       0.734719

 "88-11"       0.659403
 "46A-1"       0.629757
 "B5"          0.614479
 "46-1"        0.594959
 "48A-1"       0.590979
 "B1"          0.501909
 "56B-1"       0.497064
 "26-12"       0.472464
 "81-11"       0.416937
 "MGI-1"       0.24275
 "B3"          0.241753
 "B2"          0.127328

20×2 Array{Any,2}:
 "56-1"    1.0
 "55-1"    0.949937
 "57-1"    0.947965
 "BCH-3"   0.872622
 "15-12"   0.808709
 "68B-1"   0.758469
 "56A-1"   0.753147
 "BCH-1"   0.608981
 "B5A"     0.43926
 "17-31"   0.366493
 "18B-31"  0.348668
 "81B-1"   0.320223
 "18D-31"  0.298697
 "MGI-2"   0.291839
 "B4"      0.286734
 "18-31"   0.260379
 "B6"      0.257226
 "81-1"    0.234119
 "81A-1"   0.207054
 "B7"      0.156777
```

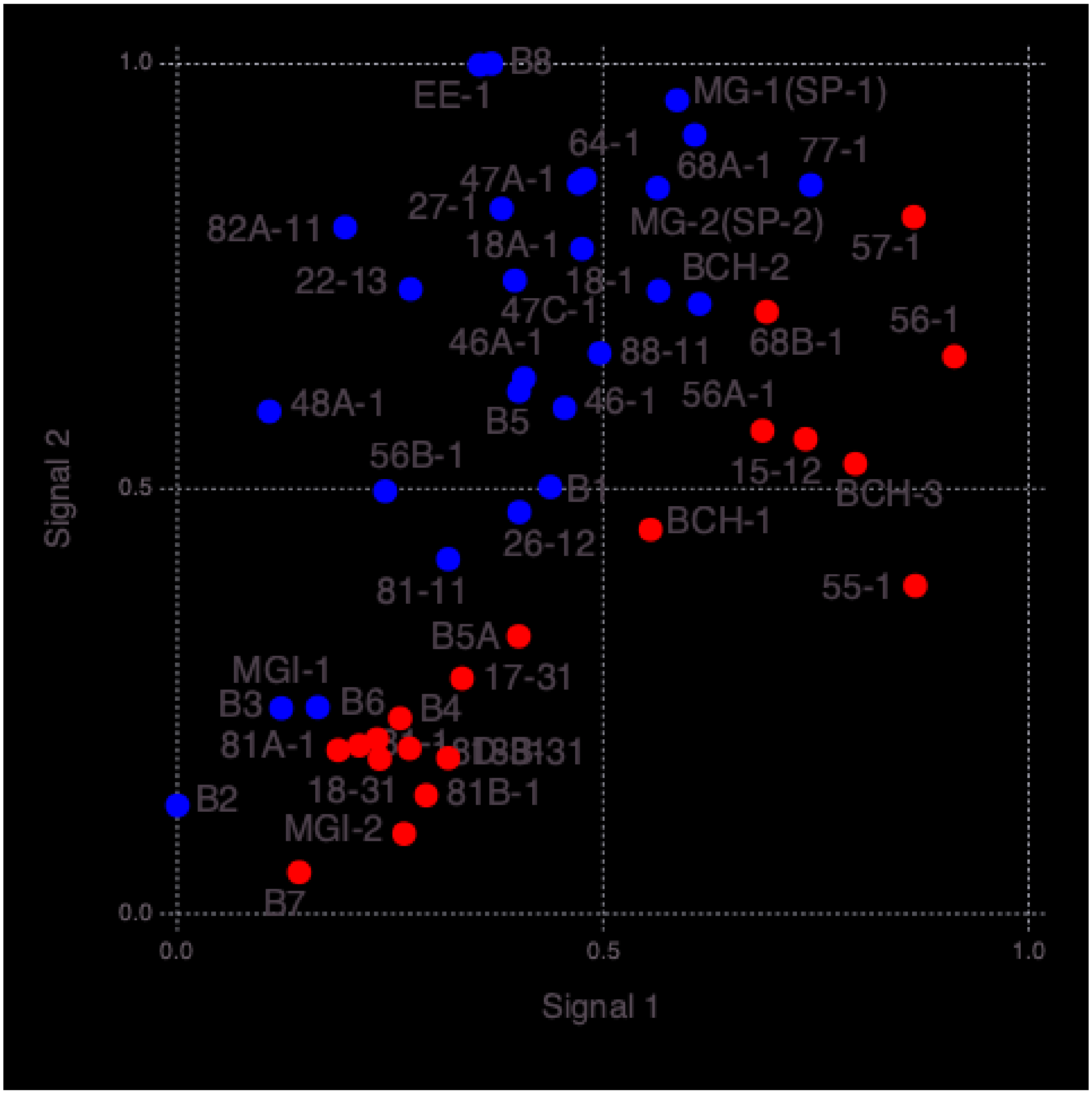


```
Info: Locations (signals=2)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S2) Count: 27
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S1) Count: 20
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal A -> A Count: 27
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> B Count: 20
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
```

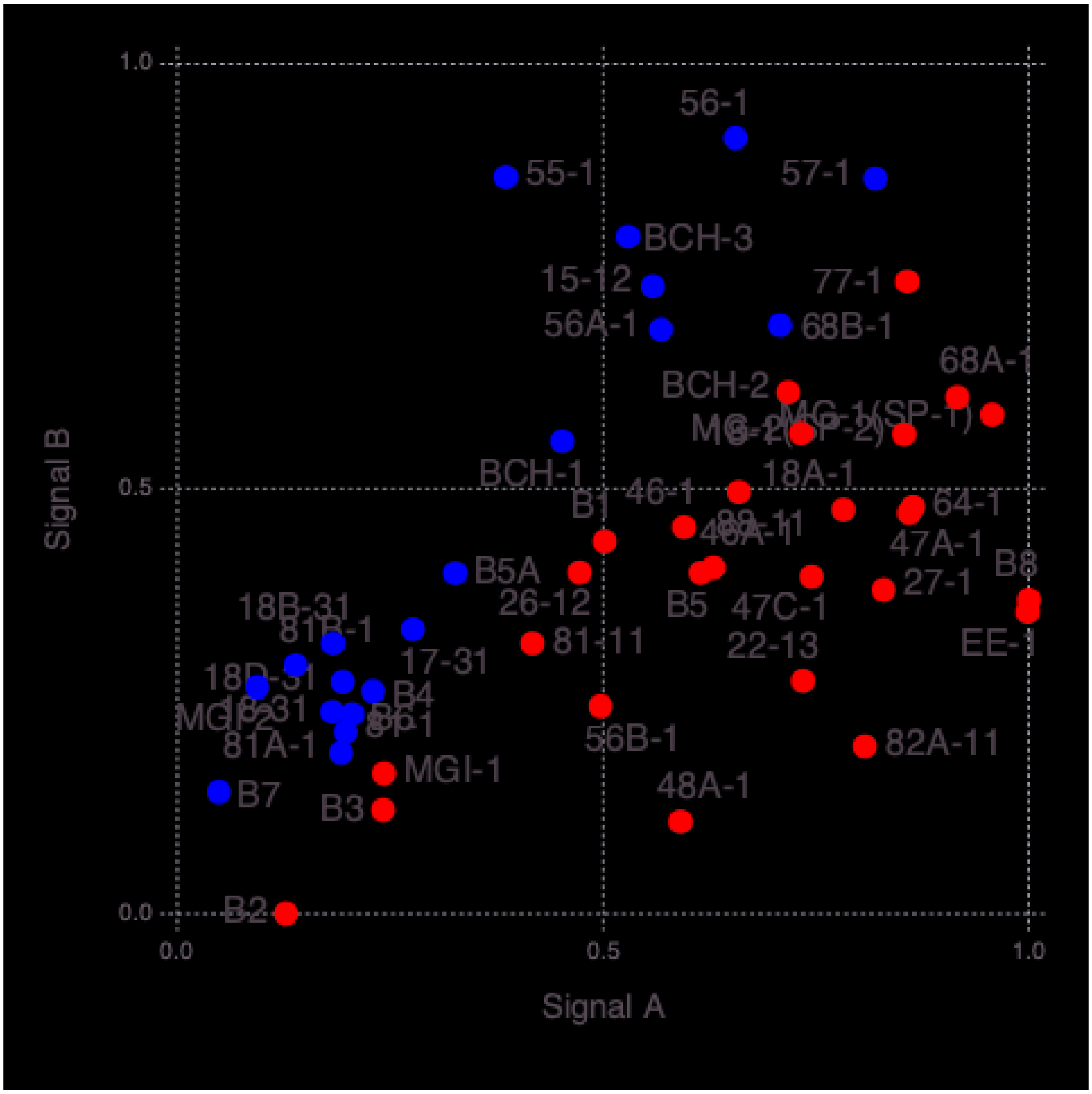
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360



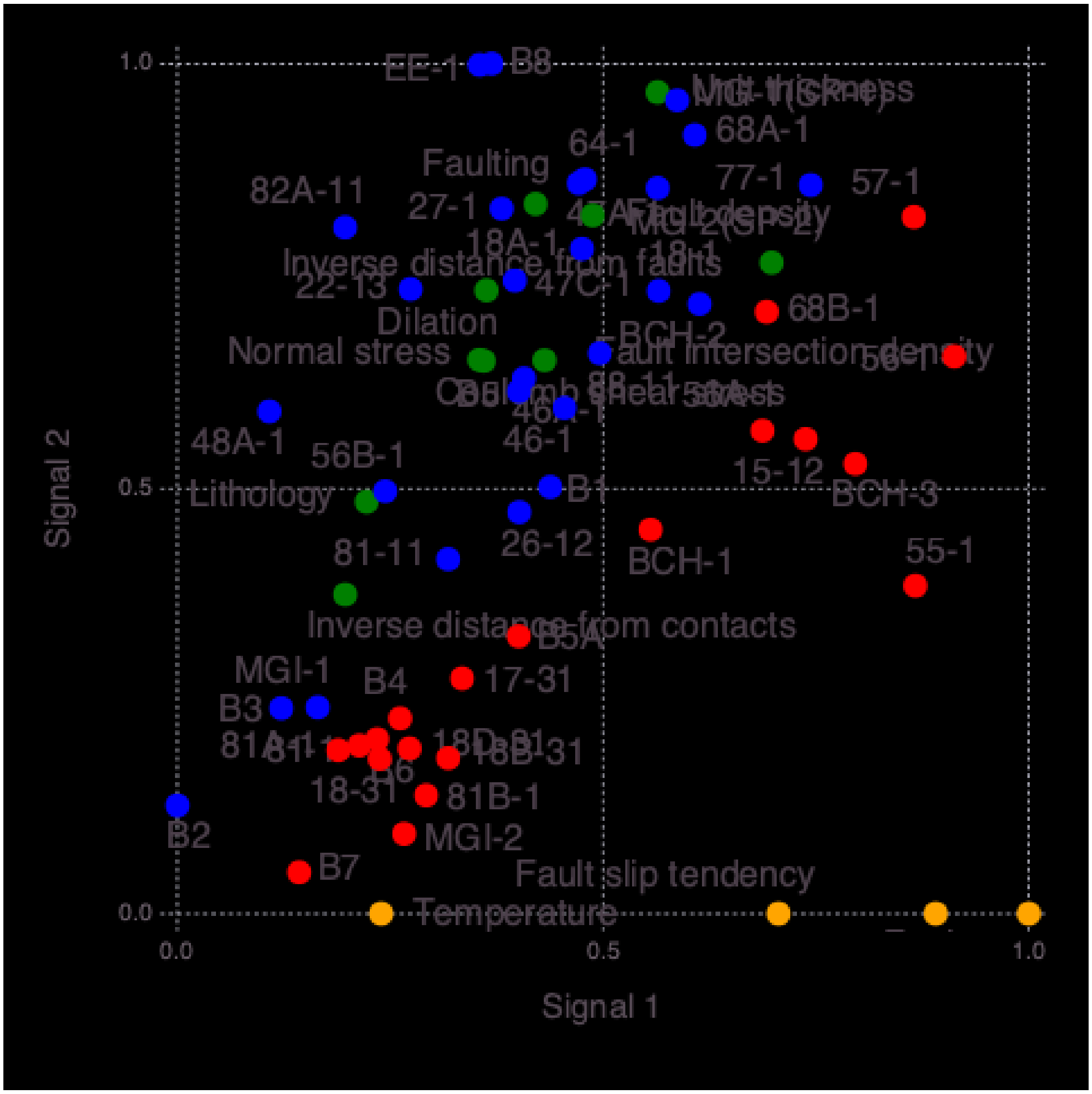


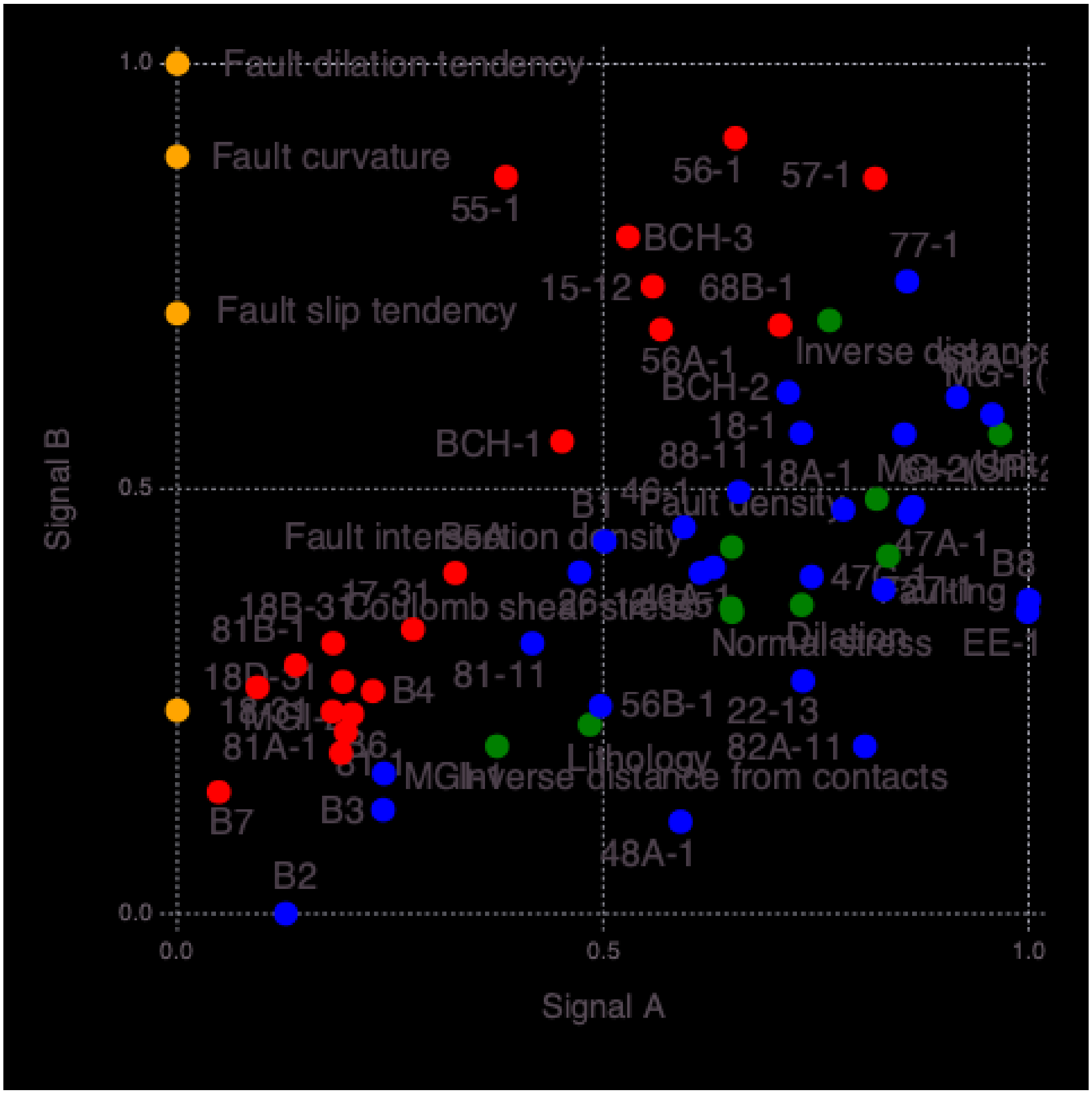


Signal 2
Signal 1
0.0
0.5
1.0
B8
EE-1
MG-1(SP-1)
64-1
68A-1
77-1
47A-1
27-1
82A-11
MG-2(SP-2)
57-1
18A-1
22-13
18-1
BCH-2
47C-1
68B-1
56-1
46A-1
88-11
48A-1
46-1
56A-1
B5
56B-1
15-12
BCH-3
B1
BCH-1
26-12
81-11
55-1
B5A
17-31
MGI-1
B3
B6
B4
81A-1
18-31
81B-1
B2
MGI-2
B7



Signal A
Signal B
0.0
0.5
1.0
56-1
55-1
57-1
BCH-3
15-12
77-1
56A-1
68B-1
68A-1
BCH-2
BCH-1
18A-1
46-1
B1
64-1
47A-1
B5A
B8
27-1
26-12
B5
47C-1
18B-31
81-11
22-13
EE-1
17-31
18D-31
B4
56B-1
82A-11
81A-1
MGI-1
48A-1
B7
B3
B2


Signal 1
Signal 2
0.0
0.5
1.0
EE-1
B8
68A-1
64-1
Faulting
82A-11
27-1
77-1
57-1
18A-1
Inverse distance from faults
22-13
47C-1
68B-1
Dilation
Normal stress
48A-1
56B-1
46-1
15-12
Lithology
B1
BCH-3
81-11
26-12
BCH-1
55-1
Inverse distance from contacts
MGI-1
B4
17-31
B3
18-31
81B-1
B2
MGI-2
B7
Fault slip tendency
Temperature



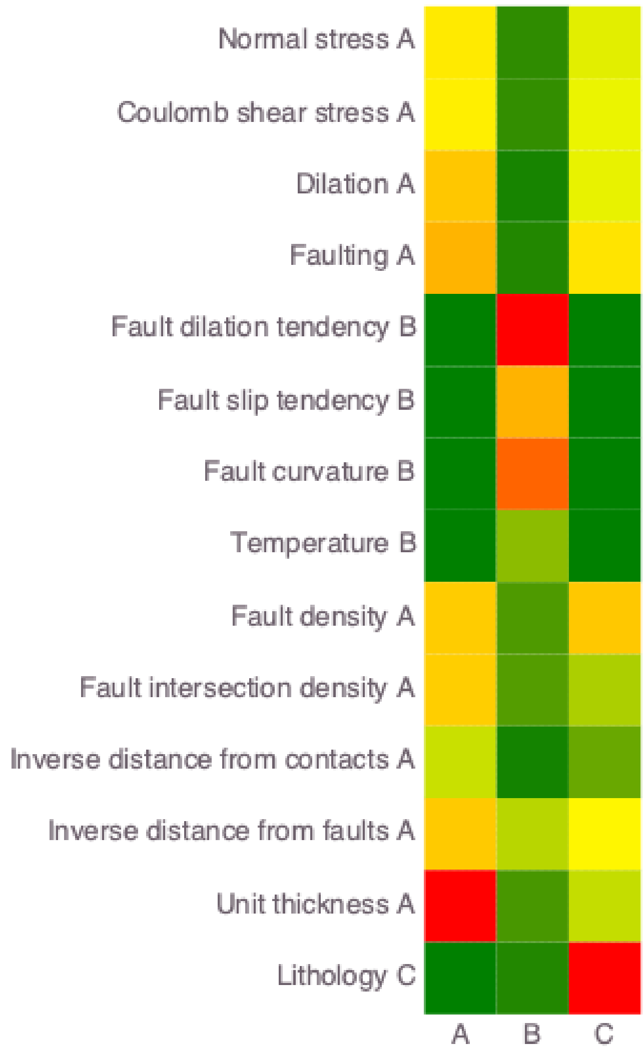

```
Signal importance (high->low): [3, 1, 2]
  Info: Number of signals: 3
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
  Info: Attributes (signals=3)
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-dlan/Hmatrix-3-3_14-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
  Warning: Procedure to find unique signals could not identify a solution …
```

```
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: Procedure to find unique signals could not identify a solution …
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
  Warning: type
Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.Float64,Core.Int64} not
present in workspace; reconstructing
  @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
  Info: Robust k-means analysis results are loaded from file results-
set00-v9-inv-750-1000-dlan/Wmatrix-3-3_47-1000.jld!
  @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
```

```
9×2 Array{Any,2}:
 "Unit thickness"                   1.0
 "Faulting"                         0.703863
 "Dilation"                         0.652914
 "Inverse distance from faults"     0.645557
 "Fault density"                    0.641279
 "Fault intersection density"       0.633706
 "Normal stress"                    0.558339
 "Coulomb shear stress"             0.544241
 "Inverse distance from contacts"   0.377979
```

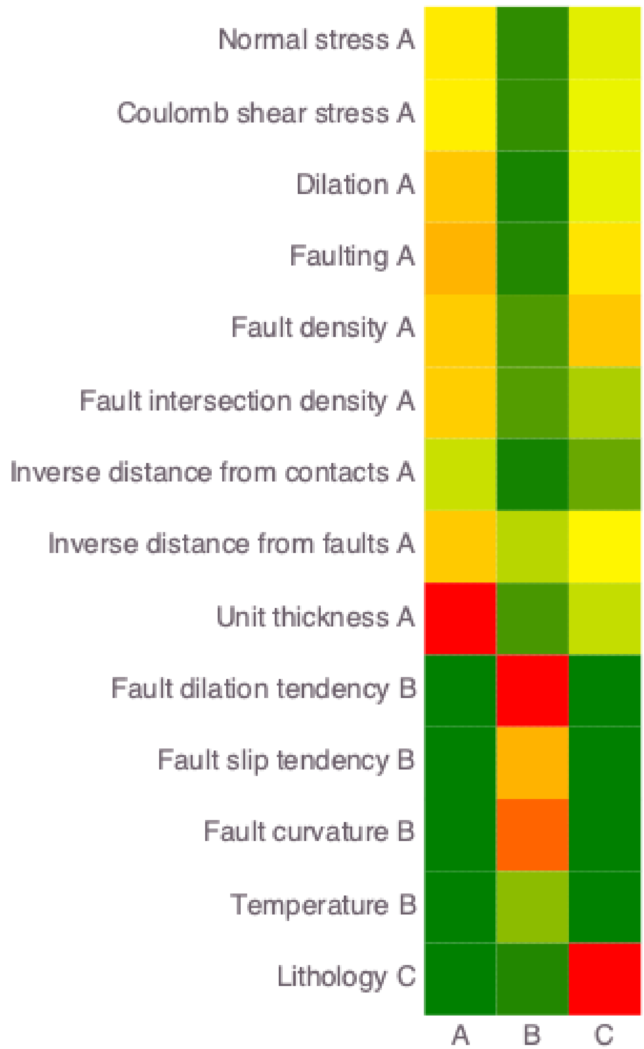
```
4×2 Array{Any,2}:
 "Fault dilation tendency"  1.0
 "Fault curvature"          0.89069
 "Fault slip tendency"      0.706146
 "Temperature"              0.239306
```

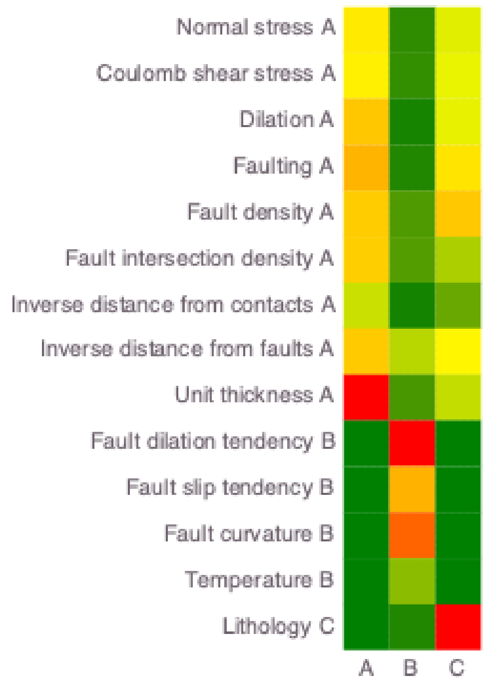
```
1×2 Array{Any,2}:
 "Lithology"  1.0
```

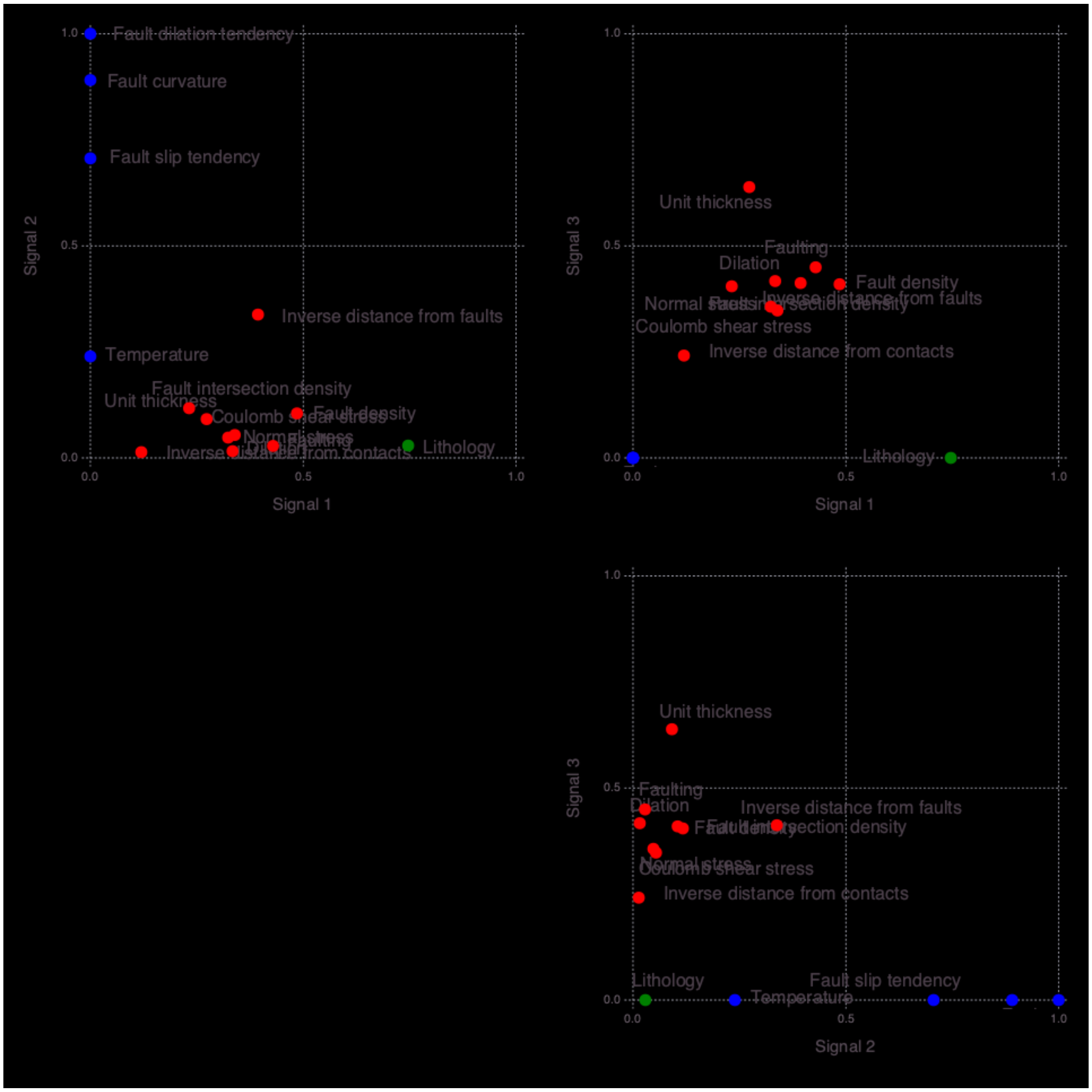


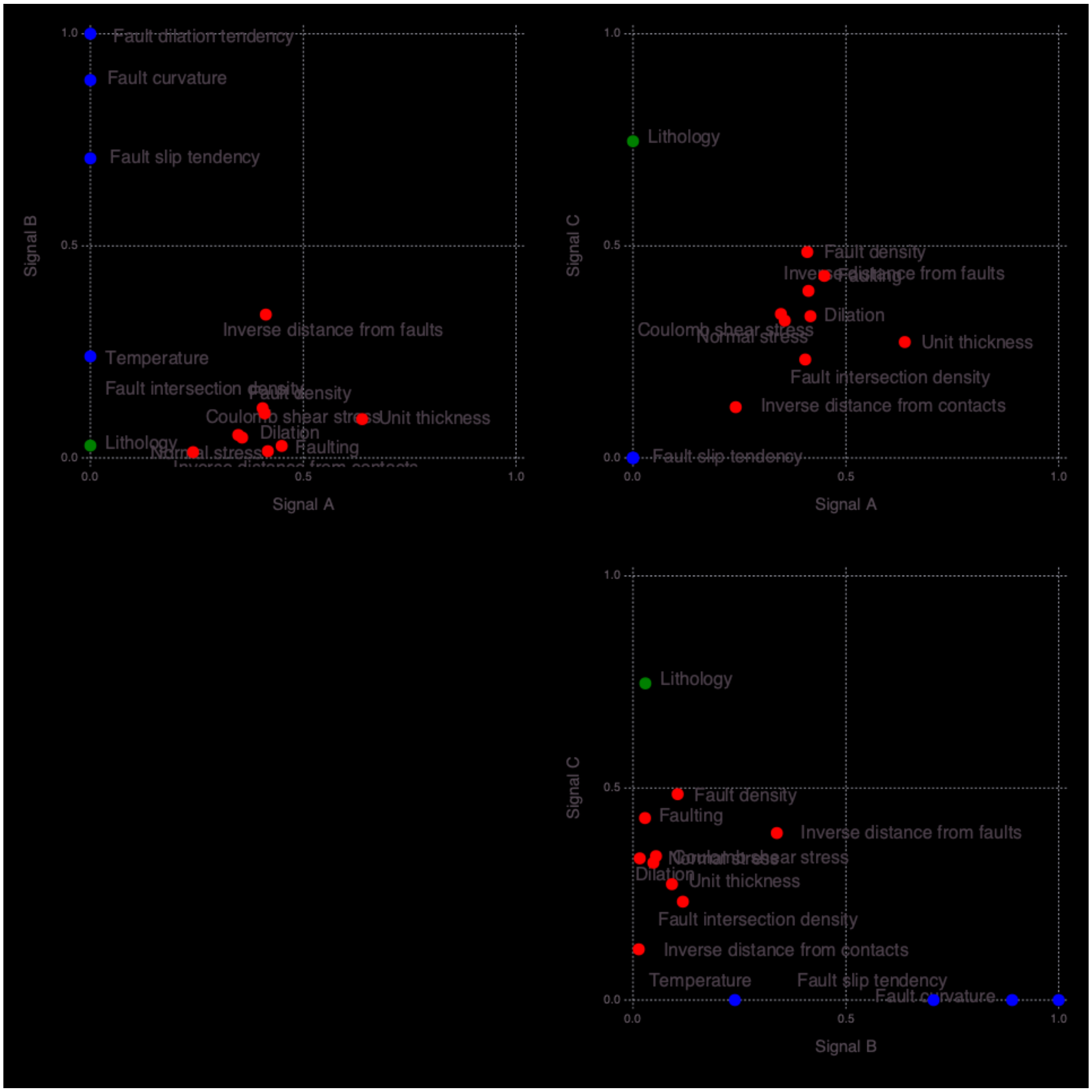

```
Warning: Procedure to find unique signals could not identify a solution …
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
Info: Signal A -> A Count: 9
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal B -> B Count: 4
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal C -> C Count: 1
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
Info: Signal A (S3) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal B (S2) (k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
Info: Signal C (S1) (k-means clustering)
```

```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```



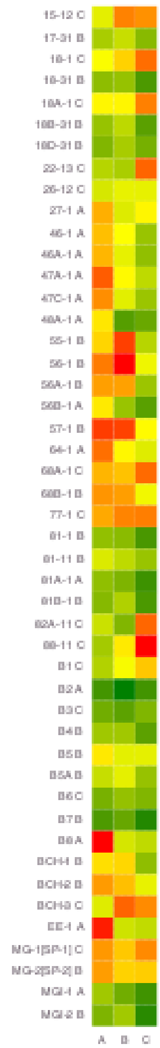

Normal stress A
Coulomb shear stress A
Dilation A
Faulting A
Fault density A
Fault intersection density A
Inverse distance from contacts A
Inverse distance from faults A
Unit thickness A
Fault dilation tendency B
Fault slip tendency B
Fault curvature B
Temperature B
Lithology C
A
B
C


Fault dilation tendency
Fault curvature
Fault slip tendency
Inverse distance from faults
Temperature
Fault intersection density
Unit thickness
Coulomb shear stress
Fault density
Normal stress
Lithology
Inverse distance from contacts
Signal 1
Signal 2
Signal 3
Faulting
Dilation
0.0
0.5
1.0



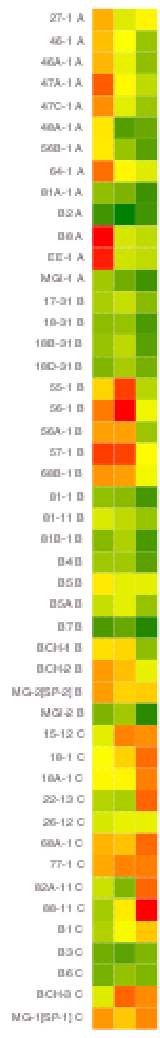

```
13×2 Array{Any,2}:
 "B8"      1.0
 "EE-1"    0.988215
 "47A-1"   0.905634
 "64-1"    0.867431
 "47C-1"   0.79874
 "27-1"    0.716696
 "46A-1"   0.699196
 "46-1"    0.675645
 "48A-1"   0.56726
 "56B-1"   0.557649
 "MGI-1"   0.286221
```

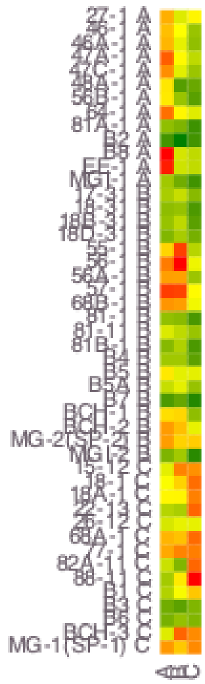
```
 "81A-1"  0.24804
 "B2"     0.0820308

20×2 Array{Any,2}:
 "56-1"        1.0
 "55-1"        0.951665
 "57-1"        0.947671
 "68B-1"       0.759123
 "56A-1"       0.752345
 "BCH-2"       0.67324
 "MG-2(SP-2)"  0.624464
 "BCH-1"       0.609265
 "B5A"         0.440143
 "B5"          0.439178
 "17-31"       0.372325
 "81-11"       0.353316
 "18B-31"      0.351038
 "81B-1"       0.32106
 "18D-31"      0.302397
 "MGI-2"       0.289056
 "B4"          0.286007
 "18-31"       0.261958
 "81-1"        0.234893
 "B7"          0.155895

14×2 Array{Any,2}:
 "88-11"       1.0
 "22-13"       0.890617
 "82A-11"      0.886939
 "68A-1"       0.878252
 "18-1"        0.872381
 "77-1"        0.834481
 "18A-1"       0.830688
 "MG-1(SP-1)"  0.807444
 "BCH-3"       0.805676
 "15-12"       0.791843
 "B1"          0.65222
 "26-12"       0.444381
 "B6"          0.213355
 "B3"          0.212844
```

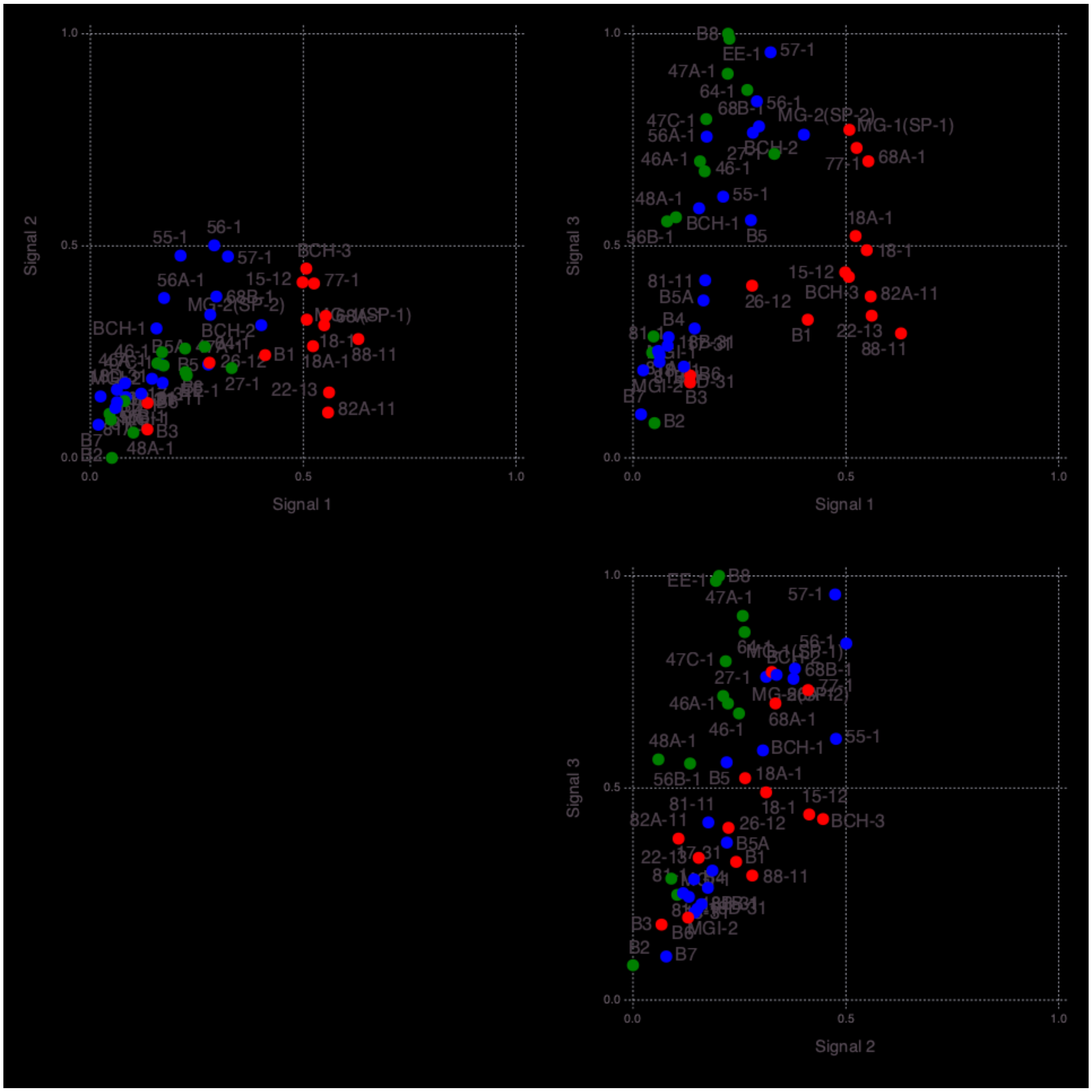


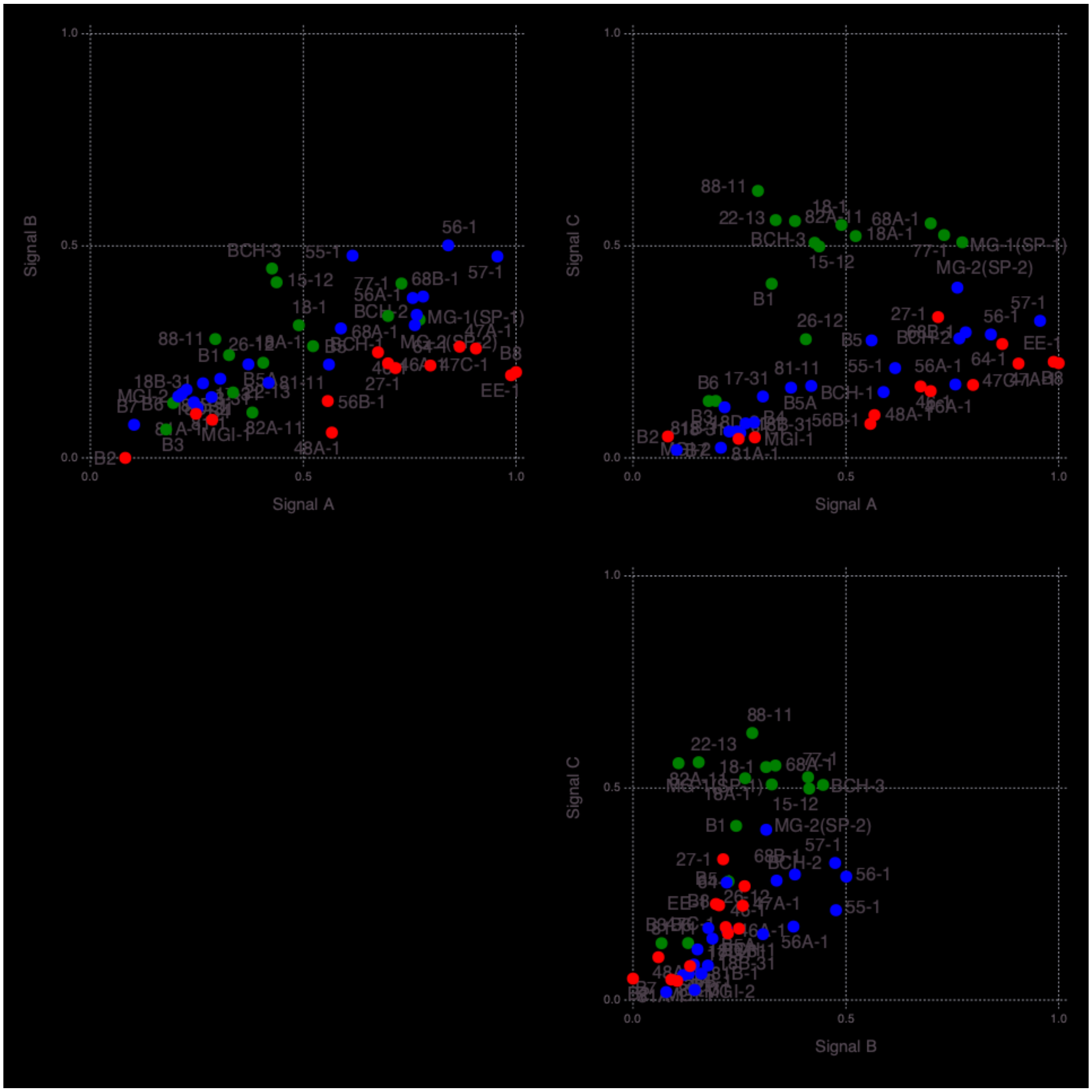
```
Info: Locations (signals=3)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
Info: Signal A (S2) Count: 20
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal B (S1) Count: 14
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C (S3) Count: 13
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
Info: Signal C -> A Count: 13
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A -> B Count: 20
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal B -> C Count: 14
```

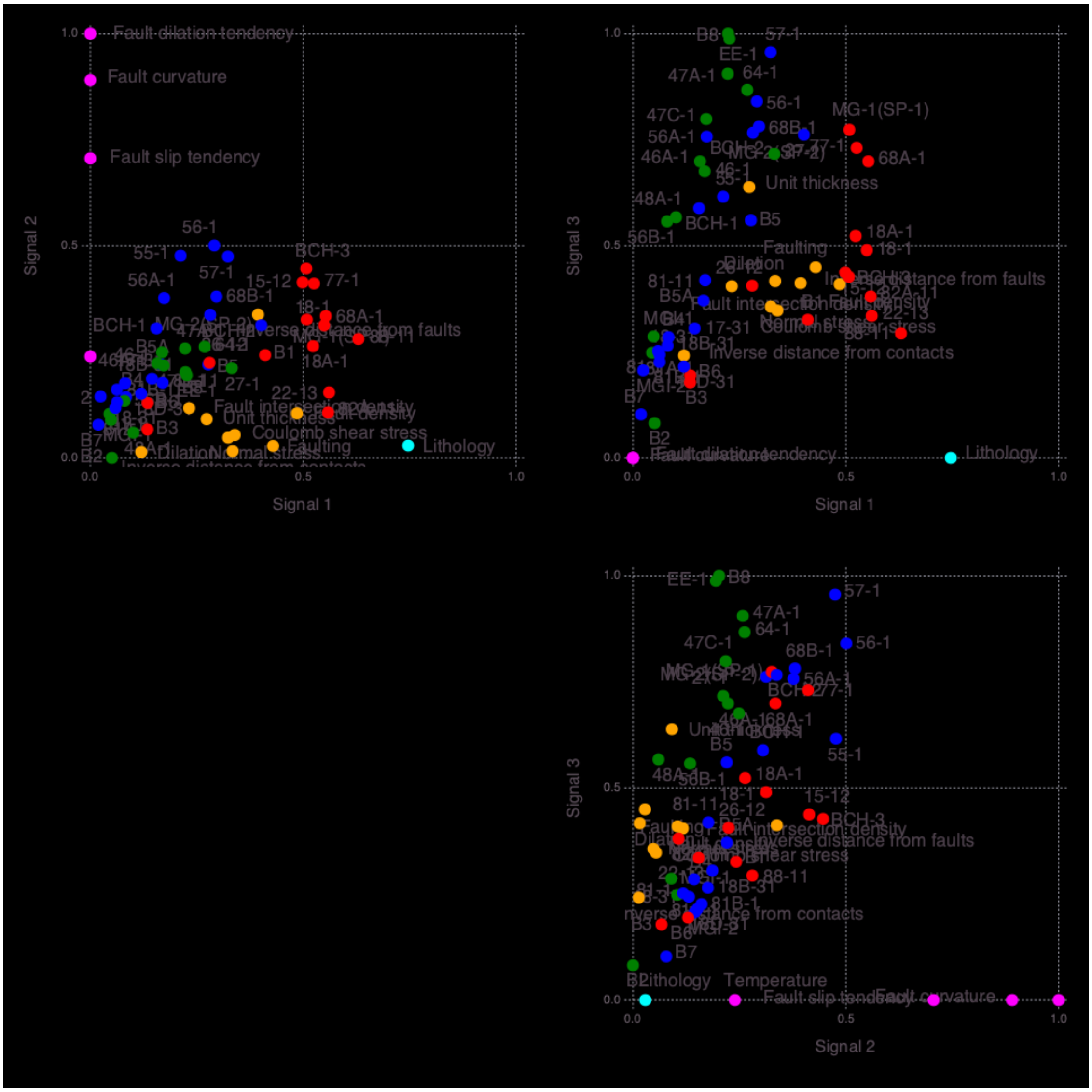
```
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
Info: Signal A (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal B (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
Info: Signal C (remapped k-means clustering)
@ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:360
```

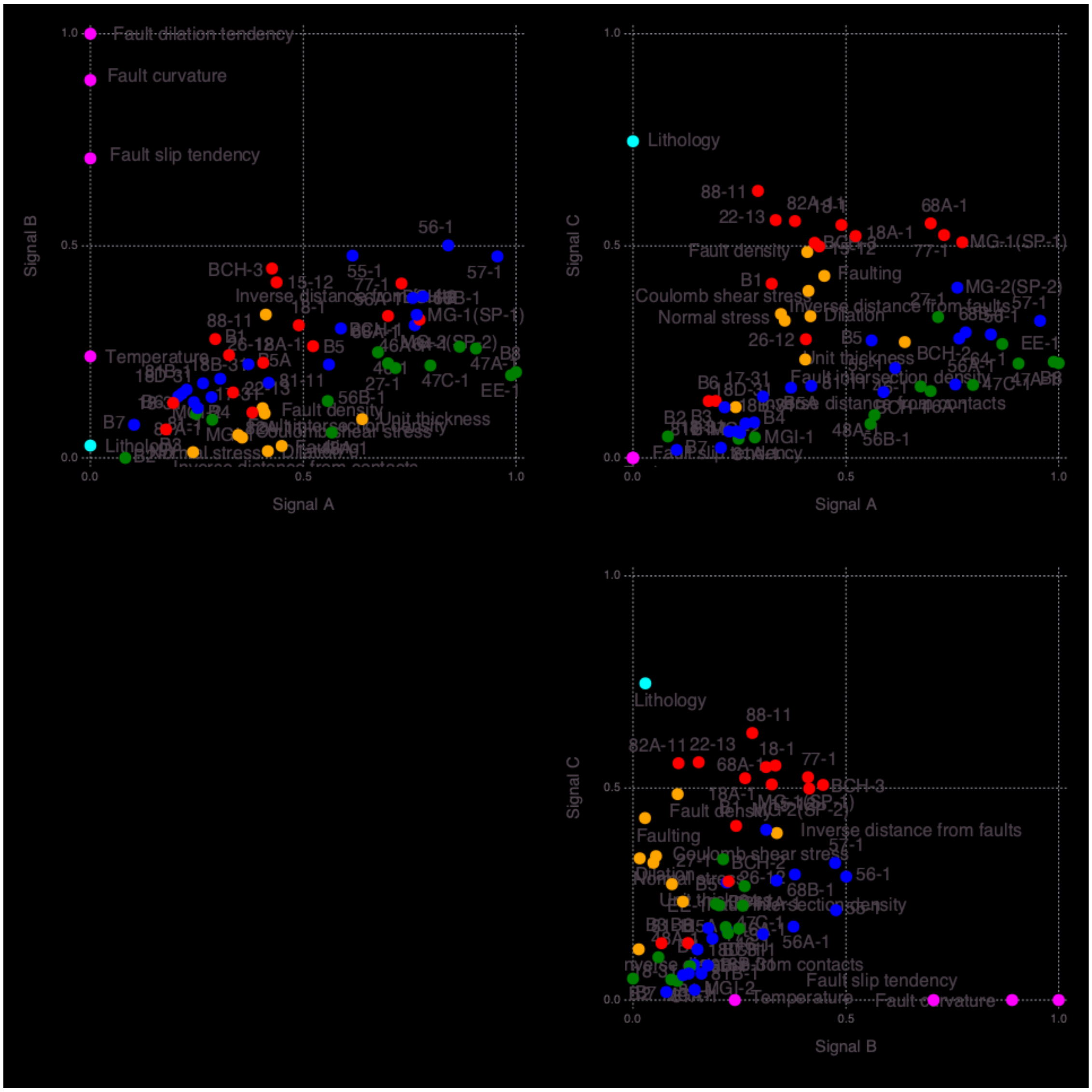





Signal 1
Signal 2
Signal 3


Signal A
Signal B
Signal C
Signal A
Signal C
Signal B


Signal 1
Signal 2
Signal 3



[27]: ([[2, 1], [3, 2, 1]], [['B', 'B', 'A', 'B', 'A', 'B', 'B', 'A', 'A', 'A' …
'B', 'A', 'B', 'A', 'B', 'A', 'A', 'A', 'A', 'B'], ['C', 'B', 'C', 'B', 'C',
'B', 'B', 'C', 'C', 'A' … 'B', 'A', 'B', 'B', 'C', 'A', 'C', 'B', 'A', 'B']],
[['A', 'A', 'A', 'A', 'B', 'B', 'B', 'B', 'A', 'A', 'A', 'A', 'A', 'A'], ['A',
'A', 'A', 'A', 'B', 'B', 'B', 'B', 'A', 'A', 'A', 'A', 'A', 'C']])

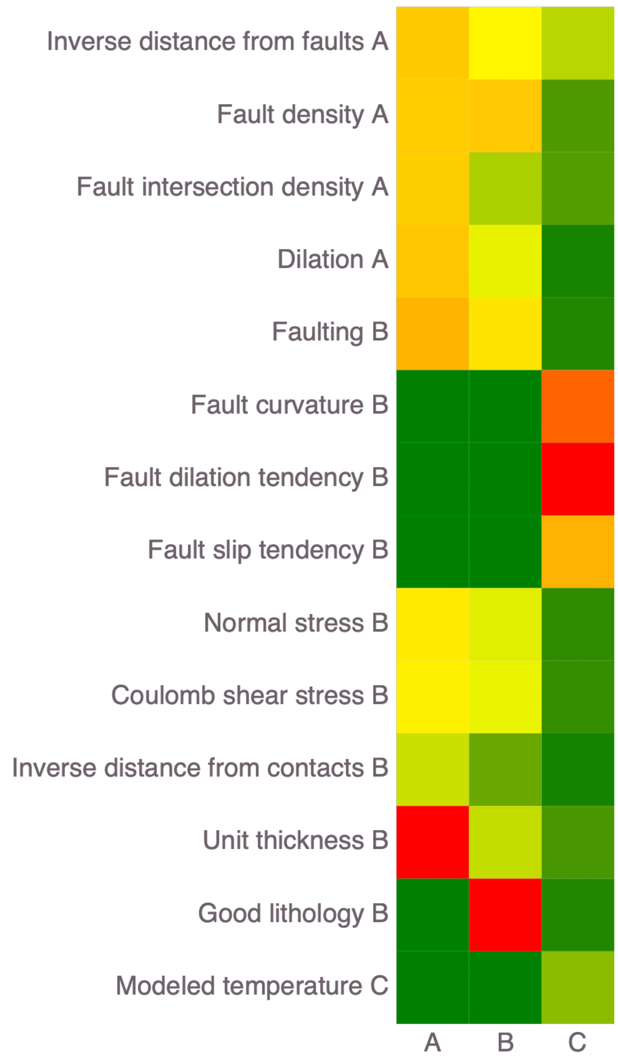
Analysis of the 3-signature solution The results for a solution with **3** signatures presented above will be further discussed here.

The well attributes are clustered into **3** groups:

<iframe src="../results-set00-v9-inv-750-1000-dlan/attributes-3-groups.txt" frameborder="0" he

```
width="95%"></iframe>
```

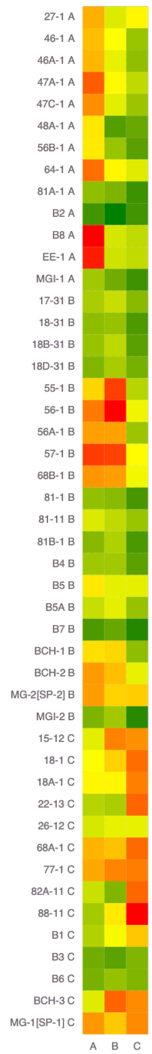
This grouping is based on analyses of the attribute matrix `W`:



Note that the attribute matrix `W` is automatically modified to account that a range of vertical depths is applied in characterizing the site wells.

The well locations are also clustered into **3** groups:

This grouping is based on analyses of the location matrix `H`:



The map ../figures-set00-v9-inv-750-1000-dlan/locations-3-map.html provides interactive visualization of the extracted well location groups (the html file can also be opened with any browser).

<iframe src="../figures-set00-v9-inv-750-1000-dlan/locations-3-map.html" frameborder="0" heigh