NMFk analysis: Geothermal data of Brady site, NV

This analysis demonstrates how **NMFk** can be applied to perform unsupervised machine-learning analyses.

The code below demonstrates the ML work related to a submitted research paper analyzing geothermal data of the Brady site, NV

Import required Julia modules

If **NMFk** is not installed, first execute `import Pkg; Pkg.add("NMFk"); Pkg.add("DelimitedFiles"); Pkg.add("Gadfly"); Pkg.add("Mads")` .

In [5]:
```
import NMFk
import DelimitedFiles
import Gadfly
import Cairo
import Fontconfig
import Mads
```

Read and pre-process the dataset

Setup the working directory containing the Brady site data

In [6]:
```
cd("/Users/vvv/Julia/GTcloud-SmartTensors.jl/Brady")
```

Load the data file

In [7]:
```
d, h = DelimitedFiles.readdlm("data/AllBradyWells_LANL_ML_9.txt", ','; head
```

Populate the missing well names

In [8]:
```
global wellname = ""
for i = 1:size(d, 1)
    if d[i, 1] != ""
        global wellname = d[i, 1]
    else
        d[i, 1] = wellname
    end
end
```

Set up missing entries to be equal to zero

In [9]:
```
d[d[:, 24] .== "", 24] .= 0;
```

Define names of the data attributes (matrix columns

Short names are used for coding.

Long names used for plotting and visualization.

In [10]:
```
attributes_short = ["ID", "D", "azimuth", "incline", "x", "y", "z", "casing
attributes_long = ["ID", "Depth", "Azimuth", "Inclination", "X", "Y", "Z",
```

Define the attributes that will be processed

In [11]:
```
attributes_process = ["normal", "coulomb", "dilation", "faults", "td", "ts"
```

Index the attributes that will be processed

In [12]:
```
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];
```

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

In [14]:
```
:length(attributes_col); println("$(attributes_col[i]): Column $i Min $(mini
:length(attributes_col); println("$(attributes_col[i]): Column $i Unique ent
```

```
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:
```

Get well locations and production

In [15]:
```
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
```

Define well types

In [16]:
```
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_
end
```

Show information about processed well attributes

In [17]:
```
for i = ai
    println("$(attributes_col[i]): $i")
    display(unique(sort(convert.(Float64, d[:,i]))))
end
```

```
  155.34254150391
  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
```

Collect the well data into 3D tensor

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

In [18]:
```
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
```

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.

In [19]:
```
depth = 750;
```

Normalize tensor slices associated with each attribute

In [20]:
```
Tn = deepcopy(T[1:depth,:,:])
for a = 1:length(ai)
    Tn[:,a,:], _, _ = NMFk.normalize!(Tn[:,a,:])
end
```

Define problem setup variables

In [21]:
```
nruns = 1000 # Number of random NMF runs
nkrange = 2:8 # range of k values

casename = "set00-v9-inv"
figuredir = "figures-$(casename)-$(depth)"
resultdir = "results-$(casename)-$(depth)";
```

Plot well data

In [22]:
```
nlocations = length(locations)
hovertext = Vector{String}(undef, nlocations)
for i = 1:nlocations
    hovertext[i] = join(map(j->("$(attributes_process_long[j]): $(round(flo
end

NMFk.plot_wells("map/dataset-$(casename).html", xcoord, ycoord, String.(wel
```

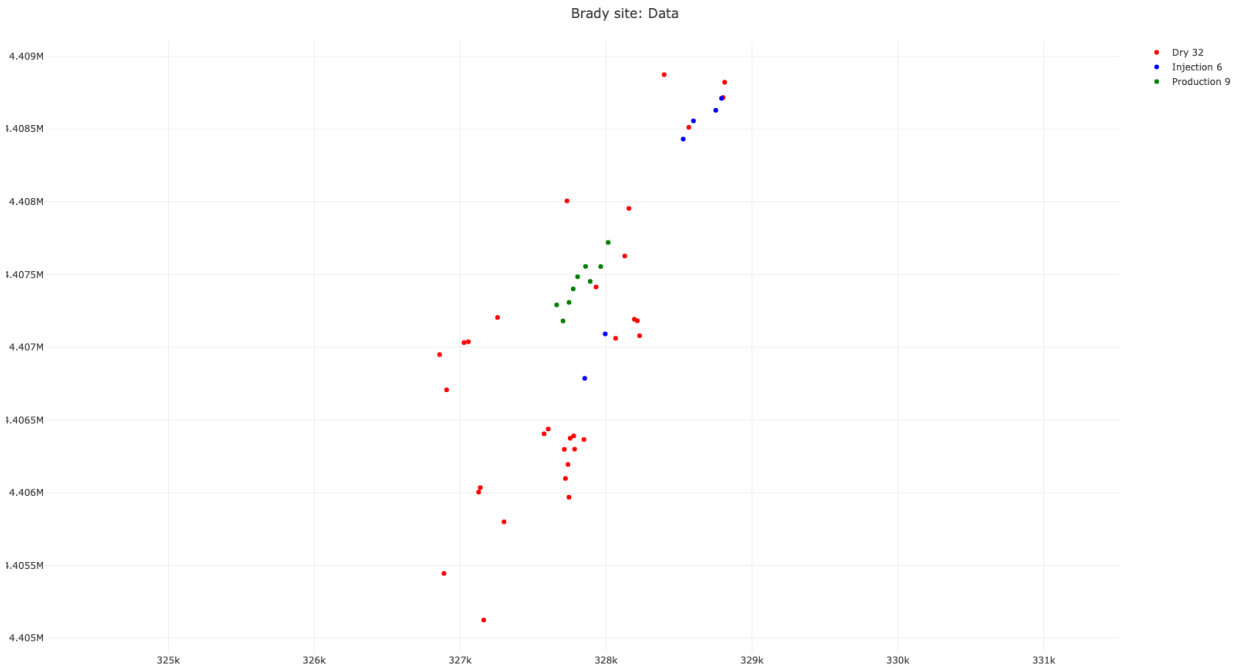
A HTML file named "map/dataset-set00-v9-inv.html" is generated.

Link to "map/dataset-set00-v9-inv.html". (map/dataset-set00-v9-inv.html)

The file provides interacive visualization of the data; it can be openned in any browser.

A static (PNG) version of the map looks like this:

In [23]:
```
display("image/png", read("map/dataset-set01-v9-inv.png"))
```



Perform ML analyses

For the ML analyses, the data tensor will be flatten two different ways:

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

Type 1 flattening: focus on locations

Flatten the tensor into a matrix

In [24]:
```
Xdaln = reshape(Tn, ((depth * length(attributes_process))), length(location
```

Matrix rows merge the depth and attribute dimensions.

Matrix cols represent the well locations.

Perform NMFk analyses

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

In [25]:
```
H, fitquality, robustness, aic = NMFk.execute(Xdaln, nkrange, nruns; result
H, fitquality, robustness, aic = NMFk.load(nkrange, nruns; resultdir=result
```

```
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
```

As seen from the output the ML 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 accetable solutions are defined as follows:

In [26]:
```
NMFk.getks(nkrange, robustness[nkrange])
```

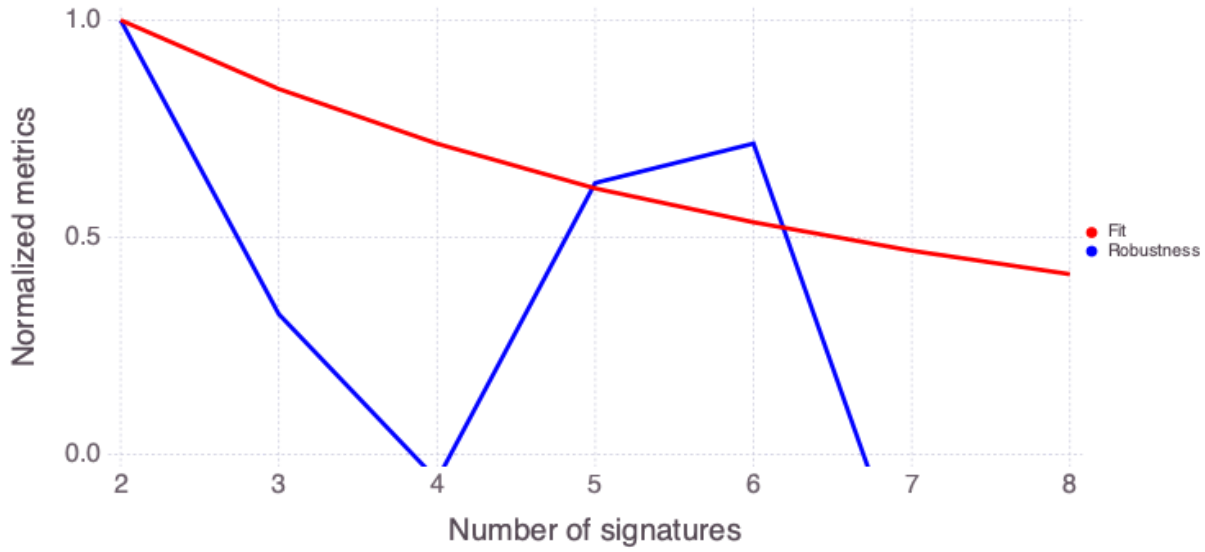
Out[26]:
```
3-element Array{Int64,1}:
 2
 5
 6
```

The accceptable solutions contain 2, 5 and 6 signatures.

Post-process NMFk results

Plot representing solution quality (fit) and silhouette width (robustness) for different number of sigantures `k` :

In [27]:
```
NMFk.plot_signal_selecton(nkrange, fitquality, robustness; figuredir="$figu
```



The ML solutions containing 2, 5 and 6 signatures are further analyzed as follows:

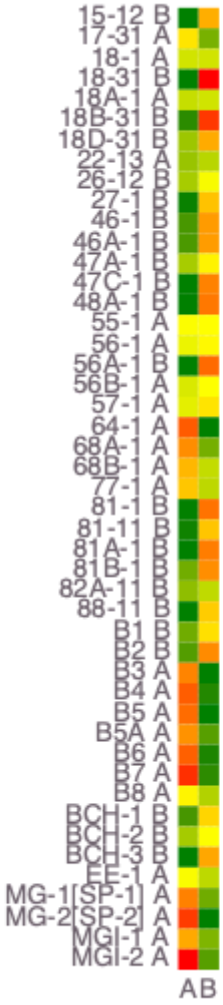
In [28]:
```
NMFk.clusterresults(NMFk.getks(nkrange, robustness[nkrange]), W, H, attribu
```

```
┌ 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.F
loat64,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-set0
0-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.F
loat64,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-set0
0-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
```

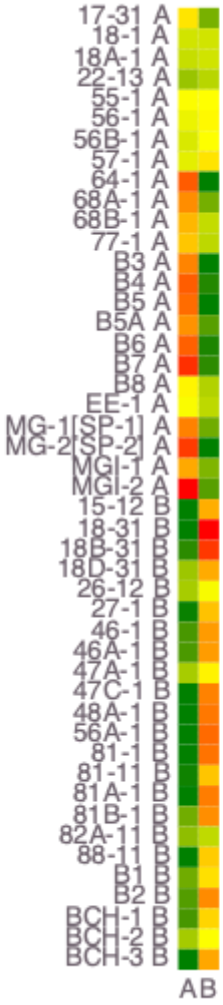
```
 "56B-1"       0.413443
 "18-1"        0.395716
 "18A-1"       0.370733
 "22-13"       0.269227
```

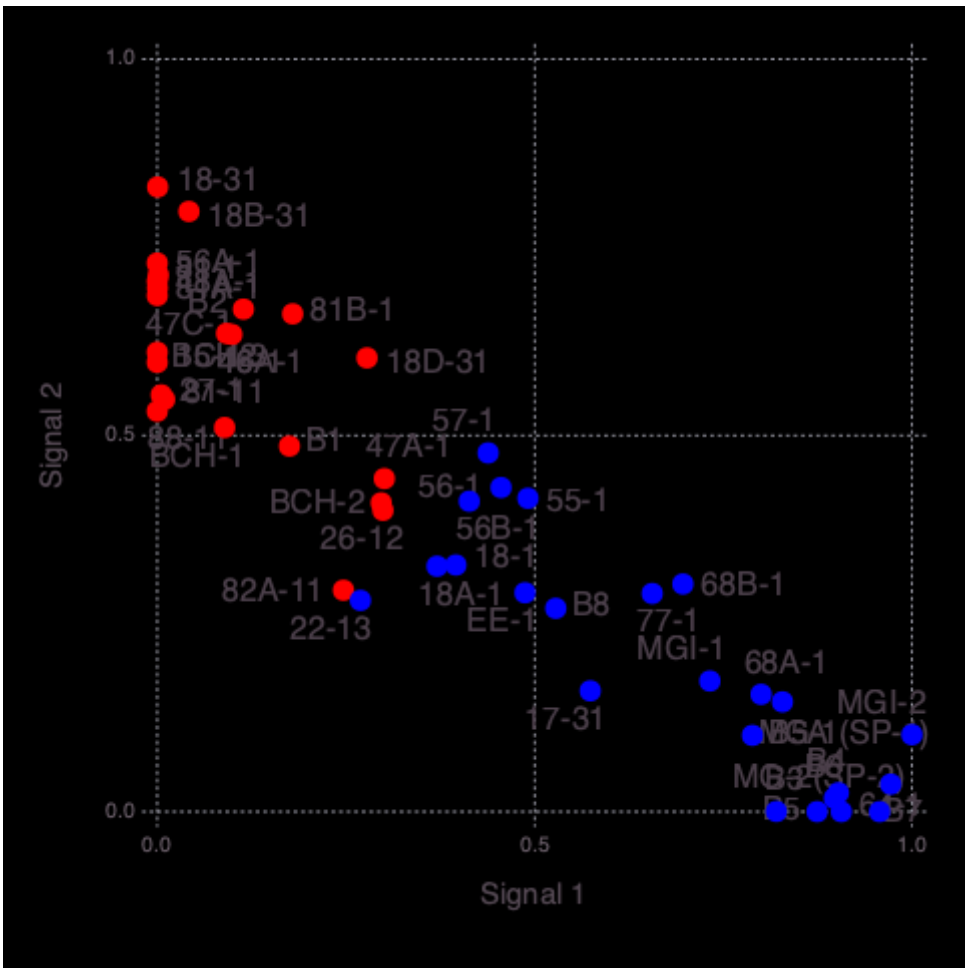
```
┌ Info: Signal B -> B Count: 23
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
┌ Info: Signal A (S1) (k-means clustering)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```

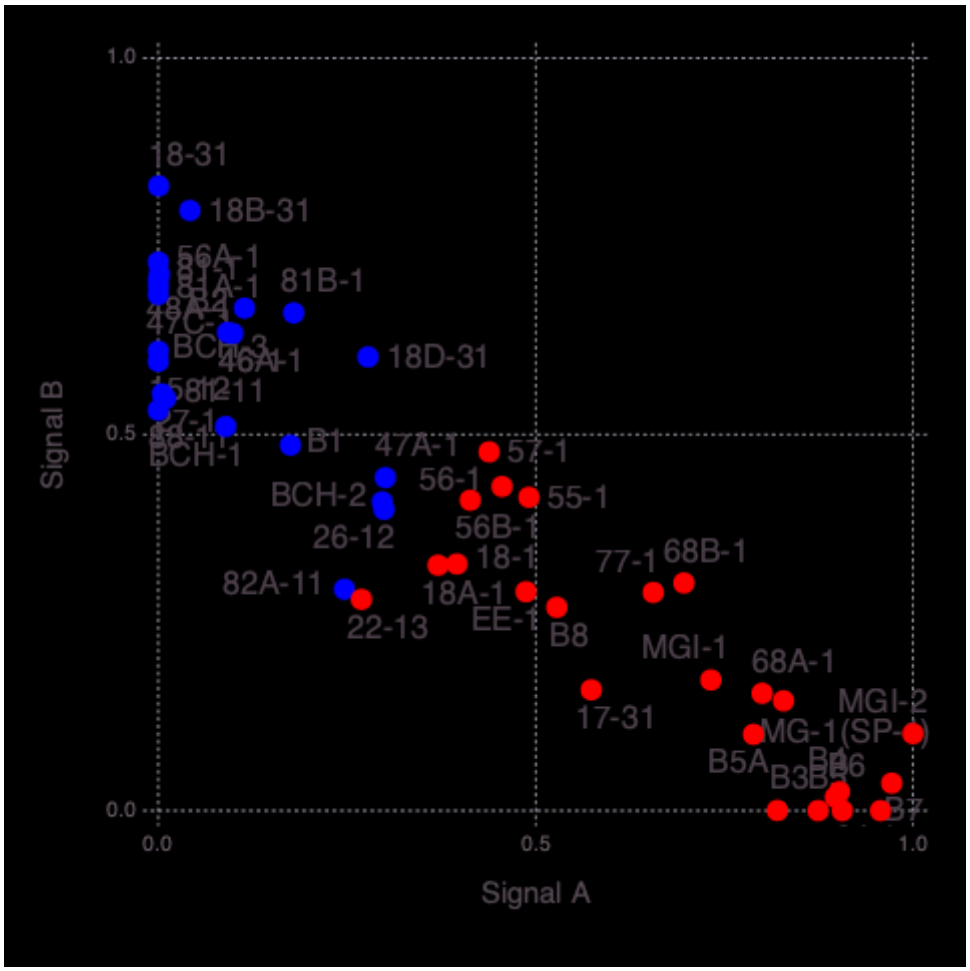
```
23×2 Array{Any,2}:
 "18-31"   1.0
 "18B-31"  0.960836
 "56A-1"   0.878124
 "81-1"    0.859001
 "48A-1"   0.849051
 "81A-1"   0.838298
 "47C-1"   0.826181
 "B2"      0.804453
 "81B-1"   0.796872
 "46-1"    0.765556
 "46A-1"   0.763833
 "BCH-3"   0.735382
 "18D-31"  0.726398
 "15-12"   0.719203
 "27-1"    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
```



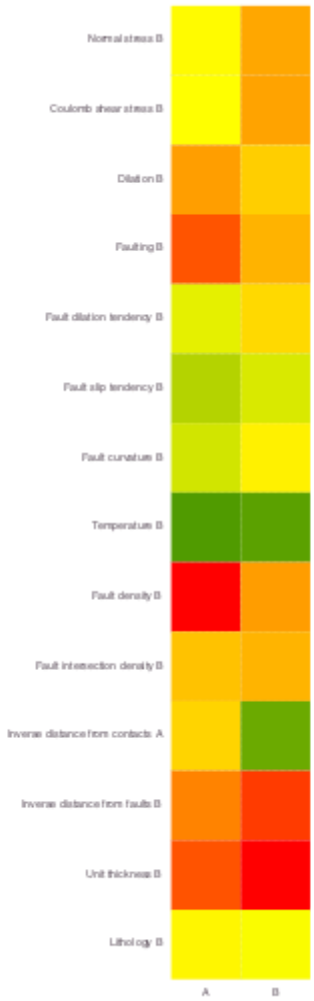

```
[ Info: Signal B (S2) (k-means clustering)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:272
```


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

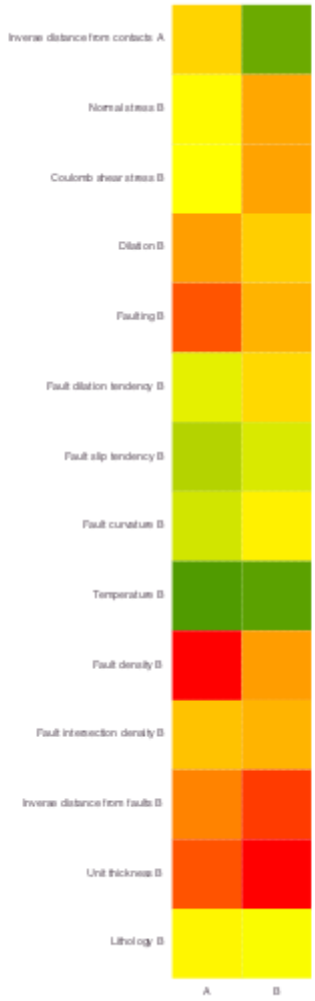

1.0
0.5
0.0
0.0
0.5
1.0
Signal 2
Signal 1
18-31
18B-31
81B-1
18D-31
57-1
47A-1
B1
BCH-1
56-1
55-1
BCH-2
26-12
56B-1
18-1
82A-11
18A-1
B8
68B-1
77-1
22-13
EE-1
MGI-1
68A-1
17-31
MGI-2

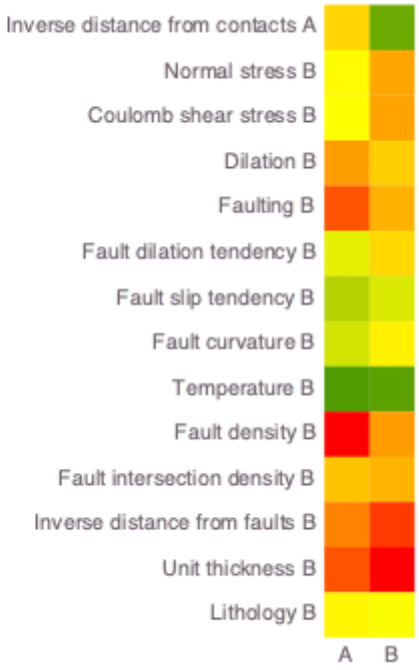


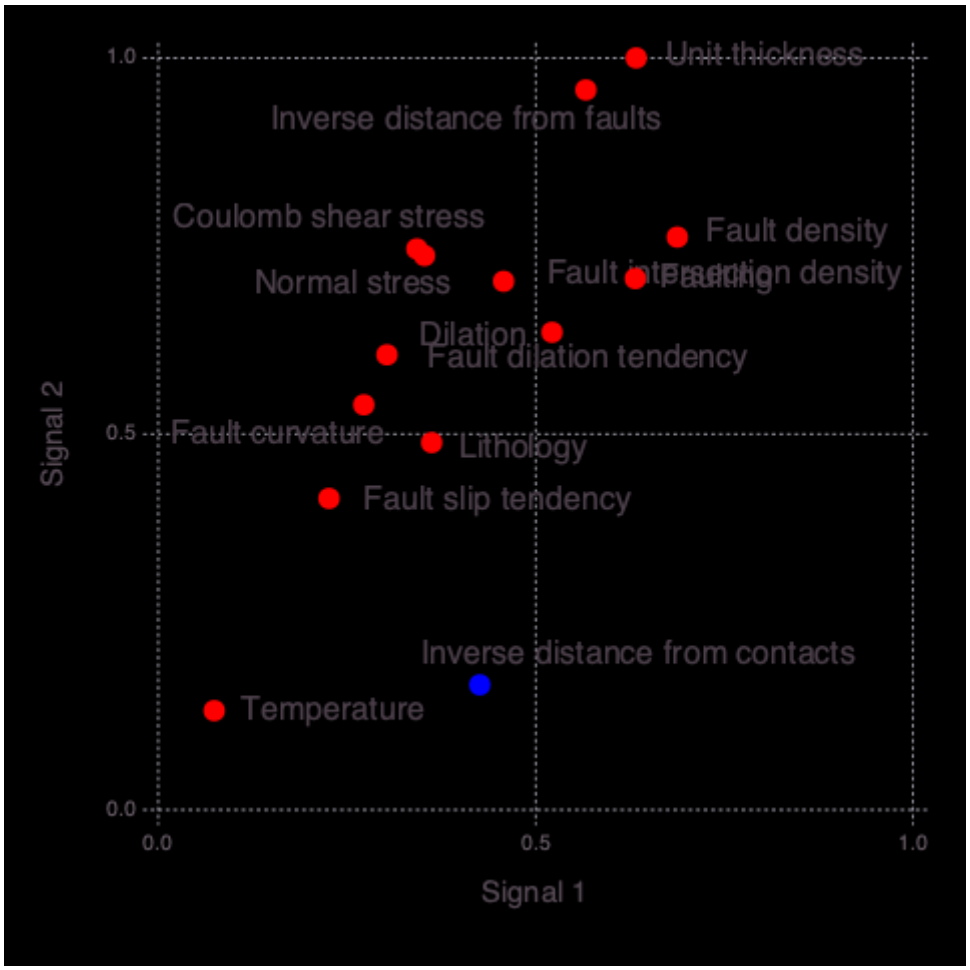

```
1×2 Array{Any,2}:
 "Inverse distance from contacts"  0.619519

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
```

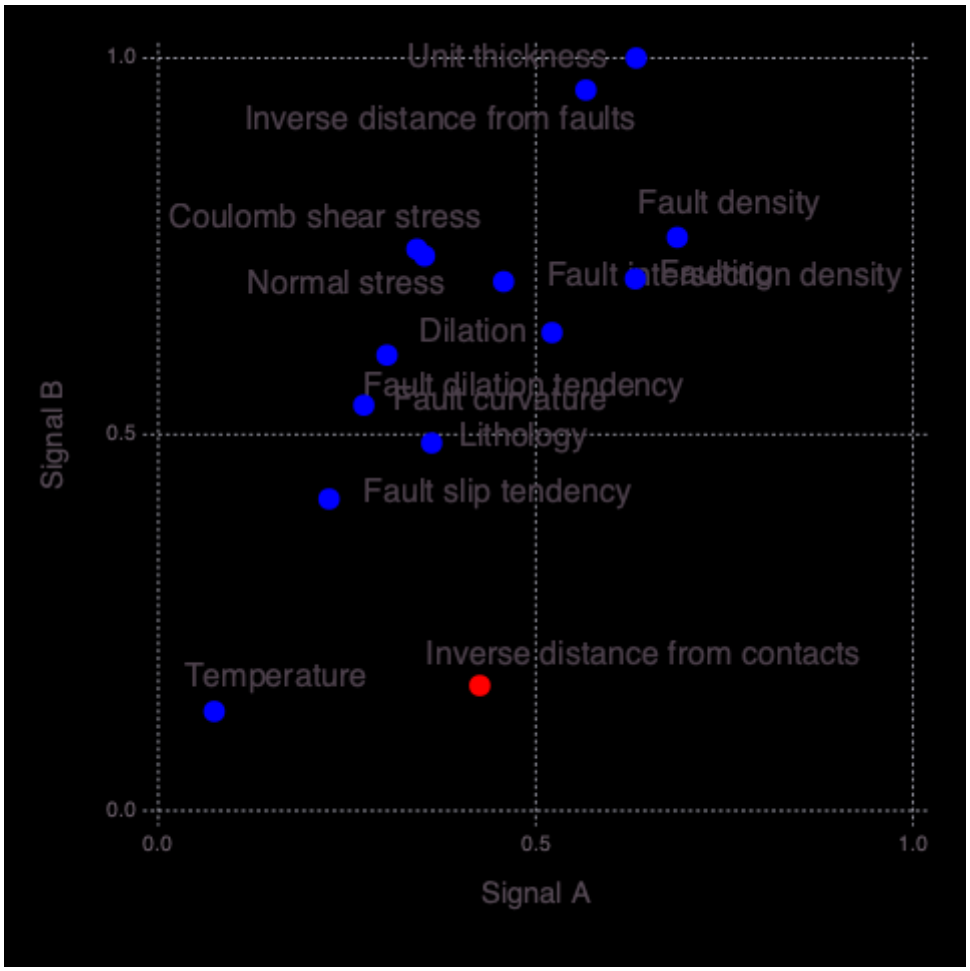


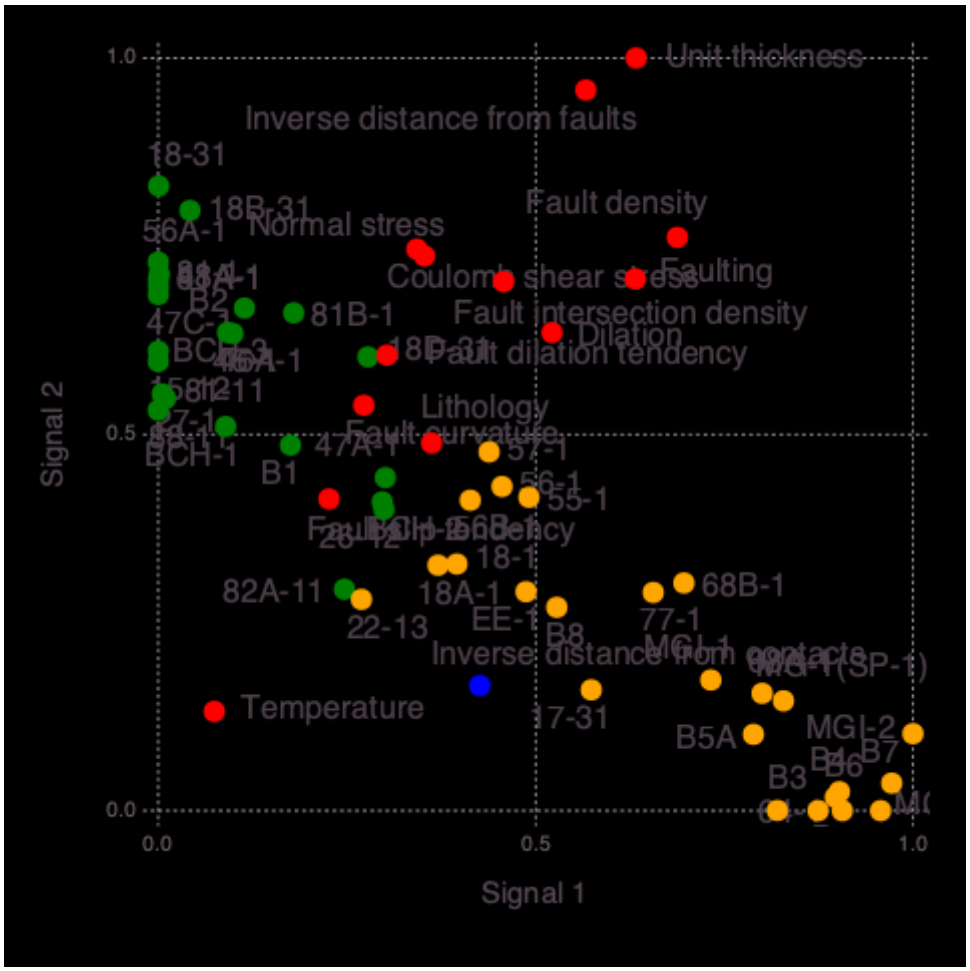

```
[ Info: Attributes (signals=2)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
[ Info: Signal A (S2) Count: 13
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal B (S1) Count: 1
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal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

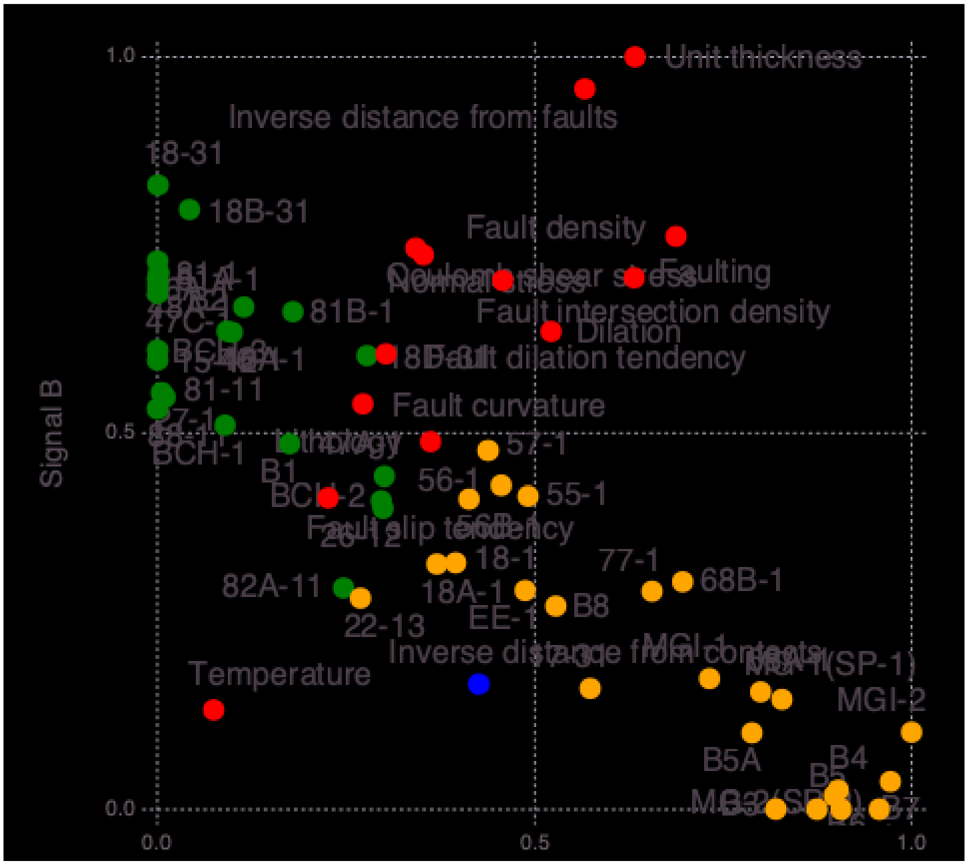

Inverse distance from contacts A
Normal stress B
Coulomb shear stress B
Dilation B
Faulting B
Fault dilation tendency B
Fault slip tendency B
Fault curvature B
Temperature B
Fault density B
Fault intersection density B
Inverse distance from faults B
Unit thickness B
Lithology B
A B


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
1.0
0.5
0.0
0.0
0.5
1.0
Signal 2
Signal 1


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

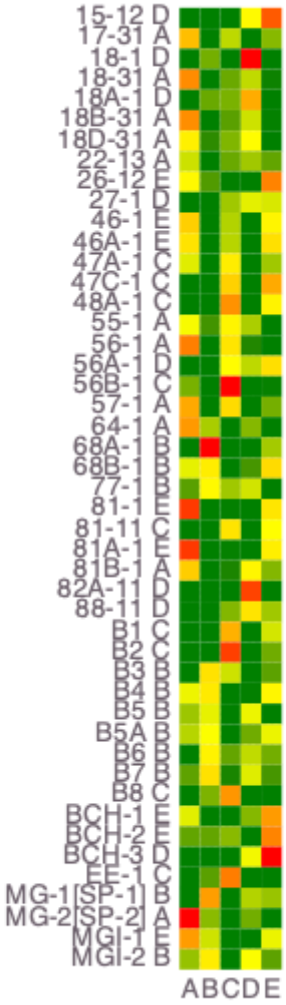



```
Signal importance (high->low): [1, 3, 5, 4, 2]
```



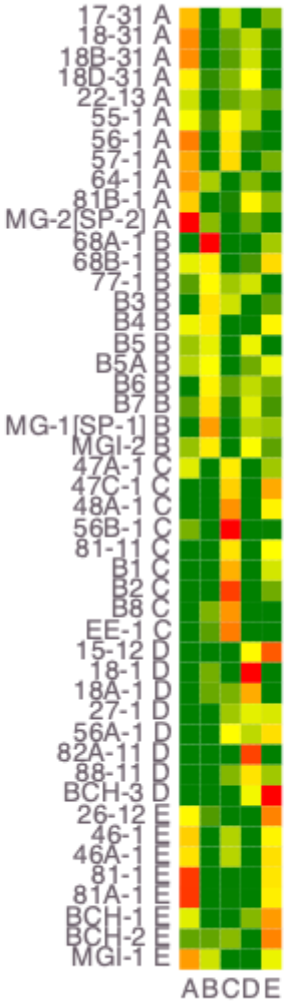

```
┌ Info: Number of signals: 5
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
┌ Info: Locations (signals=5)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
┌ Warning: type Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.F
loat64,Core.Int64} not present in workspace; reconstructing
└ @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
┌ Info: Robust k-means analysis results are loaded from file results-set0
0-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.F
loat64,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-set0
0-v9-inv-750-1000-daln/Wmatrix-5-5_14-1000.jld!
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
```

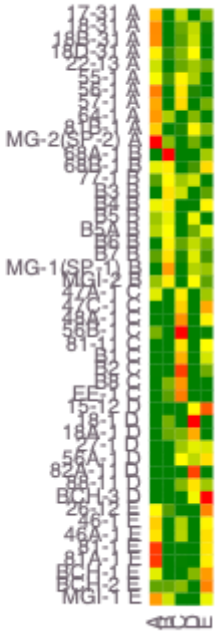
```
11×2 Array{Any,2}:
 "MG-2(SP-2)"  1.0
 "56-1"        0.833071
 "18-31"       0.803582
 "18B-31"      0.79762
 "64-1"        0.771609
 "57-1"        0.731212
 "17-31"       0.675958
 "81B-1"       0.638129
 "18D-31"      0.542359
 "55-1"        0.482608
 "22-13"       0.384279

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
```

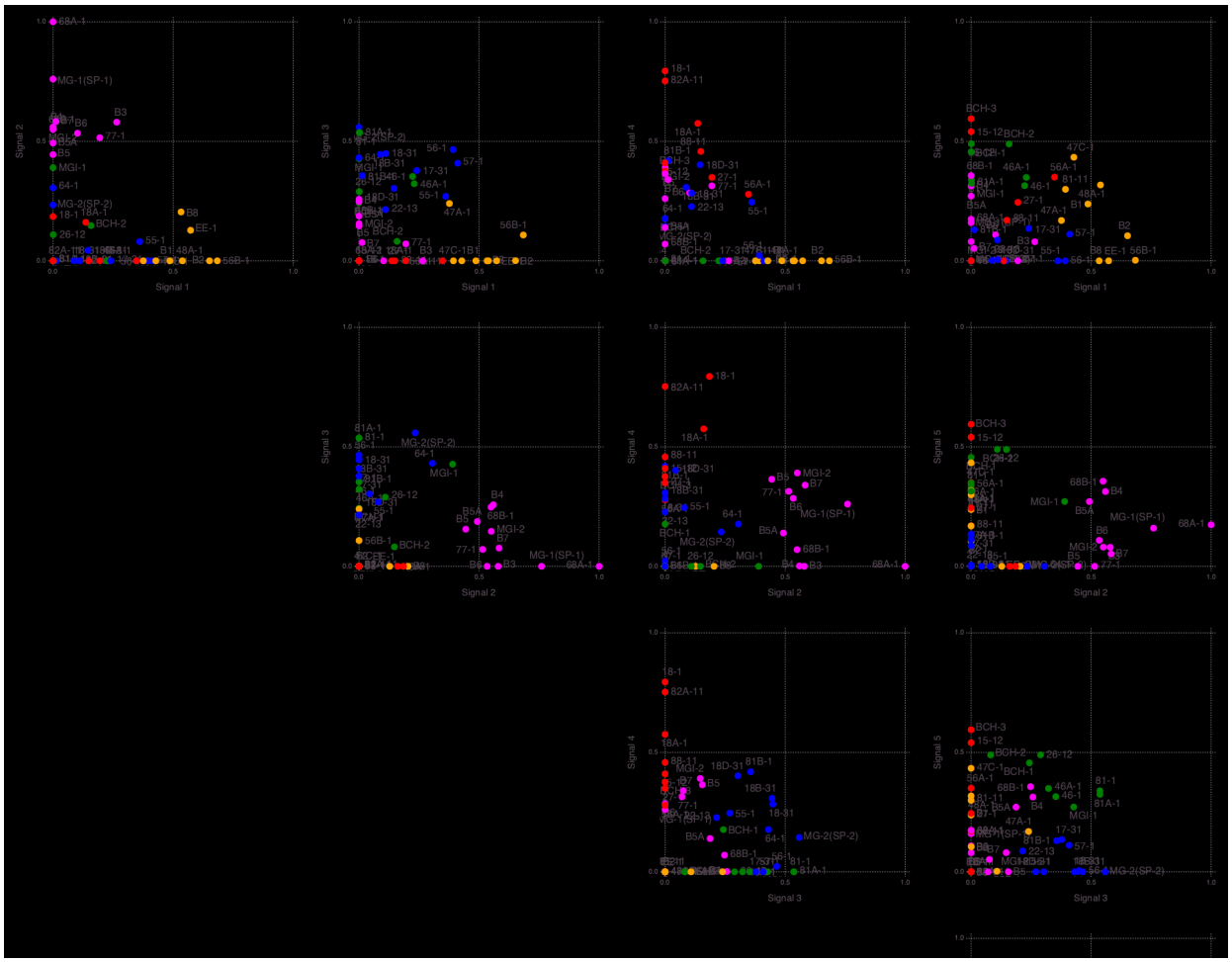


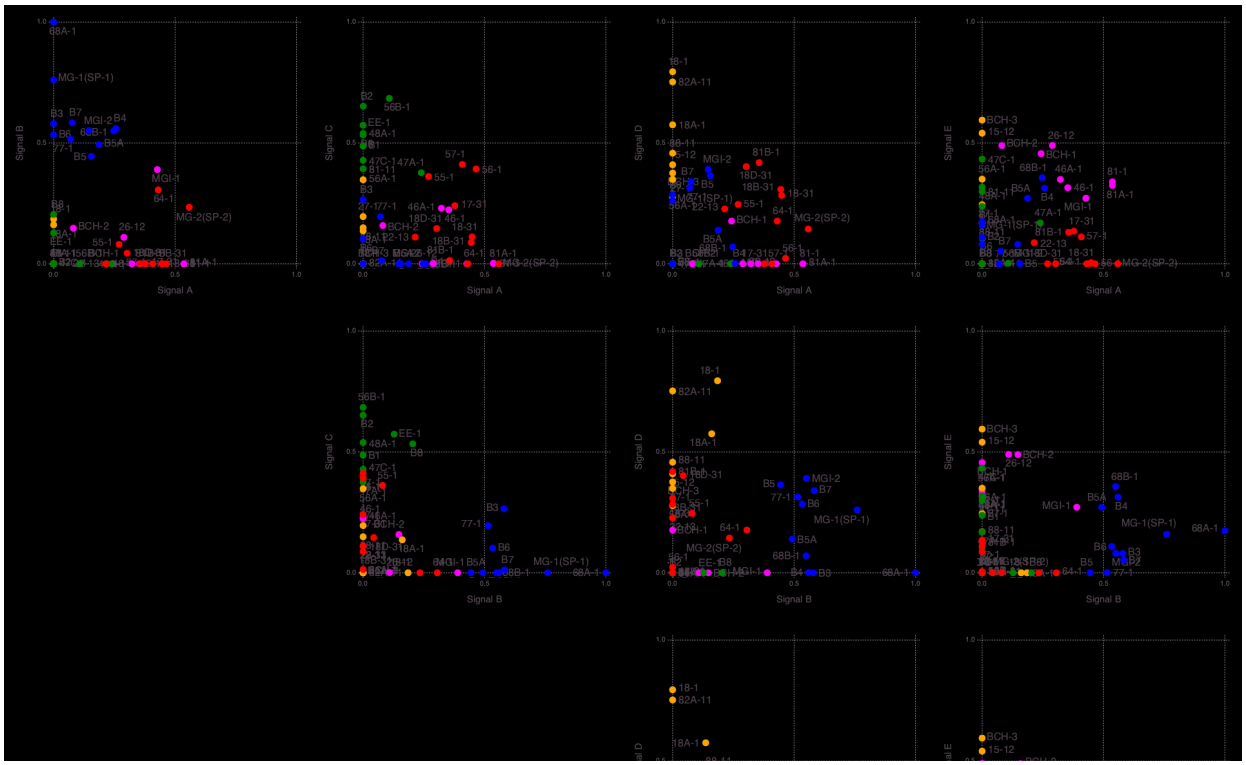

```
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ Warning: Procedure to 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
```

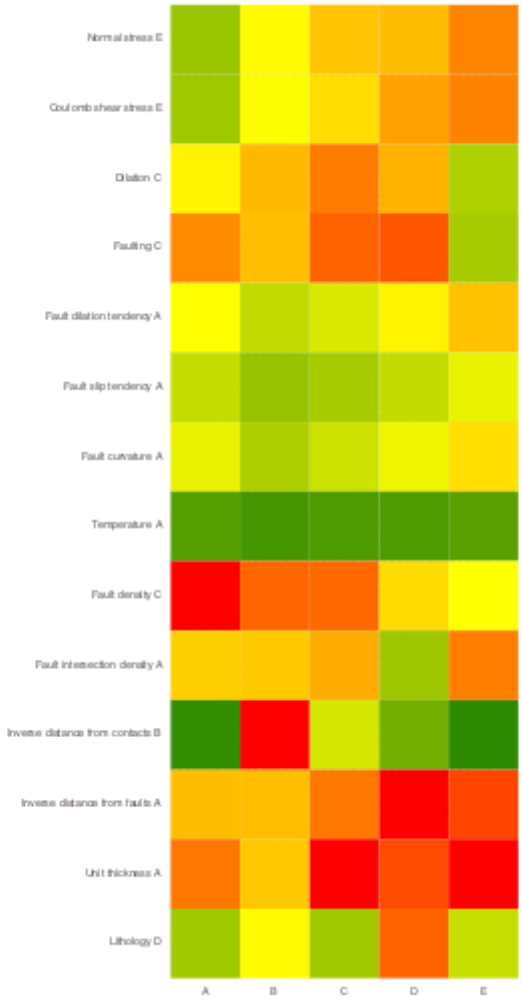



MG-2(SP-2) A
MG-1(SP-1) B
MGI-2 B
MGI-1 E


Signal 1
Signal 2
Signal 3
Signal 4
Signal 5

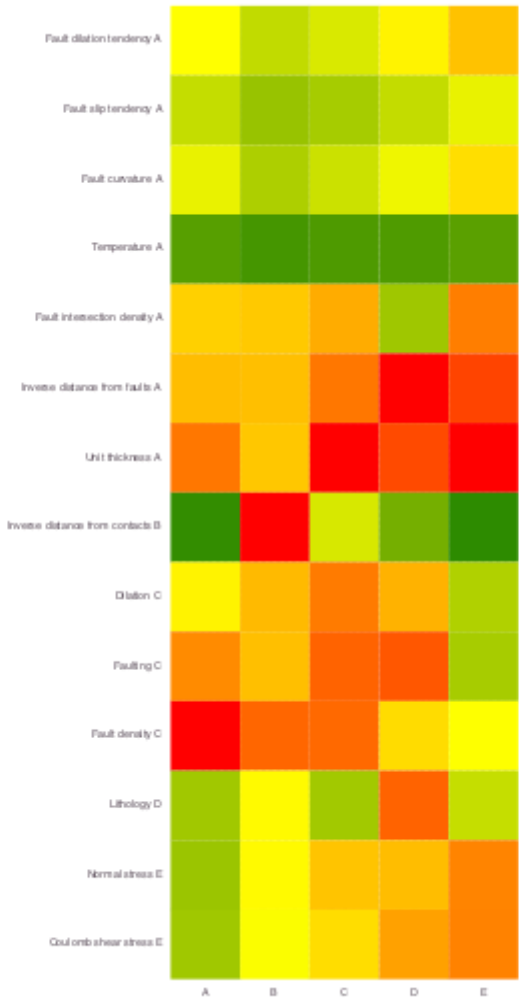


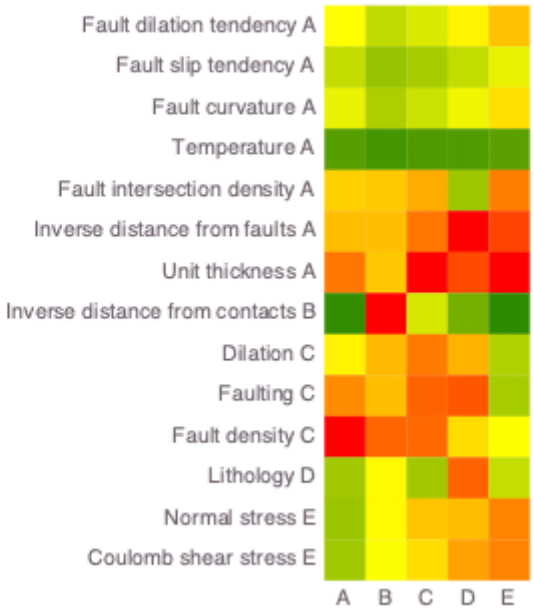

```
7×2 Array{Any,2}:
 "Unit thickness"                 0.849937
 "Inverse distance from faults"   0.680541
 "Fault intersection density"     0.629292
 "Fault dilation tendency"        0.501789
 "Fault curvature"                0.449738
 "Fault slip tendency"            0.365781
 "Temperature"      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

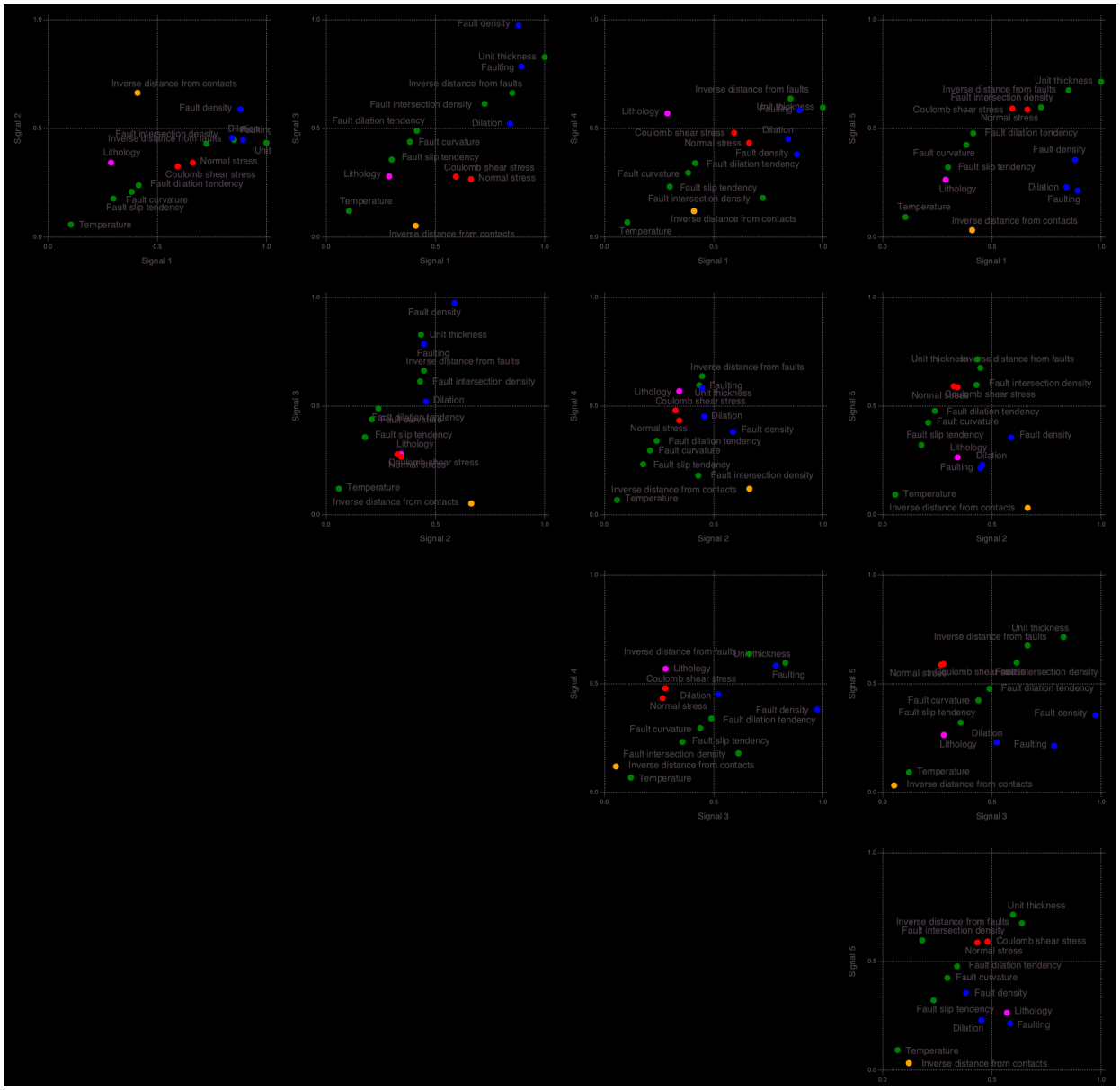


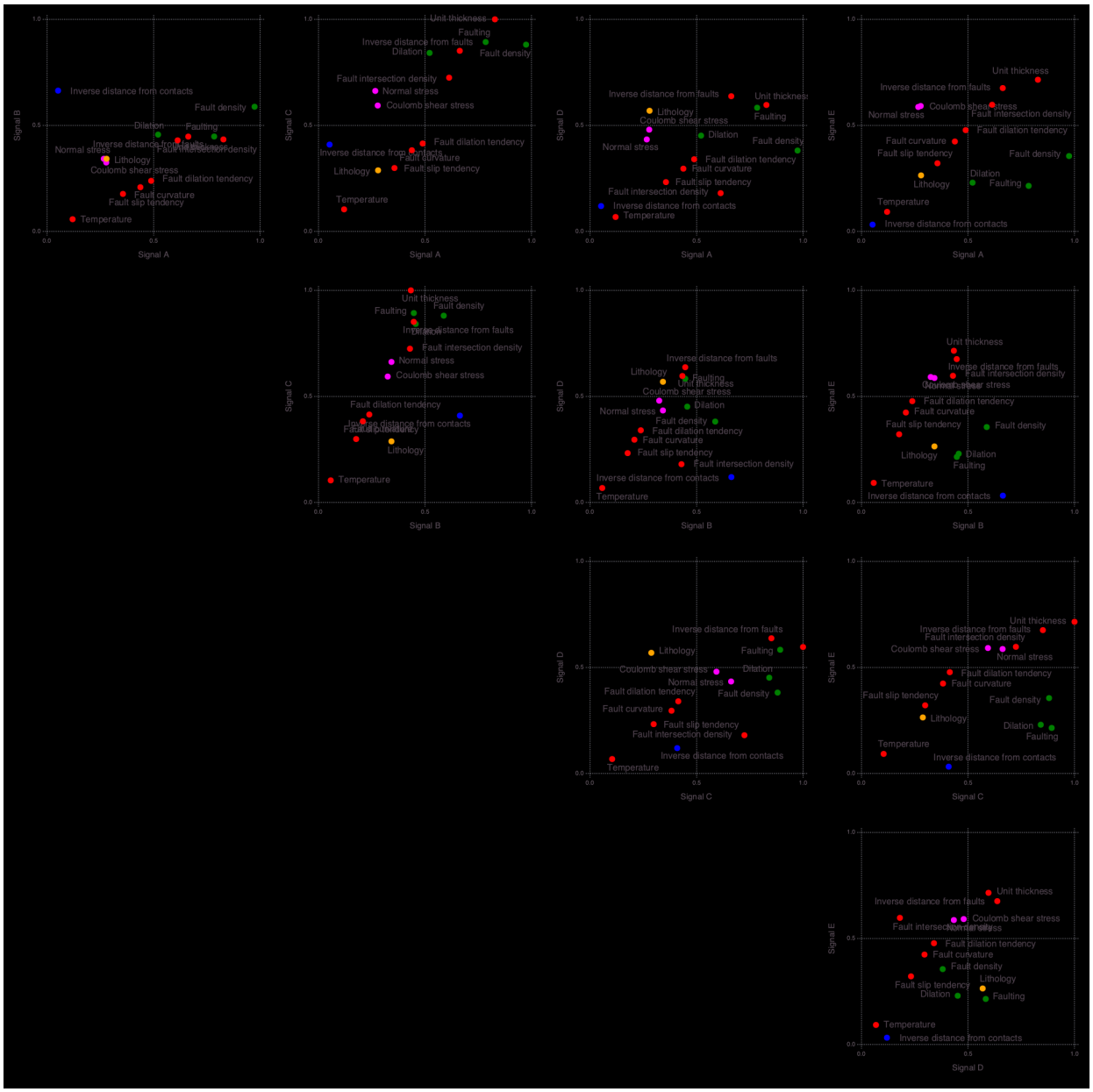

```
[ Info: Attributes (signals=5)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
[ Info: Signal A (S3) Count: 7
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal B (S1) Count: 3
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal 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
```

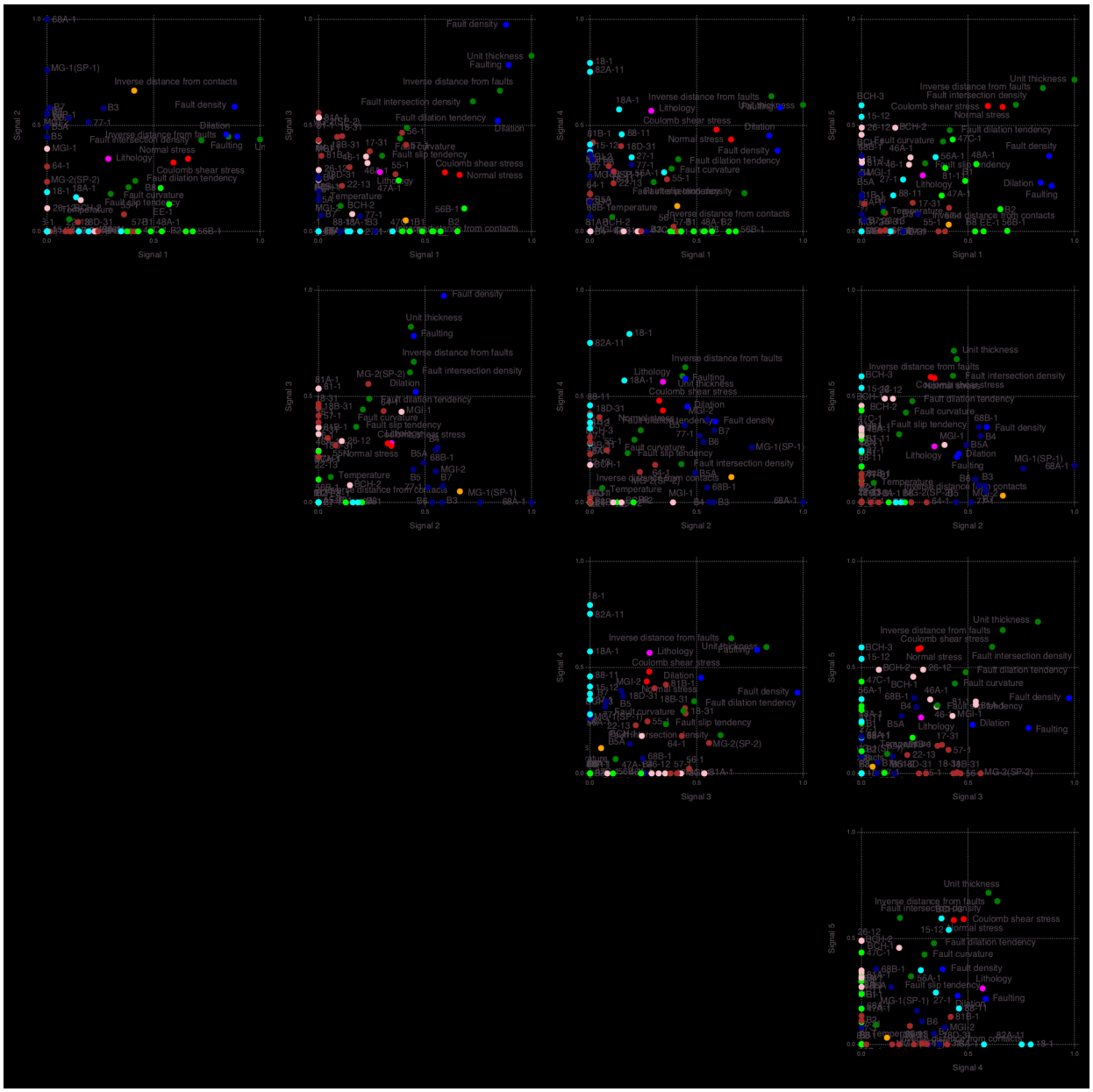
```
[ Info: Signal E (S4) Count: 1
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal A -> A Count: 7
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
[ Info: Signal D -> B Count: 1
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
[ Info: Signal 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
```



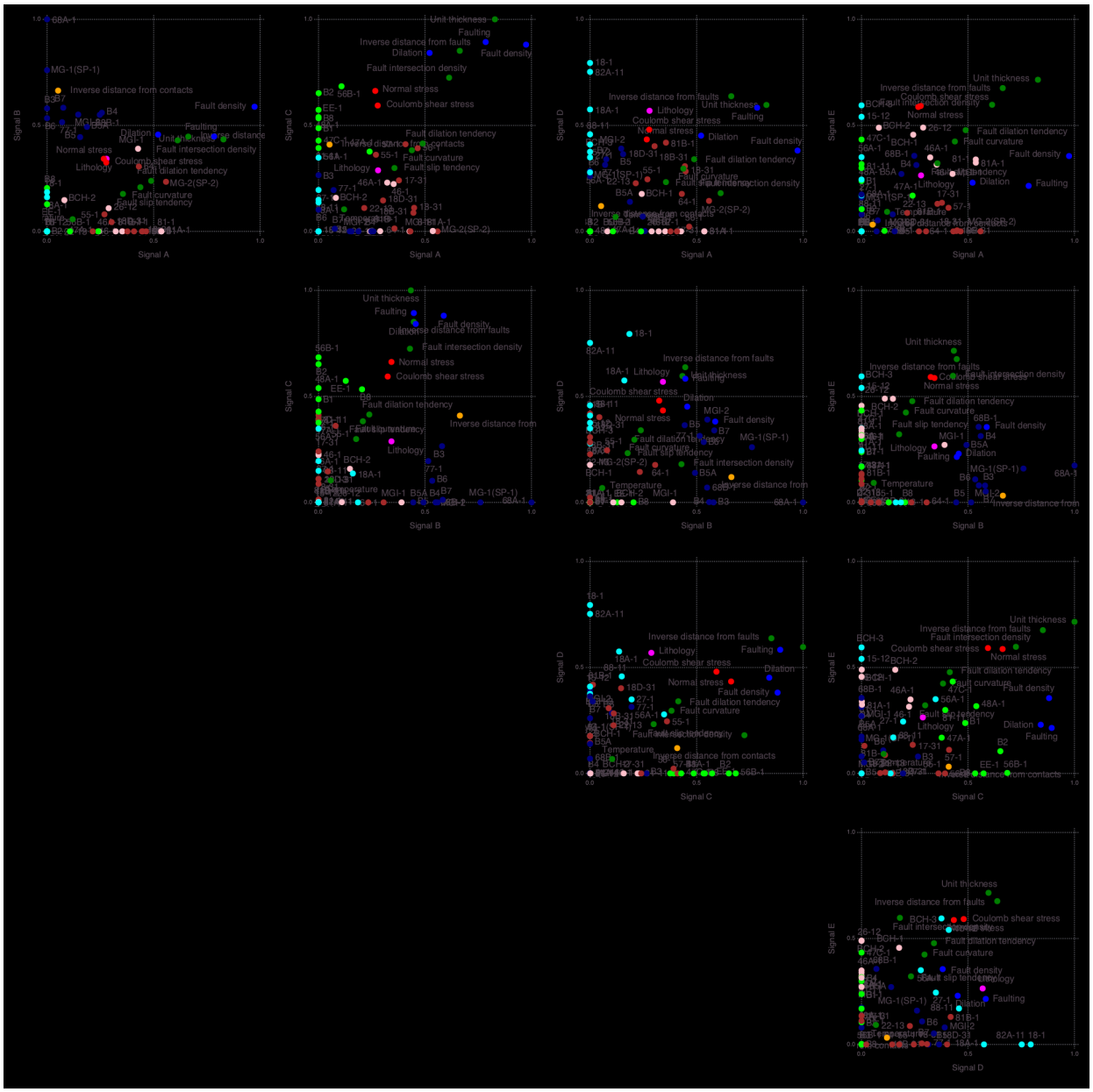

Fault dilation tendency A
Fault slip tendency A
Fault curvature A
Temperature A
Fault intersection density A
Inverse distance from faults A
Unit thickness A
Inverse distance from contacts B
Dilation C
Faulting C
Fault density C
Lithology D
Normal stress E
Coulomb shear stress E
A
B
C
D
E


Signal 1
Signal 2
Signal 3
Signal 4
Signal 5
Inverse distance from contacts
Fault density
Unit thickness
Faulting
Inverse distance from faults
Fault intersection density
Fault dilation tendency
Dilation
Fault curvature
Fault slip tendency
Coulomb shear stress
Normal stress
Lithology
Temperature


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



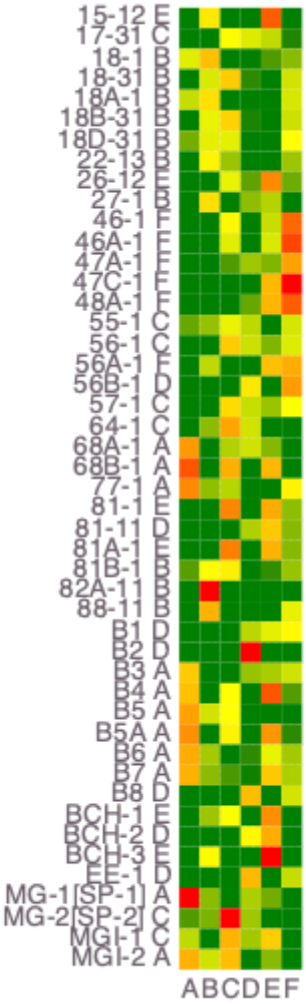

```
Signal importance (high->low): [1, 5, 2, 6, 4, 3]
```



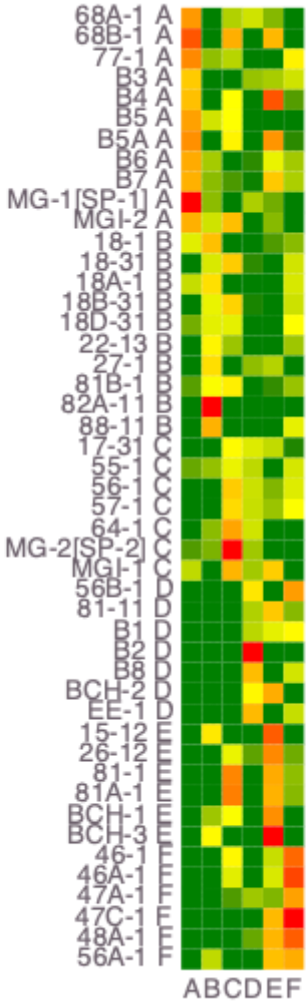

```
┌ Info: Number of signals: 6
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
┌ Info: Locations (signals=6)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
┌ Warning: type Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.F
loat64,Core.Int64} not present in workspace; reconstructing
└ @ JLD /Users/vvv/.julia/packages/JLD/nQ9iW/src/jld_types.jl:697
┌ Info: Robust k-means analysis results are loaded from file results-set0
0-v9-inv-750-1000-daln/Hmatrix-6-6_47-1000.jld!
└
```

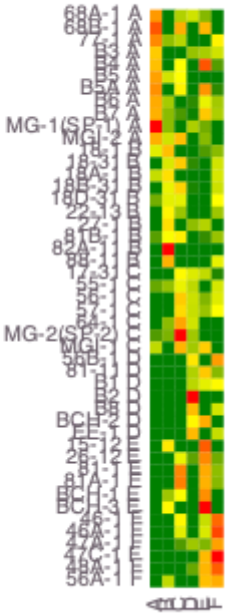
```
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ 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.F
loat64,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
```

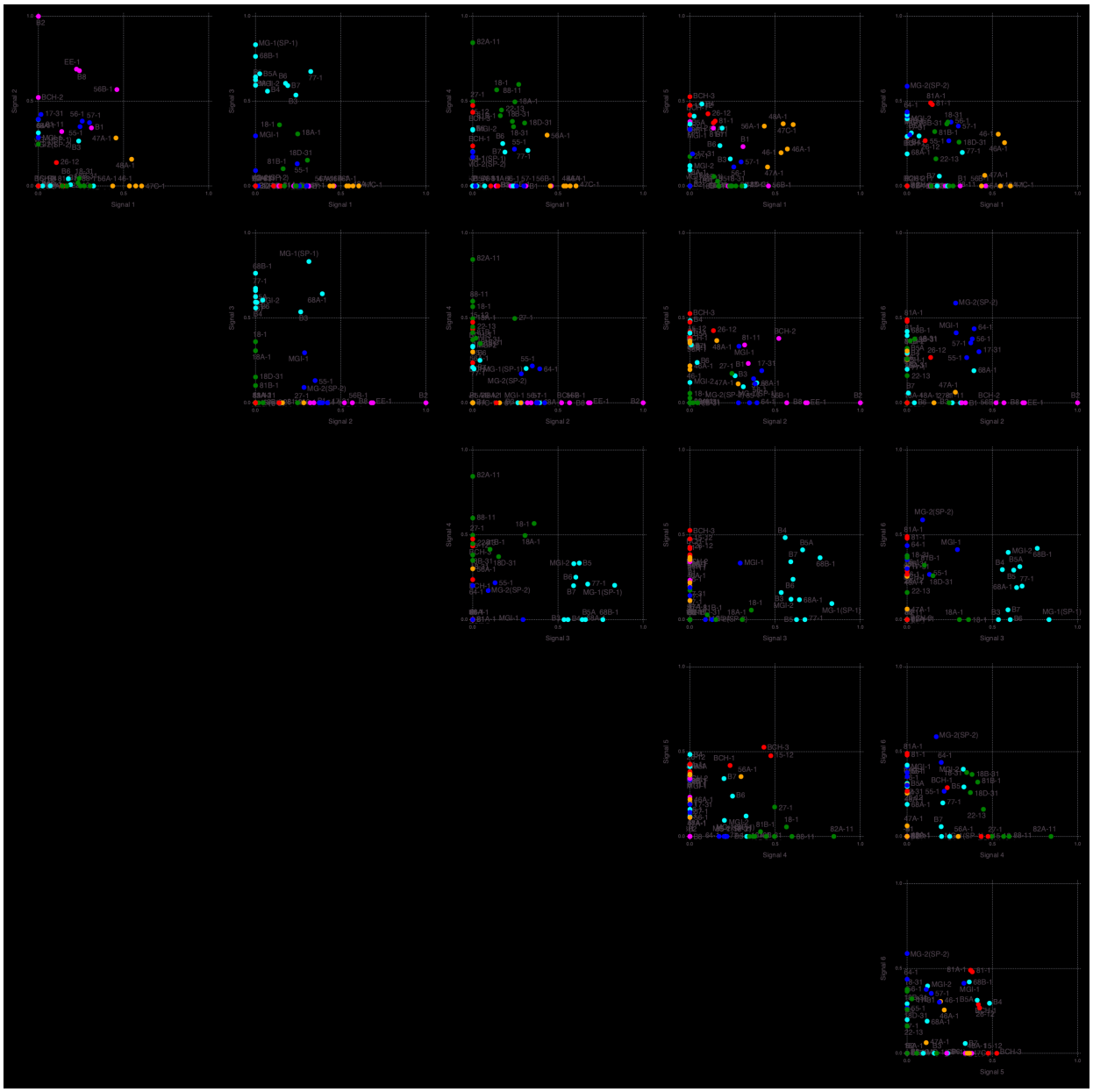
```
7×2 Array{Any,2}:
 "B2"      1.0
 "EE-1"    0.68867
 "B8"      0.679526
 "56B-1"   0.56822
 "BCH-2"   0.521776
 "B1"      0.342468
 "81-11"   0.320946

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
```

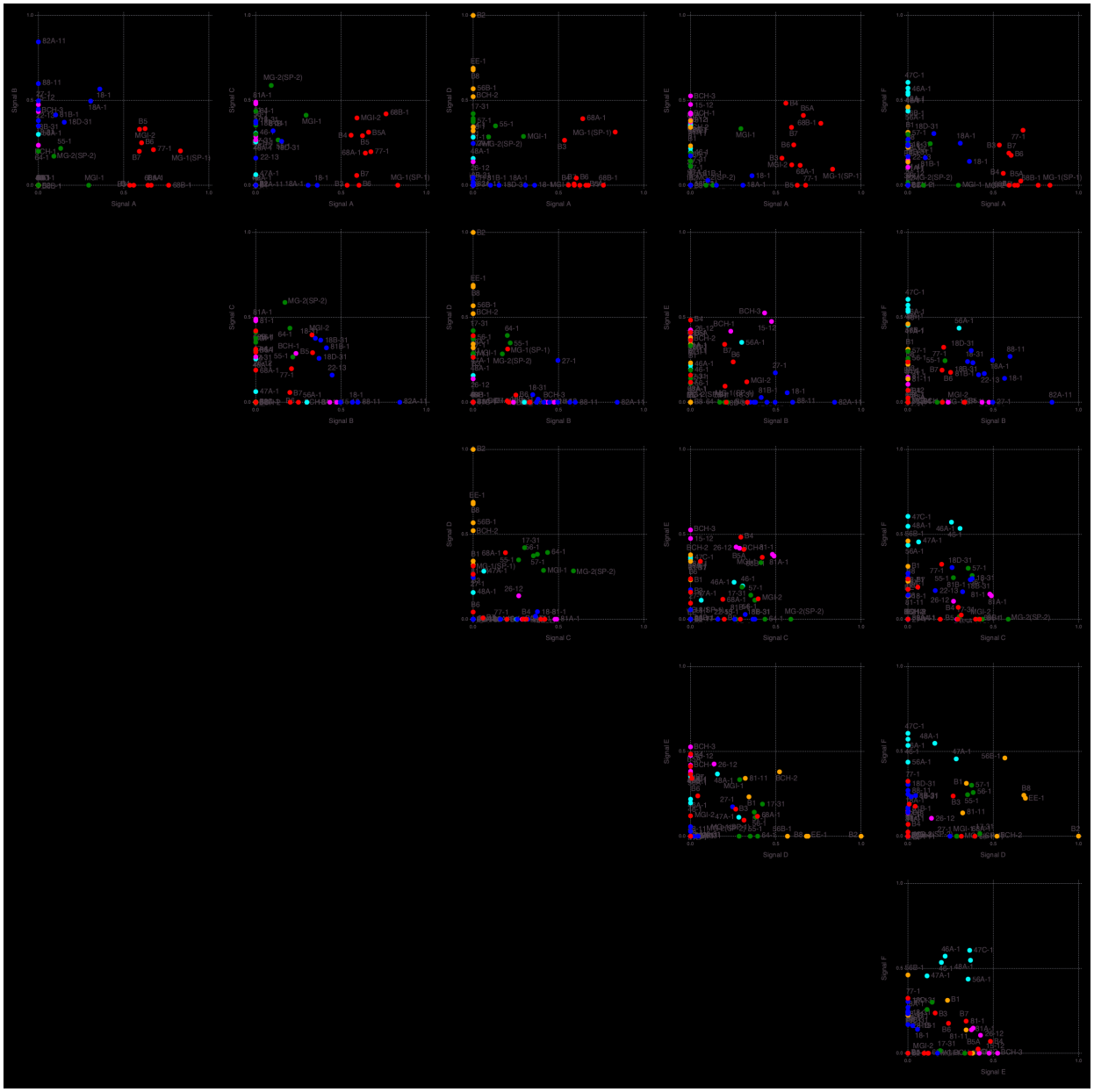


```
┌ Info: Robust k-means analysis results are loaded from file results-set0
0-v9-inv-750-1000-daln/Wmatrix-6-6_14-1000.jld!
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ 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
```

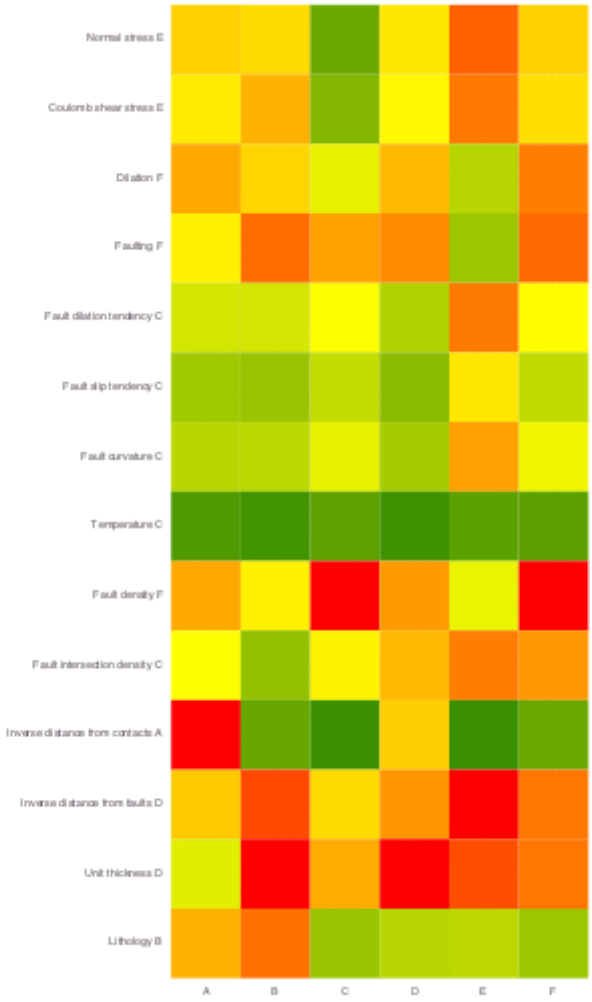

68A-1 A
68B-1 A
77-1 A
B3 A
B4 A
B5 A
B5A A
B6 A
B7 A
MG-1[SP-1] A
MGI-2 A
18-1 B
18-31 B
18A-1 B
18B-31 B
18D-31 B
22-13 B
27-1 B
81B-1 B
82A-11 B
88-11 B
17-31 C
55-1 C
56-1 C
57-1 C
64-1 C
MG-2[SP-2] C
MGI-1 C
56B-1 D
81-11 D
B1 D
B2 D
B8 D
BCH-2 D
EE-1 D
15-12 E
26-12 E
81-1 E
81A-1 E
BCH-1 E
BCH-3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





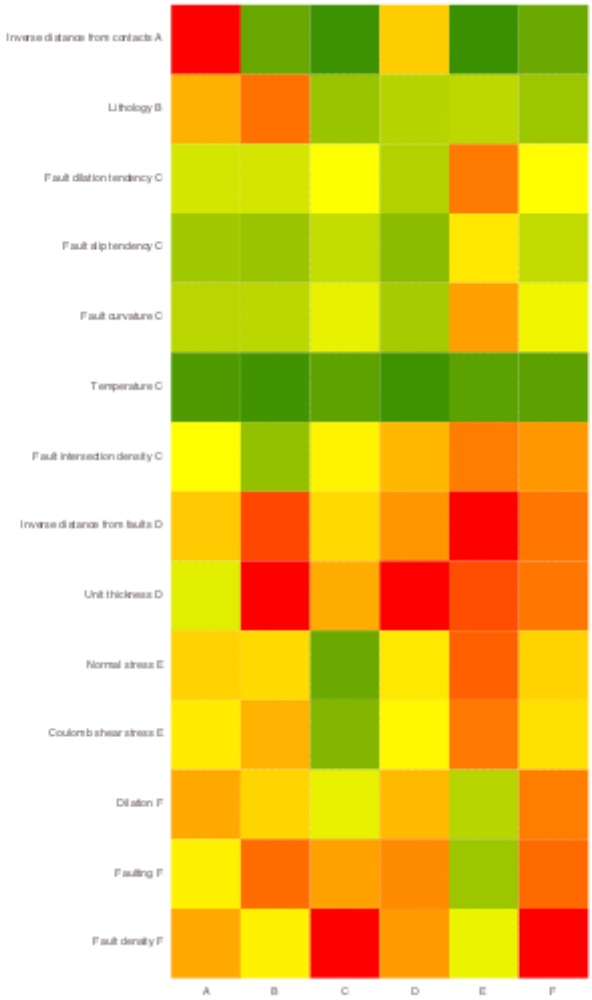


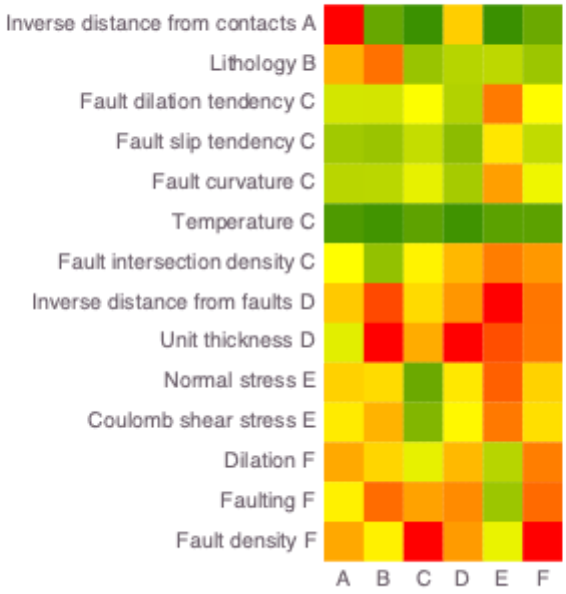
```
1×2 Array{Any,2}:
 "Inverse distance from contacts"  1.0

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
```

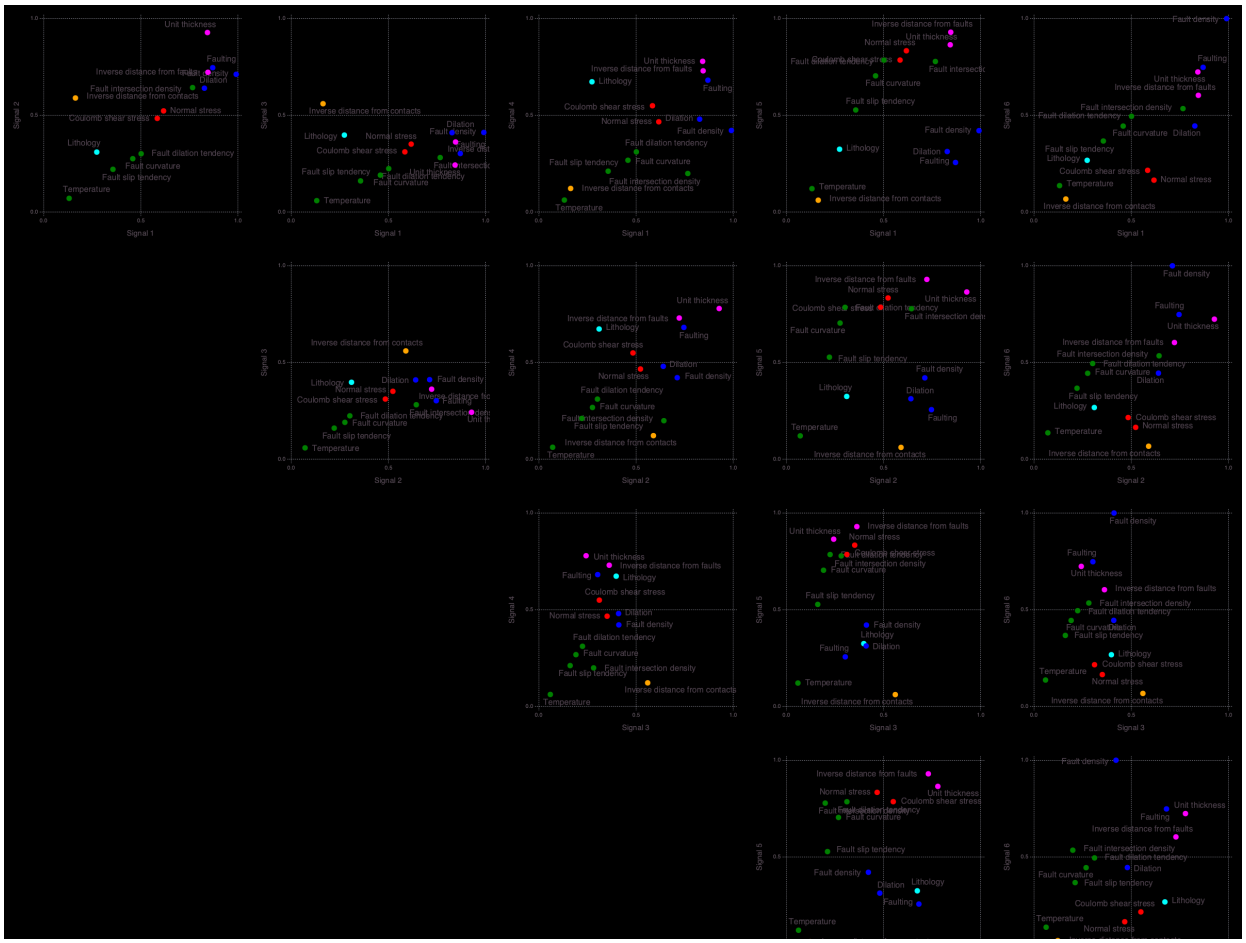


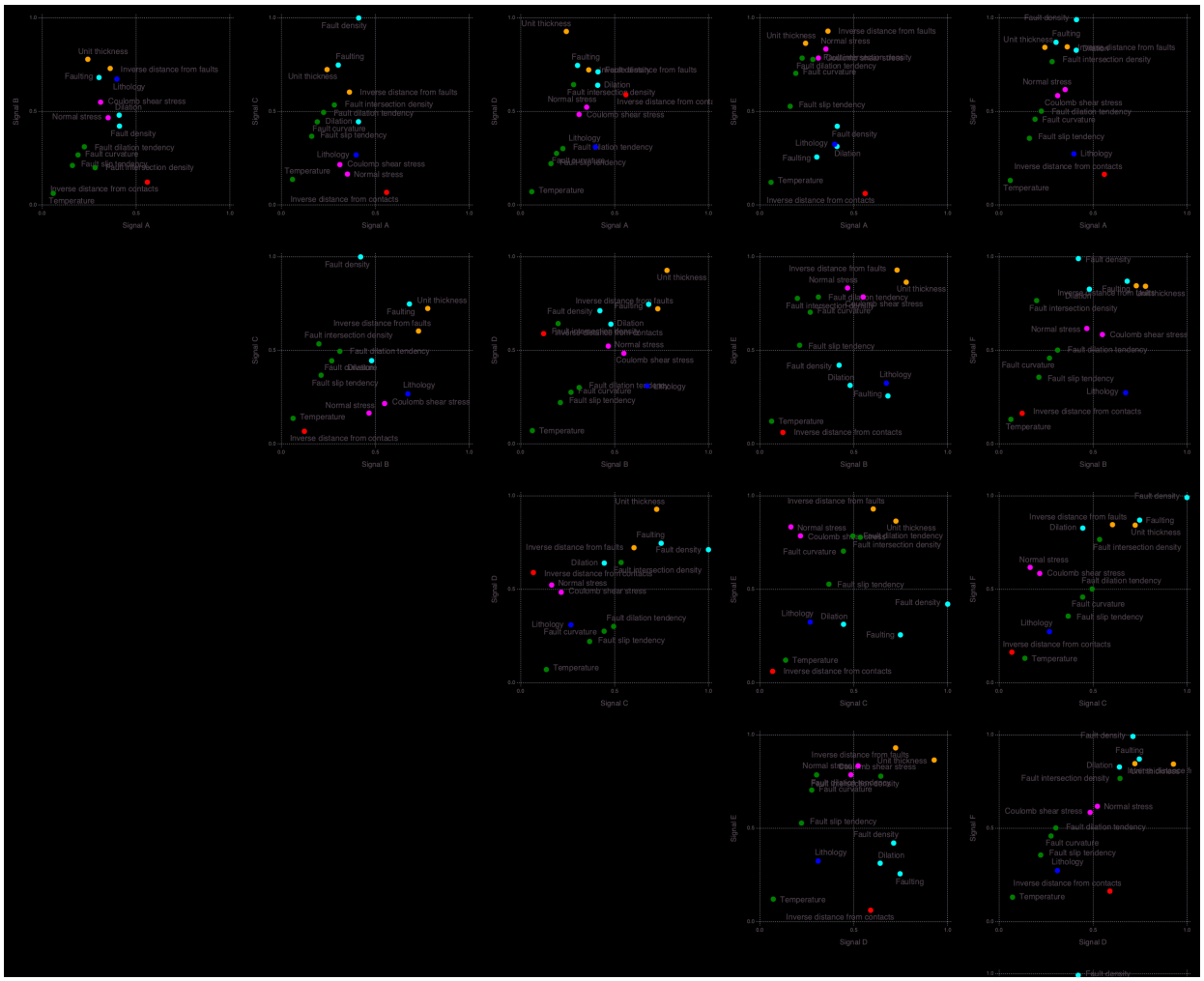

```
[ Info: Attributes (signals=6)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
[ Info: Signal A (S6) Count: 5
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal B (S1) Count: 3
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal 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
```

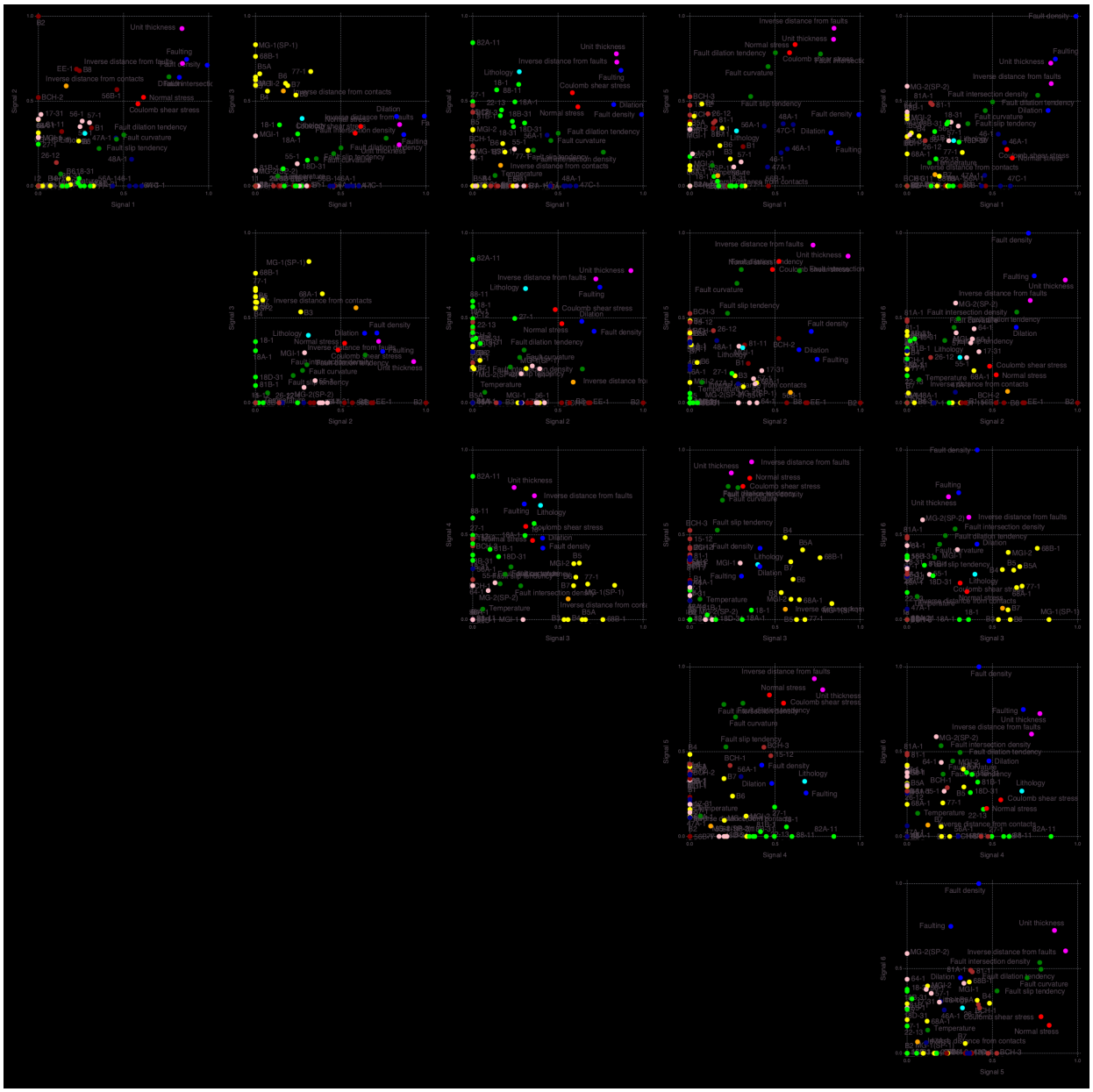
```
[ Info: Signal A -> C Count: 5
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
[ Info: Signal D -> D Count: 2
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
[ Info: Signal C -> E Count: 2
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:345
[ Info: Signal 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
```

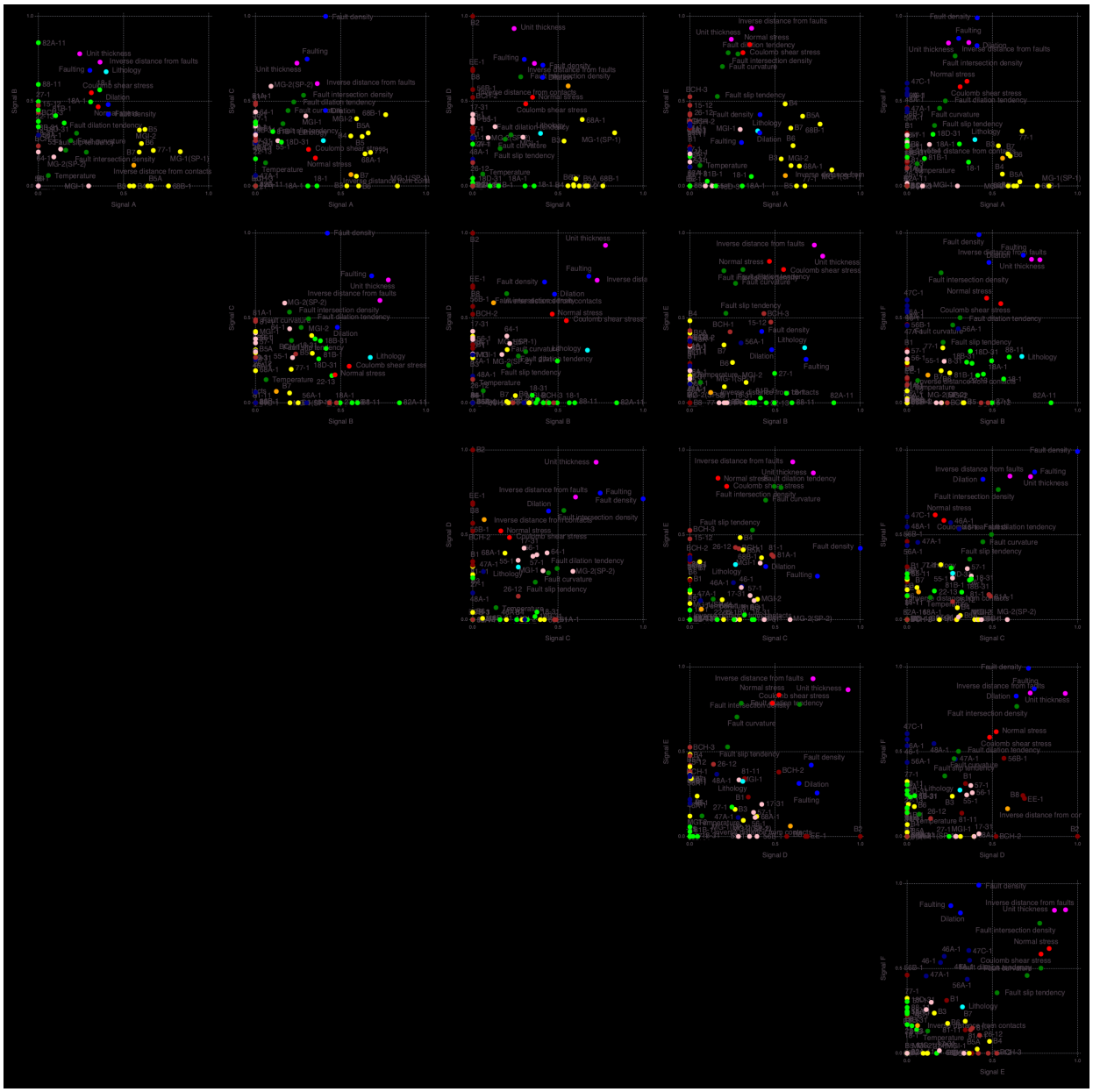



Inverse distance from contacts A
Lithology B
Fault dilation tendency C
Fault slip tendency C
Fault curvature C
Temperature C
Fault intersection density C
Inverse distance from faults D
Unit thickness D
Normal stress E
Coulomb shear stress E
Dilation F
Faulting F
Fault density F
A B C D E F


Unit thickness
Faulting
Inverse distance from faults
Fault density
Dilation
Fault intersection density
Inverse distance from contacts
Normal stress
Coulomb shear stress
Lithology
Fault dilation tendency
Fault curvature
Fault slip tendency
Temperature
Signal 1
Signal 2
Signal 3
Signal 4
Signal 5
Signal 6







Out[28]:
```
([[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']])
```

Type 2 flattening: focus on attributes

Flatten the tensor into a matrix

In [64]:
```
Xdlan = reshape(permutedims(Tn, (1,3,2)), ((depth * length(locations)), le
```

Matrix rows merge the depth and well locations dimensions.

Matrix cols represent the well attributes.

Perform NMFk analyses

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

In [65]:
```
W, H, fitquality, robustness, aic = NMFk.execute(Xdlan, nkrange, nruns; res
W, H, fitquality, robustness, aic = NMFk.load(nkrange, nruns; resultdir=res
```

```
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
```

As seen from the output the ML 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 accetable solutions are defined as follows:

In [66]:
```
NMFk.getks(nkrange, robustness[nkrange])
```

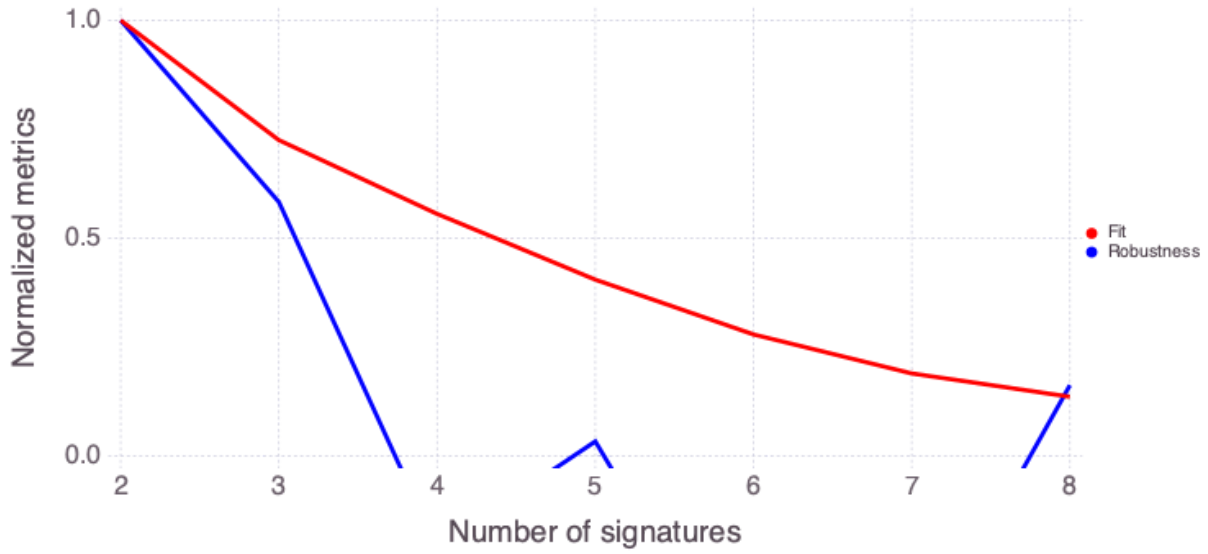
Out[66]:
```
2-element Array{Int64,1}:
 2
 3
```

The accceptable solutions contain 2 and 3 signatures.

Post-process NMFk results

Plot representing solution quality (fit) and silhouette width (robustness) for different number of sigantures `k` :

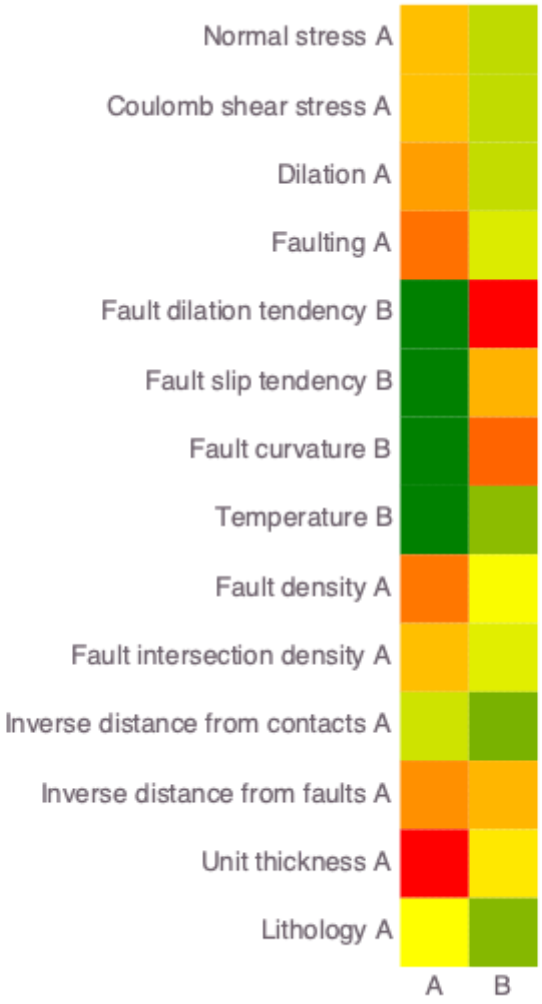
In [68]:
```
NMFk.plot_signal_selecton(nkrange, fitquality, robustness; figuredir="$figu
```



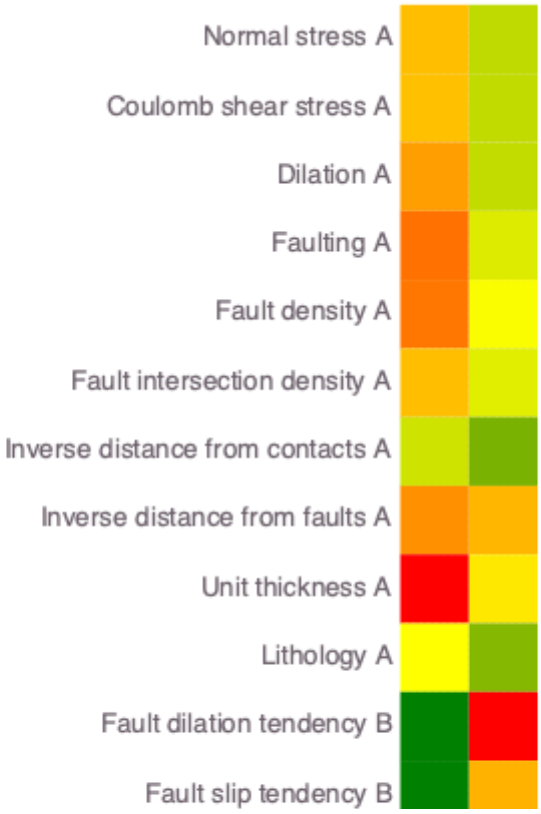
The ML solutions containing 2 and 3 signatures are further analyzed as follows:

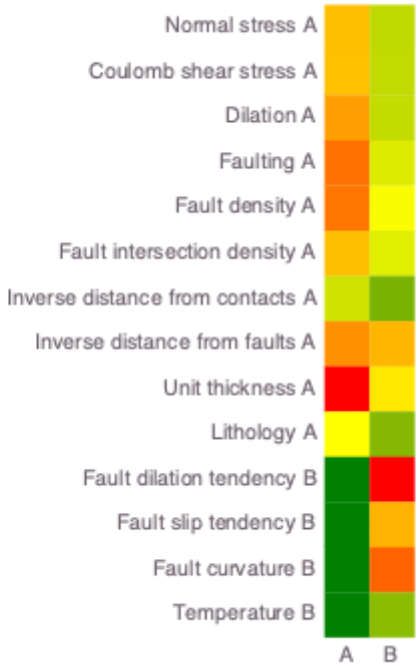
In [69]:
```
NMFk.clusterresults(NMFk.getks(nkrange, robustness[nkrange]), W, H, locatio
```

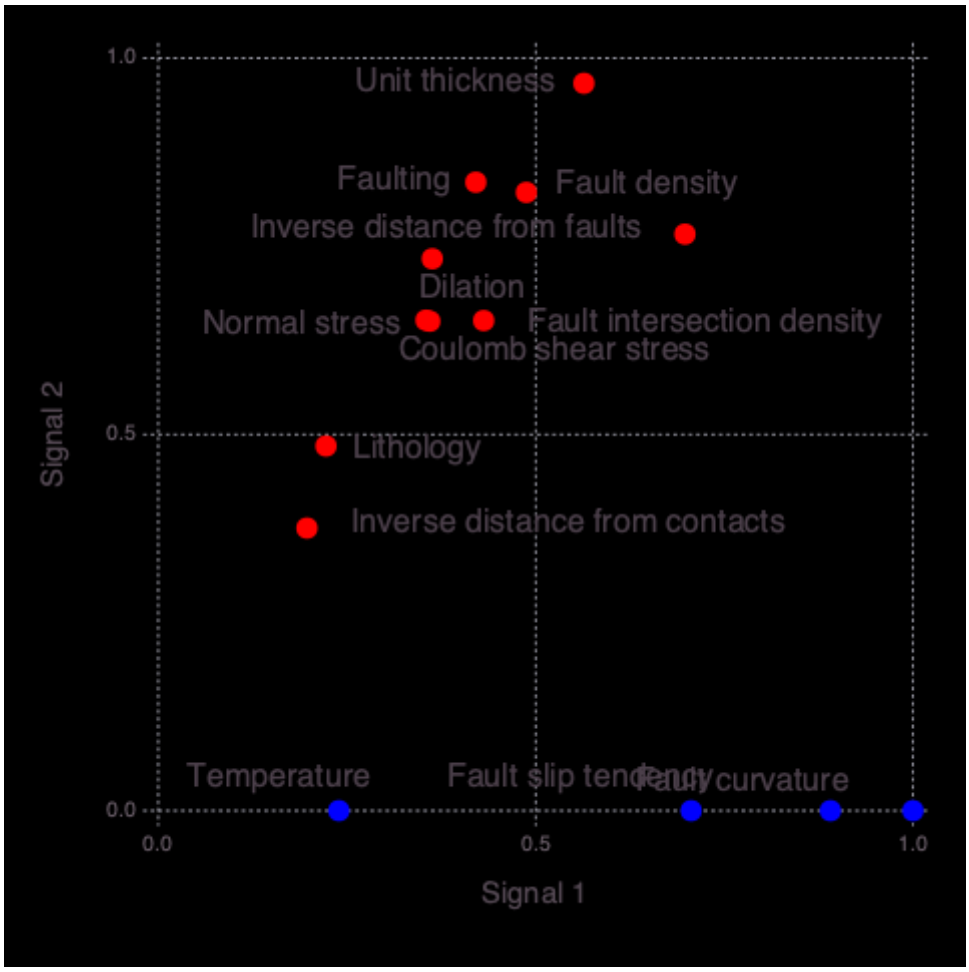
```
Signal importance (high->low): [2, 1]
┌ Info: Number of signals: 2
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
┌ Info: Attributes (signals=2)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
┌ Warning: type Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.F
loat64,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-set0
0-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.F
loat64,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
```

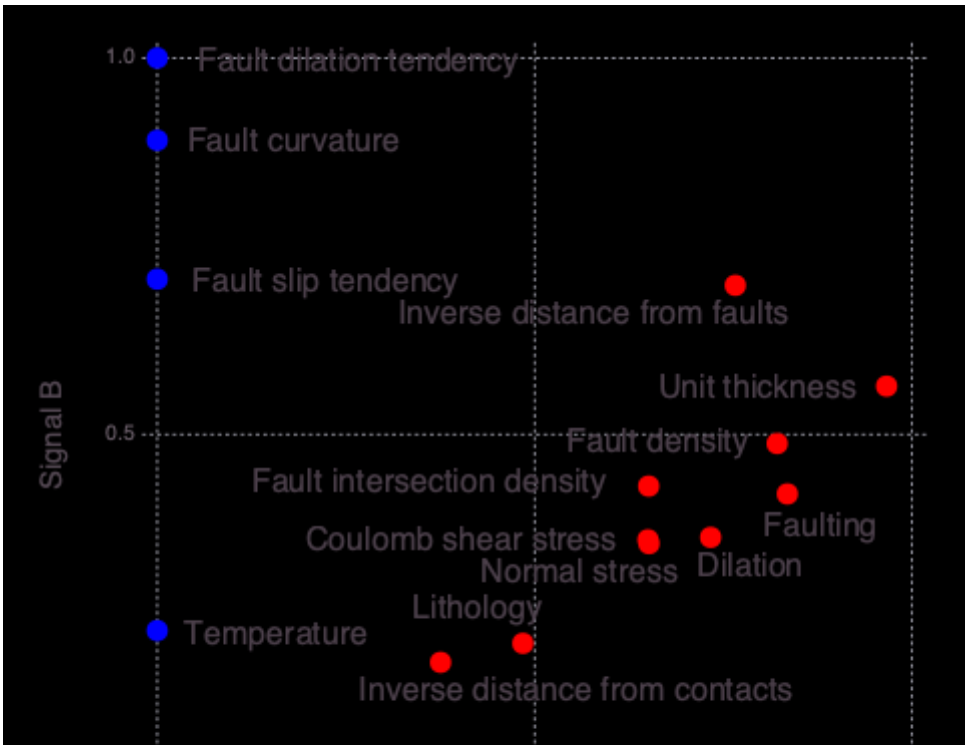



```
┌ Info: Robust k-means analysis results are loaded from file results-set0
0-v9-inv-750-1000-dlan/Wmatrix-2-2_47-1000.jld!
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:67
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ 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


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
1.0
0.5
0.0
Signal 2
0.0
0.5
1.0
Signal 1

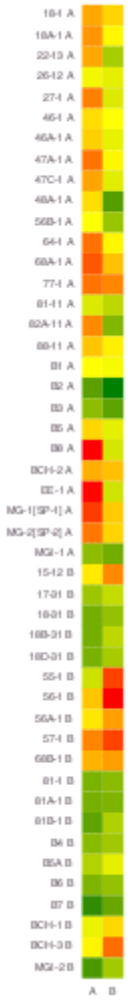


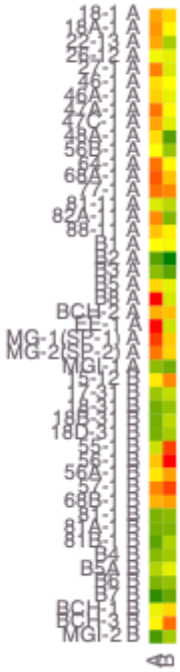

```
27×2 Array{Any,2}:
 "B8"           1.0
 "EE-1"         0.998613
 "MG-1(SP-1)"   0.956943
 "68A-1"        0.916159
 "64-1"         0.864026
 "47A-1"        0.859446
 "77-1"         0.857345
 "MG-2(SP-2)"   0.853707
 "27-1"         0.829554
 "82A-11"       0.807563
 "18A-1"        0.782265
 "47C-1"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

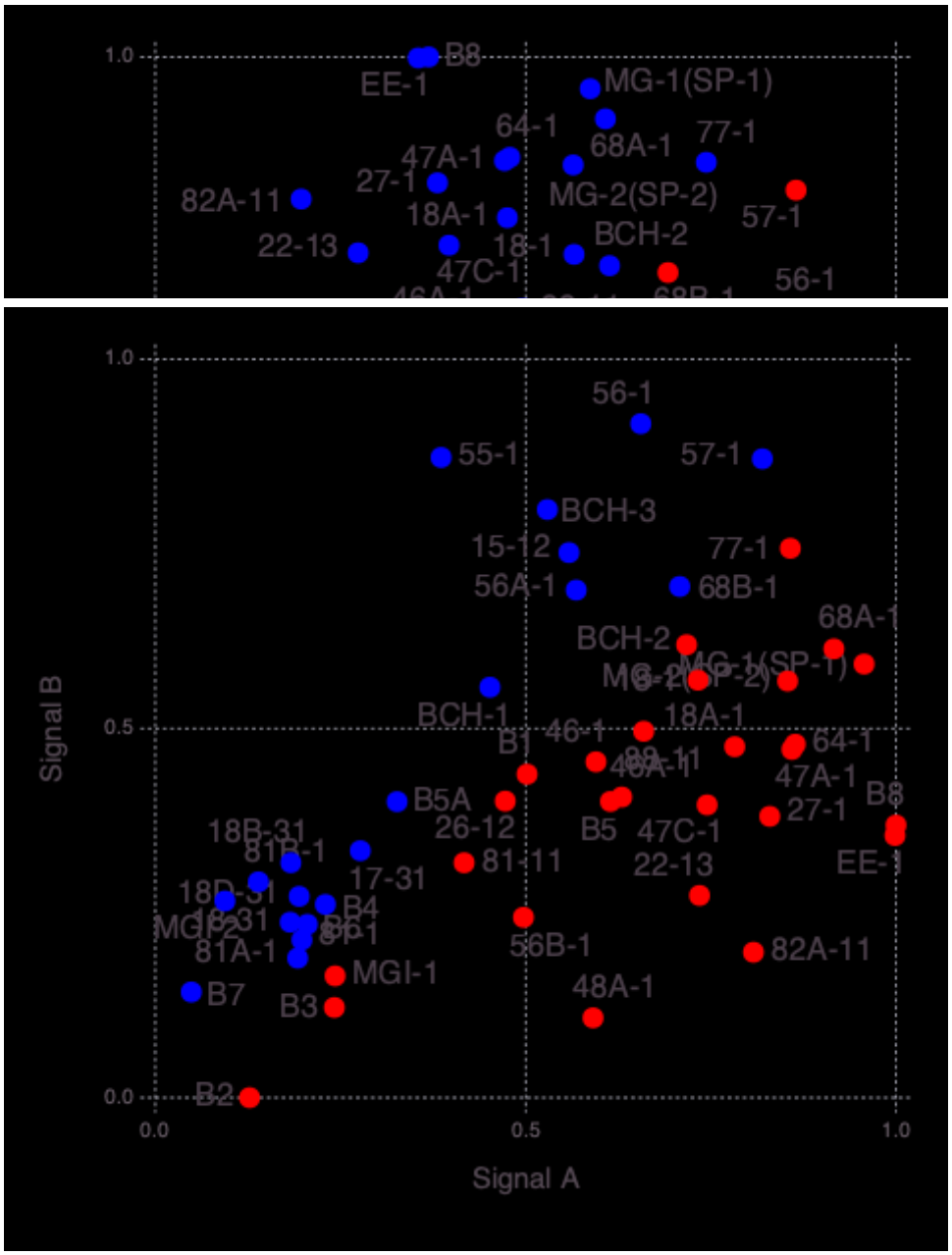
```
20×2 Array{Any,2}:
 "56-1"    1.0
 "55-1"    0.949937
 "57-1"    0.947965
 "BCH-3"   0.872622
 "15-12"   0.808709
 "68B-1"   0.758469
```

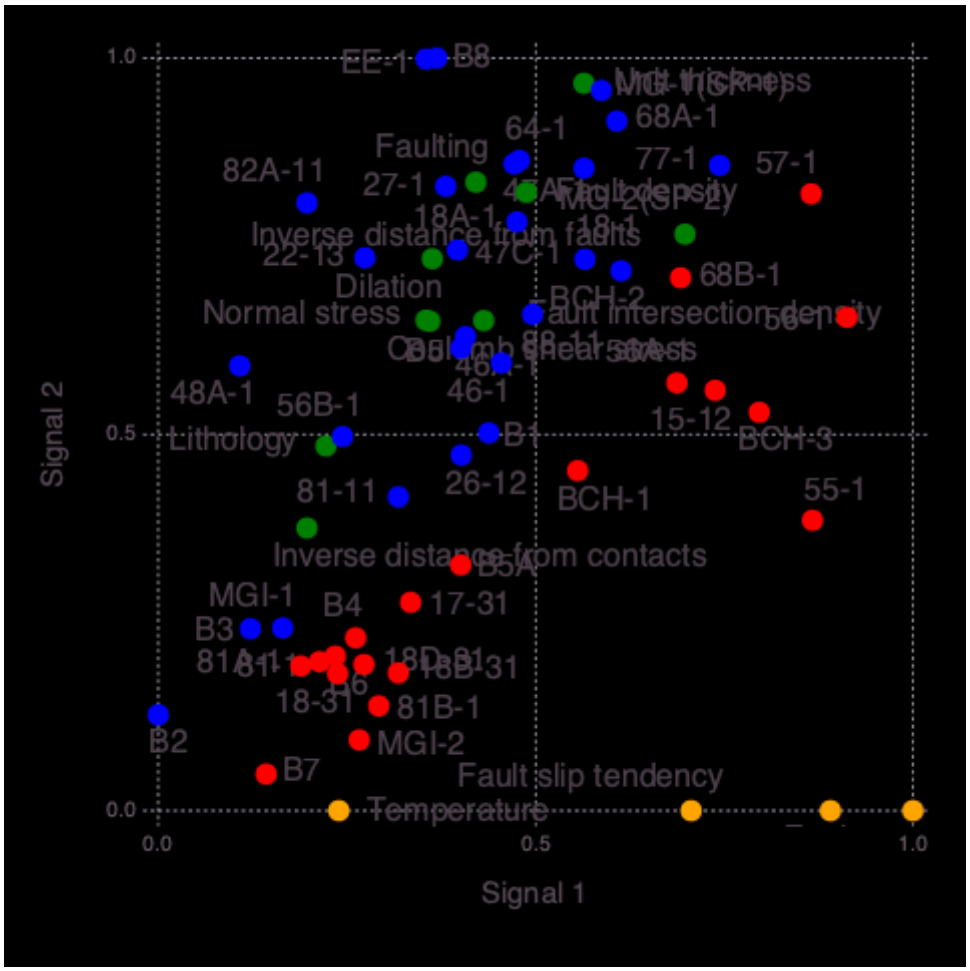
```
"56A-1"   0.753147
"BCH-1"   0.608981
"B5A"     0.43926
"17-31"   0.366493
"18B-31"  0.348668
"81B-1"   0.320223
"18D-31"  0.298697
"MGI-2"   0.291839
"B4"      0.286734
"18-31"   0.260379
"B6"      0.257226
"81-1"    0.234119
"81A-1"   0.207054
"B7"      0.156777
```

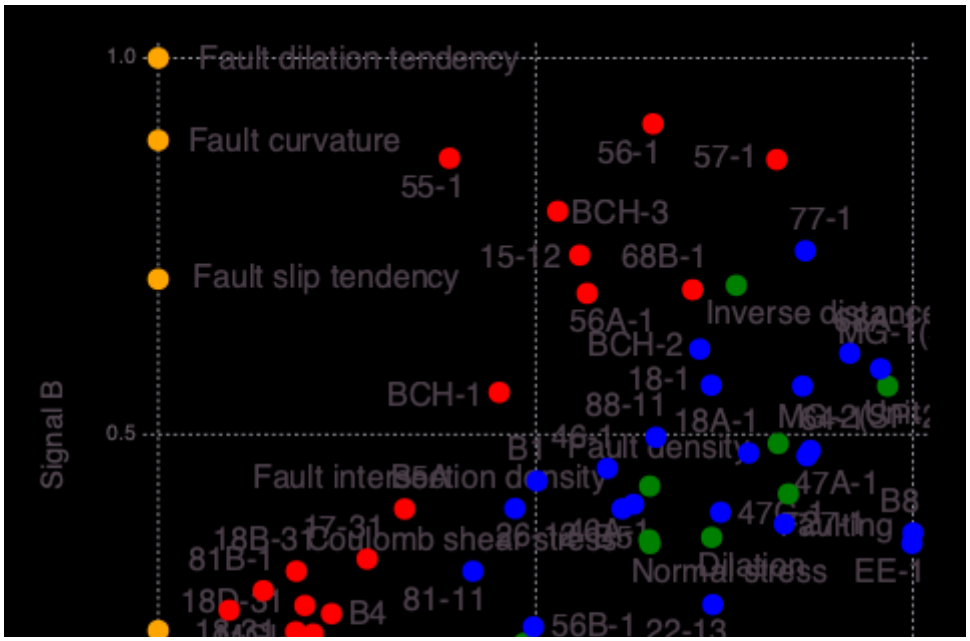
```
[ Info: Locations (signals=2)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
[ Info: Signal A (S2) Count: 27
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal B (S1) Count: 20
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
[ Info: Signal 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
```




18-1 A
18A-1 A
22-13 A
26-12 A
27-1 A
46-1 A
46A-1 A
47A-1 A
47C-1 A
48A-1 A
56B-1 A
64-1 A
68A-1 A
77-1 A
81-1 A
82A-1 A
88-1 A
B1 A
B2 A
B3 A
B5 A
B8 A
BCH-2 A
EE-1 A
MG-1(SP-1) A
MG-2(SP-2) A
MGI-1 A
15-12 B
17-31 B
18-31 B
18B-31 B
18D-31 B
55-1 B
56-1 B
56A-1 B
57-1 B
68B-1 B
81-1 B
81A-1 B
81E-1 B
B4 B
B5A B
B6 B
B7 B
BCH-1 B
BCH-3 B
MGI-2 B
<40

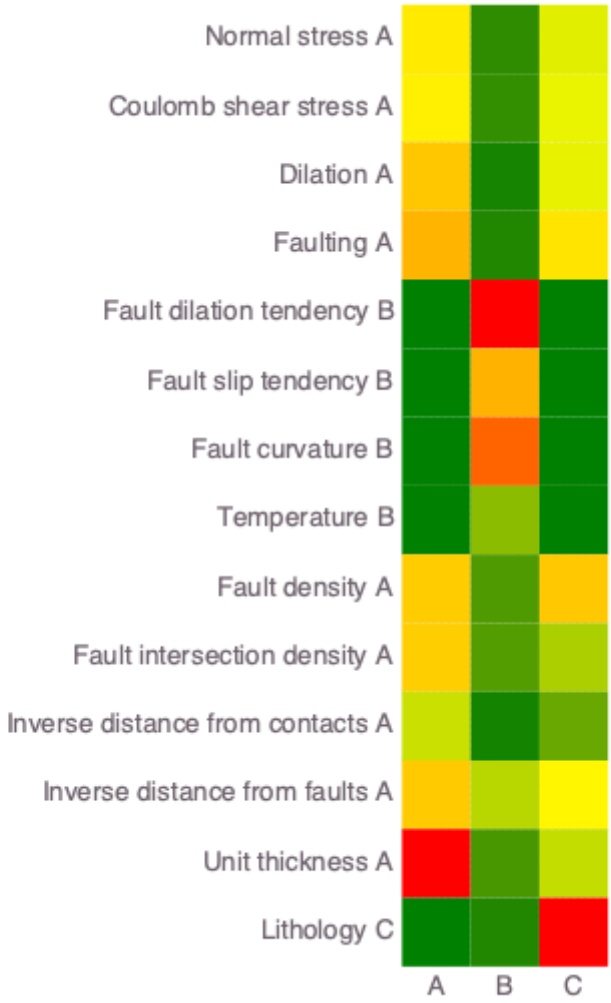

1.0
B8
EE-1
MG-1(SP-1)
64-1
68A-1
77-1
47A-1
27-1
82A-11
MG-2(SP-2)
57-1
18A-1
22-13
18-1
BCH-2
47C-1
56-1
1.0
56-1
55-1
57-1
BCH-3
15-12
77-1
56A-1
68B-1
68A-1
BCH-2
MG-1(SP-1)
BCH-1
18A-1
64-1
47A-1
B8
B5A
27-1
26-12
B5
47C-1
18B-31
81B-1
81-11
22-13
EE-1
17-31
B4
82A-11
81A-1
MGI-1
56B-1
B7
B3
48A-1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


1.0
0.5
0.0
0.0
0.5
1.0
Signal 2
Signal 1
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
BCH-2
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
18B-31
18-31
81B-1
B2
MGI-2
B7
Fault slip tendency
Temperature



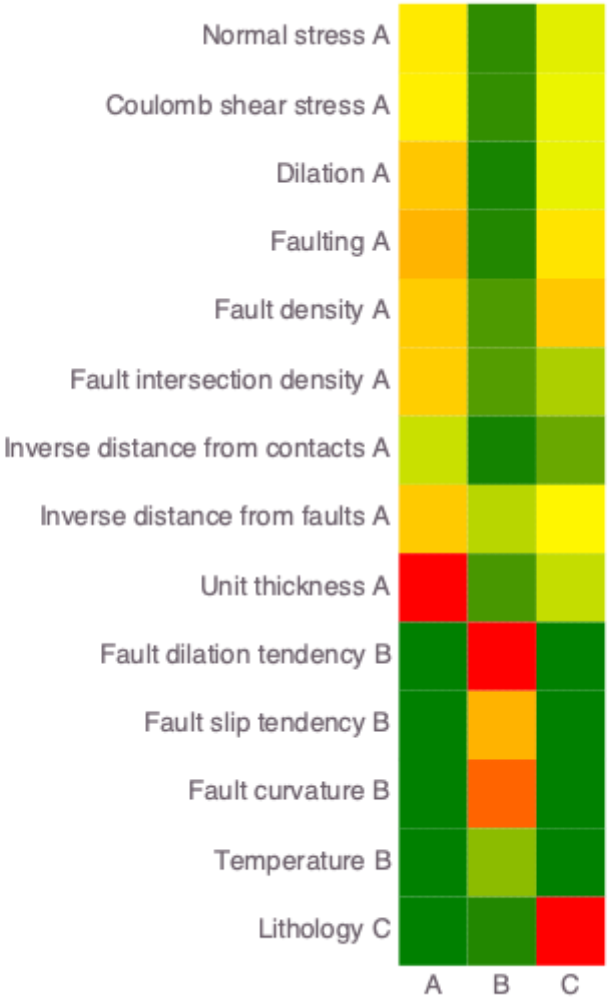

```
Signal importance (high->low): [3, 1, 2]
┌ Info: Number of signals: 3
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:144
┌ Info: Attributes (signals=3)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:148
┌ Warning: type Clustering.KmeansResult{Core.Array{Core.Float64,2},Core.F
loat64,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-set0
0-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.F
loat64,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-set0
0-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
```

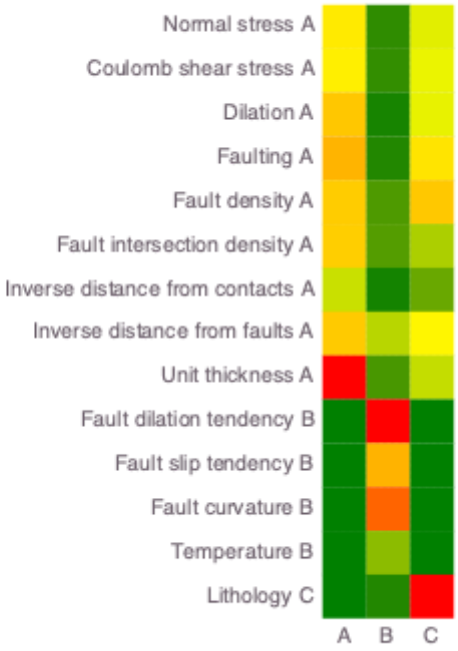
```
4×2 Array{Any,2}:
 "Fault dilation tendency"  1.0
 "Fault curvature"          0.89069
 "Fault slip tendency"      0.706146
 "Temperature"              0.239306

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

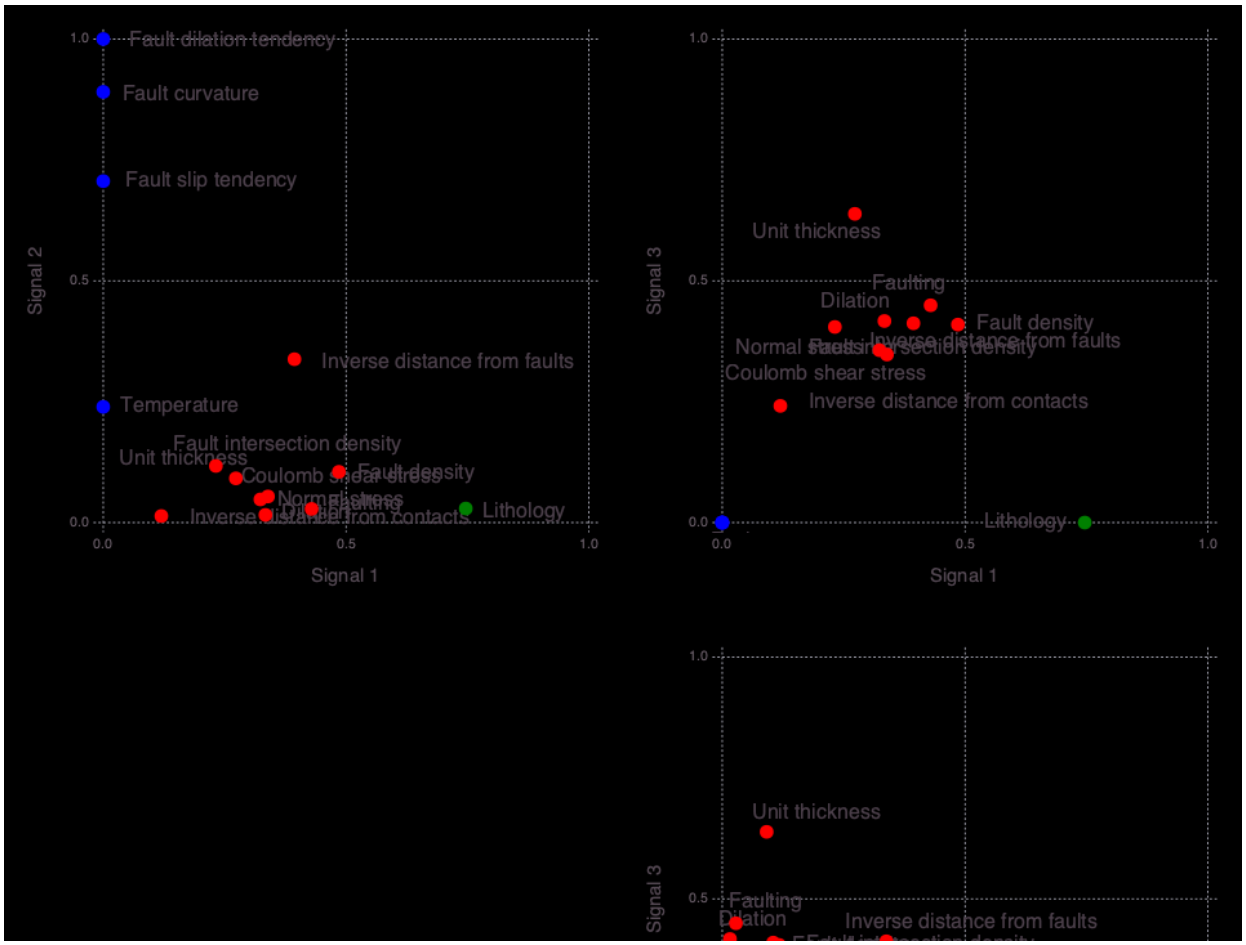


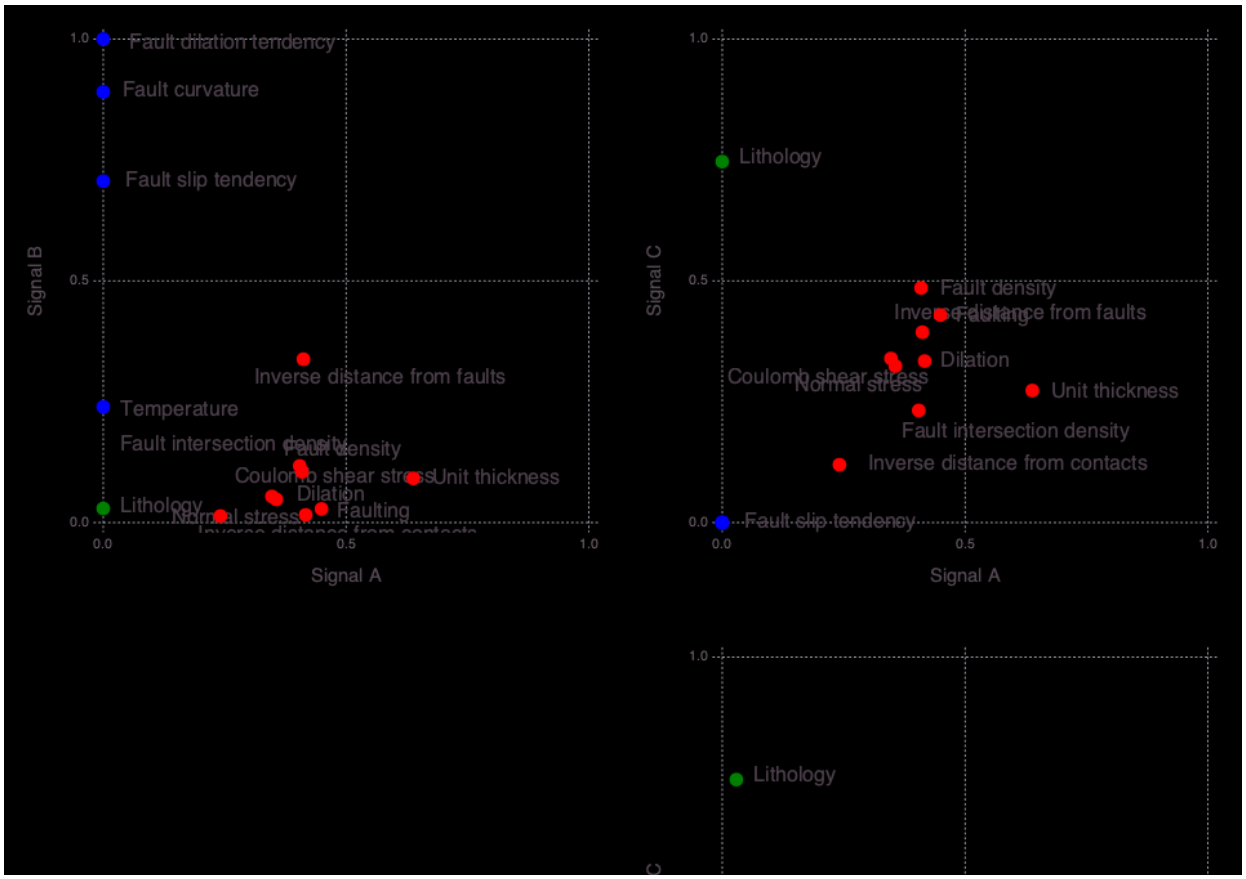

```
┌ Warning: Procedure to find unique signals could not identify a solution
...
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkCluster.jl:158
┌ Info: Signal A -> A Count: 9
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:255
```

```
[ 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

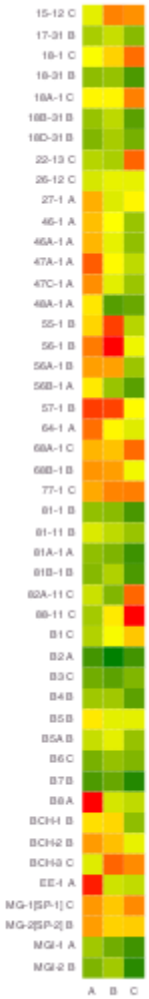

Fault dilation tendency
Fault curvature
Fault slip tendency
Inverse distance from faults
Temperature
Fault intersection density
Unit thickness
Coulomb shear stress
Fault density
Lithology
Signal 1
Signal 2
Signal 3
Unit thickness
Faulting
Dilation
Fault density
Coulomb shear stress
Inverse distance from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



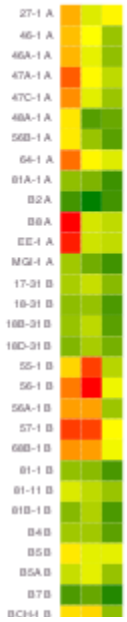

```
13×2 Array{Any,2}:
 "B8"      1.0
 "EE-1"    0.988215
 "47A-1"   0.905634
 "64-1"    0.867431
 "47C-1"   0.79874
 "27-1"    0.716696
 "46A-1"   0.699196
 "46-1"    0.675645
 "48A-1"   0.56726
 "56B-1"   0.557649
 "MGI-1"   0.286221
 "81A-1"   0.24804
 "B2"      0.0820308
```

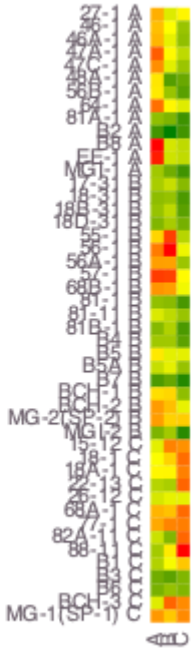
```
20×2 Array{Any,2}:
 "56-1"         1.0
 "55-1"         0.951665
 "57-1"         0.947671
 "68B-1"        0.759123
 "56A-1"        0.752345
 "BCH-2"        0.67324
 "MG-2(SP-2)"   0.624464
 "BCH-1"        0.609265
 "B5A"          0.440143
 "B5"           0.439178
 "17-31"        0.372325
 "81-11"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

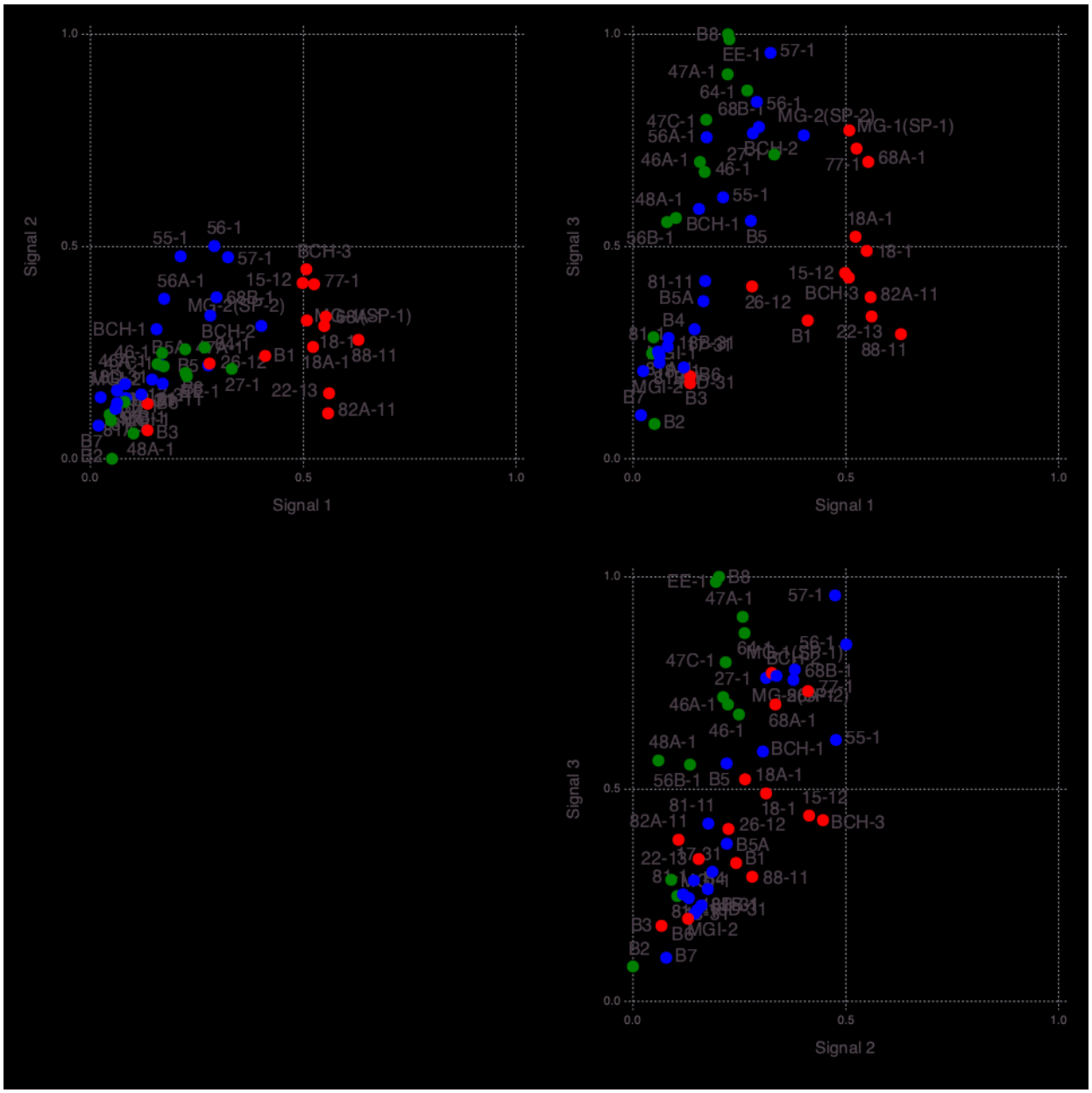
```
 "MGI-2"        0.289056
 "B4"           0.286007
 "18-31"        0.261958
 "81-1"         0.234893
 "B7"           0.155895

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
```

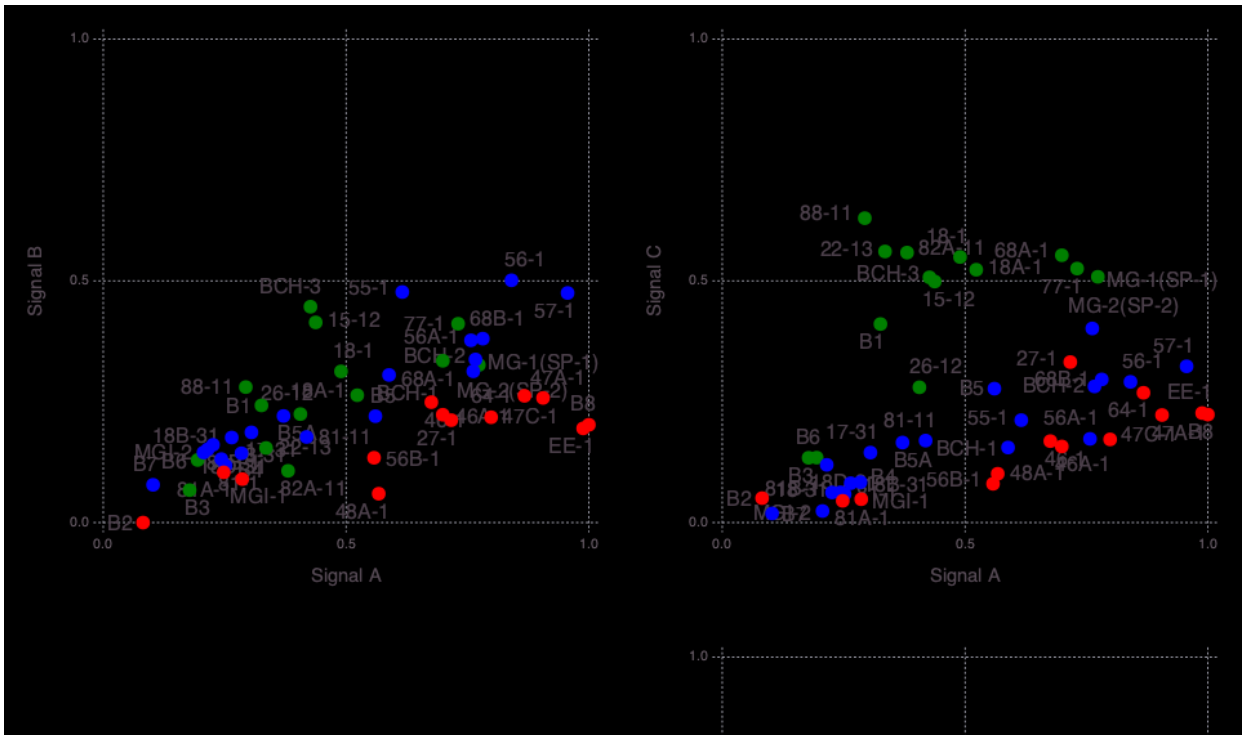


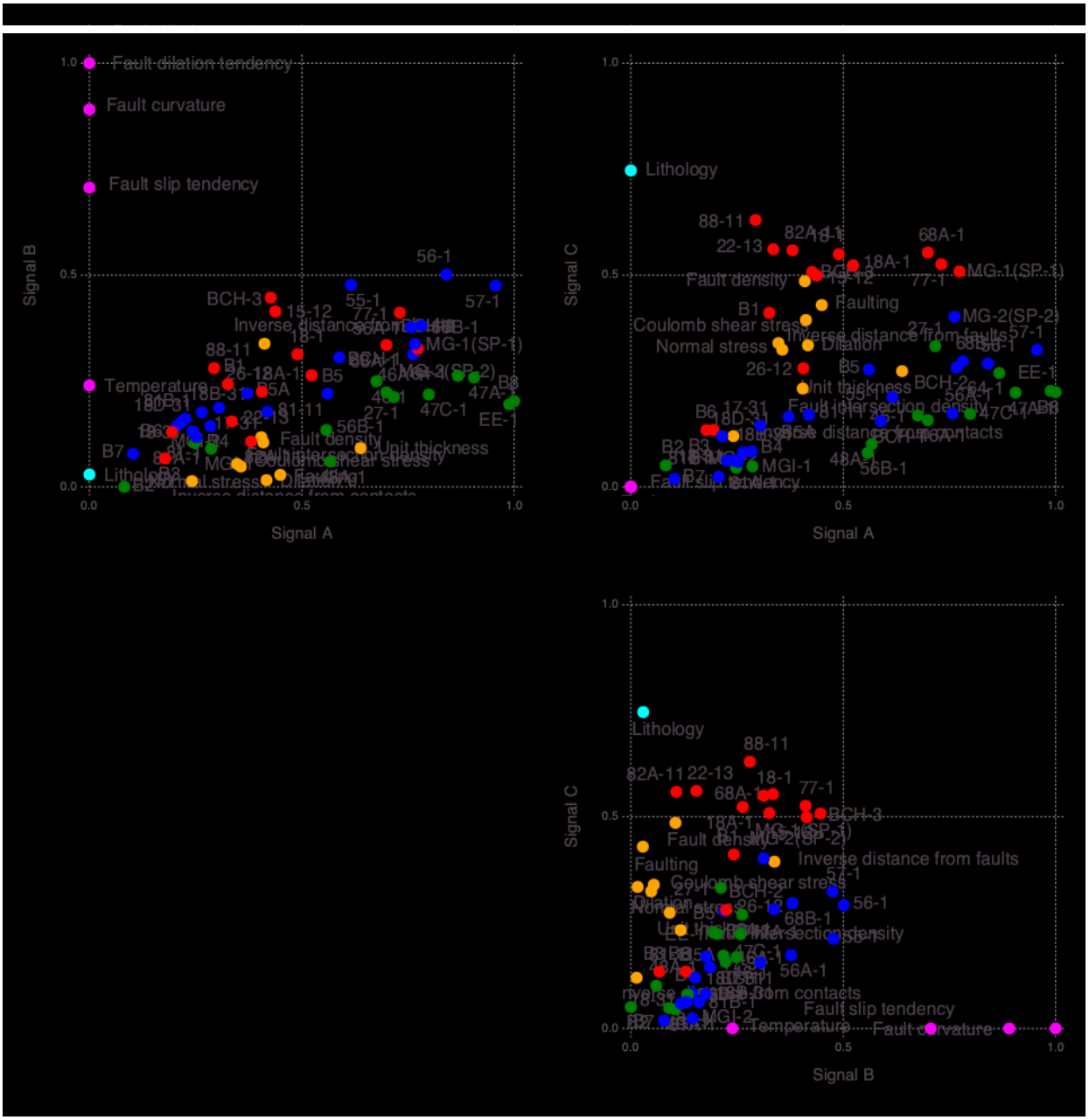
```
┌ Info: Locations (signals=3)
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:322
┌ Info: Signal A (S2) Count: 20
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
┌ Info: Signal B (S1) Count: 14
└ @ NMFk /Users/vvv/.julia/dev/NMFk/src/NMFkPostprocess.jl:335
┌ Info: Signal 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
```


27-1 A
46-1 A
46A-1 A
47A-1 A
47C-1 A
48A-1 A
56B-1 A
64-1 A
81A-1 A
B2 A
B8 A
EE-1 A
MG1-1 A
17-31 B
18-31 B
18B-31 B
18D-31 B
55-1 B
56-1 B
56A-1 B
57-1 B
68B-1 B
81-1 B
81-11 B
81B-1 B
B4 B
B5 B
B5A B
B7 B


27-1 A
46-1 A
46A-1 A
47A-1 A
47C-1 A
48A-1 A
56B-1 A
64-1 A
81A-1 A
B2 A
B8 A
EE-1 A
MG1-1 A
17-31 B
18-31 B
18B-31 B
18D-31 B
55-1 B
56-1 B
56A-1 B
57-1 B
68B-1 B
81-1 B
81-11 B
81B-1 B
B4 B
B5 B
B5A B
B7 B
BCH-1 B
BCH-2 B
MG-2(SP-2) B
MG1-2 B
15-12 C
18-1 C
18A-1 C
22-13 C
25-12 C
68A-1 C
77-1 C
82A-1 C
88-1 C
B1 C
B3 C
B6 C
BCH-3 C
MG-1(SP-1) C


Signal 2
Signal 1
Signal 3
Signal 1
Signal 3
Signal 2


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



Out[69]:
```
([[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']])
```