GEOmap: mapping and geology in R

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Abstract

Geomap software is aimed at geological applications in mapping.

1 Introduction

I developed a set of programs for making complex geological maps in R. These program parallel, to a certain extent, the maps and the mapdata packages already available but they are different in significant ways and provide a slightly different set of the utilities. Maps currently available in the mapdata package can be used by GEOmap, but most of the data required by GEOmap is included in a separate package called geomapdata, loaded independently.

The main differences between maps and GEOmap is the lower demands GEOmap has on requiring the maps information to be stored as independent strokes and topologically related polygons. This step, while useful and powerful for many applications, is onerous to set up for maps that are digitized on the fly, either from paper copies or from digital images on the screen.

The other difference is in the handling of projections. GEOmap has a few simple cartographic projections built in and can be expanded later by users.

2 Projections

There are 7 cartographic projections currently installed in GEOmap that can be called by the user and applied to data either in the forward mode (Lat-Lon to x-y) or in the inverse mode to go from the projected world back to geographic coordinates.

The set up of the projection is accomplished by running, for example,

```
> library(GEOmap)
```

Spatial Point Pattern Analysis Code in S-Plus
    Version 2 - Spatial and Space-Time analysis GEOmap is loaded

```
> options(continue = " ")
> kliuLL = c(56.056, 160.64)
> PROJ = setPROJ(type = 2, LAT0 = kliuLL[1], LON0 = kliuLL[2],
     LATS = NULL, LONS = NULL, DLAT = NULL, DLON = NULL, FN = 0)
```

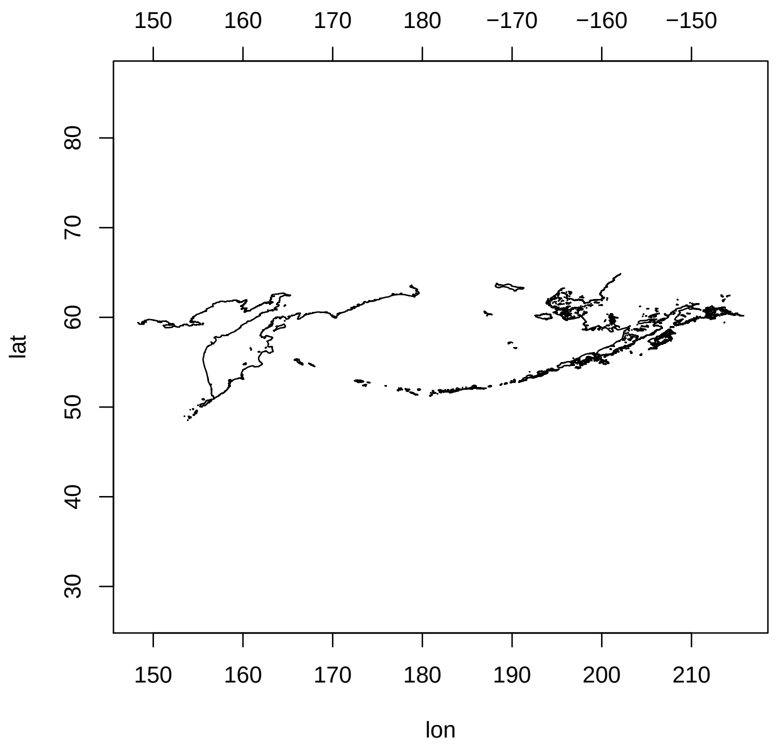
This makes this location (Kliuchevskoi volcano in Kamchatka, Russia) the origin of a utm spherical projection. The structure PROJ must be passed as an argument to subsequent calls to GEOmap plotting routines and conversions. The choices for projections can be seen by calling projtype() as in,

```
> projtype()
```

```
[1] Projection Types
[1] 0 = None
[1] 1 = merc.sphr
[1] 2 = utm.sphr
[1] 3 = lambert.cc
[1] 4 = stereo.sphr
[1] 5 = utm.elps
[1] 6 = equid.cyl
[1] 99 = old crosson projection
```

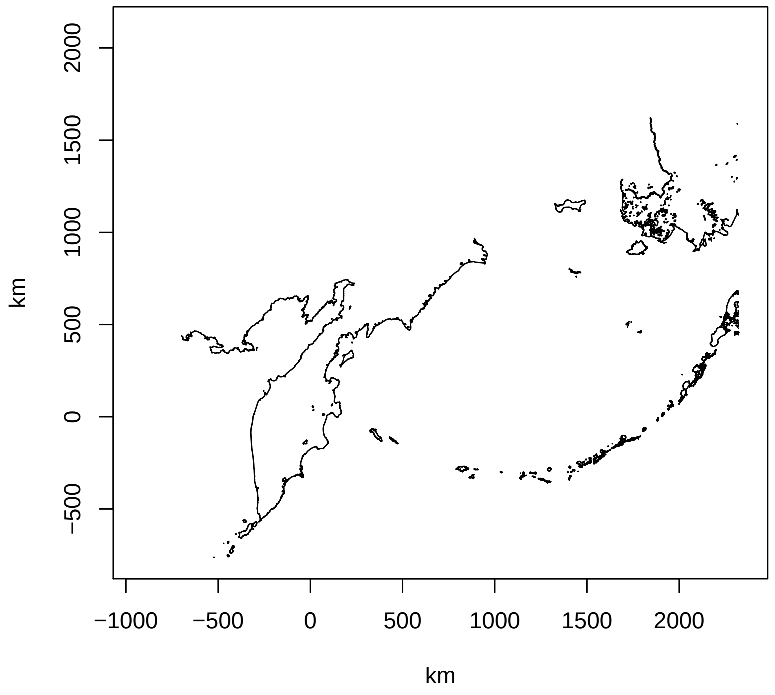
And we can see the usage of the projection by loading and plotting a map. First we plot the map with no projection, so the xy coordinates are Lat-Lon and the map will be distorted.

```
> require("geomapdata")
> data(kammap)
> plotGEOmap(kammap, add = FALSE, asp = 1)
```



Next we show how to plot the map in projected form,

```
> plotGEOmapXY(kammap, PROJ = PROJ, add = FALSE, xlab = "km", ylab = "km")
```



Notice that by resizing the window the map retains the proper aspect ration and the units are correct.

3 Simple Map

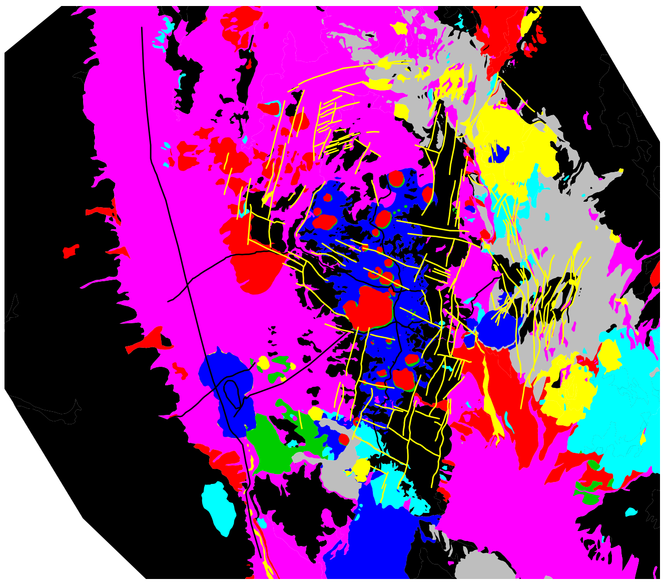
4 Map Structure

The internal structure of a GEOmap objection consists of three elements which are lists themselves. The raw XY coordinates are stored as long vectors on the POINTS list. These are all the geographic coordinates of the points int he map structure. The STROKES structure contains the meta data that allows one to access the POINTS and perform tasks and create graphical output. The STROKES structure includes a set of vectors which have the following structure:

5 Geologic Example

The following illustrates some of the features available in GEOmap. First we set up the data and then begin making the plot after manipulating the database.

```
> data(cosomap)
> data(faults)
> data(hiways)
> data(owens)
> data(cosogeol)
> proj = cosomap$PROJ
> plotGEOmapXY(cosomap, PROJ = proj, add = FALSE, ann = FALSE,
     axes = FALSE)
> cosogeol = boundGEOmap(cosogeol)
> plotGEOmapXY(cosogeol, PROJ = proj, add = TRUE, ann = FALSE,
     axes = FALSE)
> plotGEOmapXY(cosomap, PROJ = proj, add = TRUE, ann = FALSE, axes = FALSE)
> plotGEOmapXY(faults, PROJ = proj, add = TRUE, ann = FALSE, axes = FALSE)
```

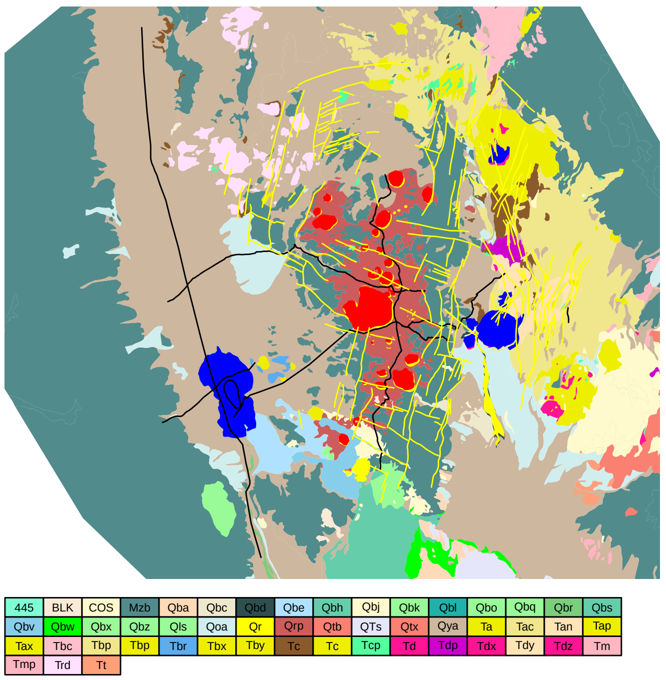


The colors here are not very useful, so we can modify them by assigning colors from a given palette, in this case the palette of the program geotouch,

```
> XMCOL = setXMCOL()
> cosocolnumbers = 1:length(cosogeol$STROKES$col)
> newcol = XMCOL[cosogeol$STROKES$col]
> cosocolnums = cosogeol$STROKES$col
> cosogeol$STROKES$col = newcol
```

and lastly we must create a legend by matching the colors with the symbols or names of hte units:

```
> ss = strsplit(cosogeol$STROKES$nam, split = "_")
> geo = unlist(lapply(ss, FUN = "getmem", mem = 1))
> UGEO = unique(geo)
> mgeo = match(geo, UGEO)
> cosogeol = boundGEOmap(cosogeol)
> gcol = paste(sep = ".", geo, cosogeol$STROKES$col)
> ucol = unique(gcol)
> spucol = strsplit(ucol, split = "\\.")
> N = length(spucol)
> names = unlist(lapply(spucol, FUN = "getmem", mem = 1))
> shades = unlist(lapply(spucol, FUN = "getmem", mem = 2))
> ORDN = order(names)
> plotGEOmapXY(cosomap, PROJ = proj, add = FALSE, ann = FALSE,
     axes = FALSE)
> plotGEOmapXY(cosogeol, PROJ = proj, add = TRUE, ann = FALSE,
     axes = FALSE)
> plotGEOmapXY(cosomap, PROJ = proj, add = TRUE, ann = FALSE, axes = FALSE)
> plotGEOmapXY(faults, PROJ = proj, add = TRUE, ann = FALSE, axes = FALSE)
> geoLEGEND(names[ORDN], shades[ORDN], 0.28, 0.14, 16, 6)
```



6 Building a map plot and controling the figure

In this section I illustrate how to build a map figure by adding several components, and controlling the plotting functions. We start by first reading in some data. The volcano data is taken from the Smithsonian Institution web site listing volcanoes of the world. These have been converted to s simple file including LAT, LON, Elevation and volcano name. The station represent the station locations for the NIED network in Japan. The earthquakes are taken from a catalog of earthquake hypocenters that can be downloaded from the Internet from a variety of websites currently available.

```
> jvolcs = scan(file = "Volc_points.LLZ", what = list(name = "",
     lat = 0, lon = 0, h = 0), sep = " ")
> stas = scan(file = "newFUJIstation.LLZ", what = list(name = "",
     lat = 0, lon = 0, h = 0), sep = " ")
> eqs = scan(file = "japan.eng", what = list(lon = 0, lat = 0,
     z = 0, m = 0))
```

Next we set the projection to be centered on Mt. Fuji with a UTM projection. To extract the LAT-LON of Mt. Fuji from the volcano data base, we use the grep function to match the character string FUJI with the corresponding name in the data set.

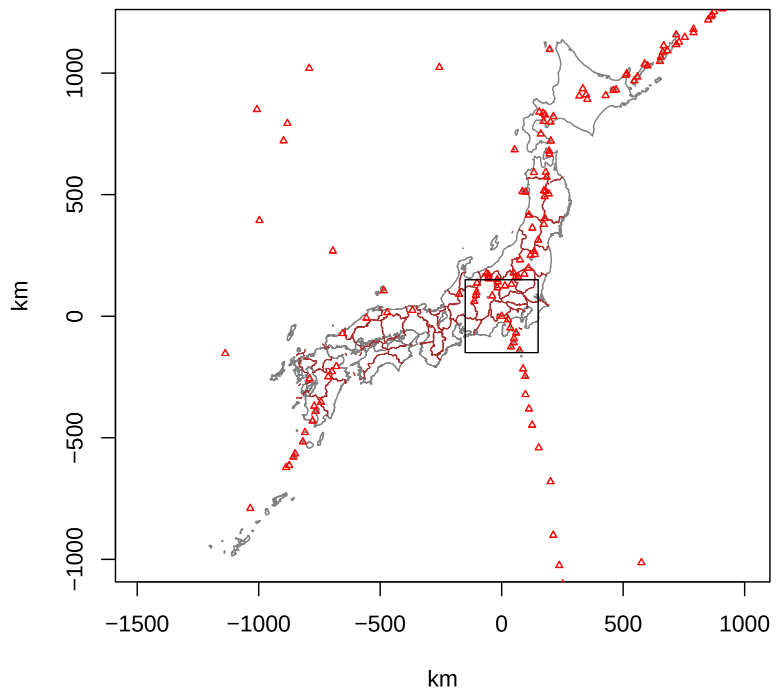
```
> ifuji = grep("FUJI", jvolcs$name)
> PROJ = setPROJ(type = 2, LAT0 = jvolcs$lat[ifuji], LON0 = jvolcs$lon[ifuji])
```

We load up the japmap provided by the geomapdata package, create the projected plot and limit the plotting region to a LAT-LON rectangle described by the vector FUJIAREA. This is calculated using the XY.GLOB function that takes x-y coordinates in km and converts to LAT-LON geographic coordinates. These are stored in vector FUJIAREA as a rectangular region, and used in plotGEOmapXY to restrict the plotting region. Here we have used a distance of 15o km north and south of Mt. Fuji as our target region.

```
> LL = XY.GLOB(c(-150, 150), c(-150, 150), PROJ = PROJ)
> FUJIAREA = c(LL$lon[1], LL$lat[1], LL$lon[2], LL$lat[2])
```

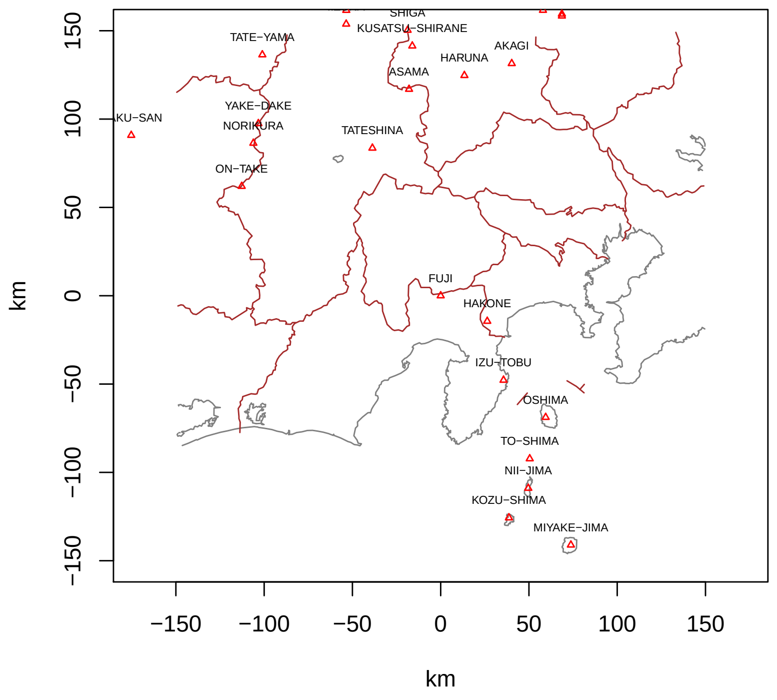
Now we are ready to plot the data previously scanned and add to the current plot using the same projection parameters stored in list PROJ. First the whole of Japan is plotted with the volcanoes plotted as triangle.

```
> require("geomapdata")
> data("japmap", package = "geomapdata")
> plotGEOmapXY(japmap, PROJ = PROJ, xlab = "km", ylab = "km")
> pointsGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, col = "red",
     pch = 2, cex = 0.5)
> rect(-150, -150, 150, 150)
```



Next we can zoom into the desired target region shown as a rectangle in the previous figure:

```
> plotGEOmapXY(japmap, LIM = FUJIAREA, PROJ = PROJ, xlab = "km",
     ylab = "km")
> pointsGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, col = "red",
     pch = 2, cex = 0.5)
> textGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, labels = jvolcs$name,
     cex = 0.5, pos = 3)
```



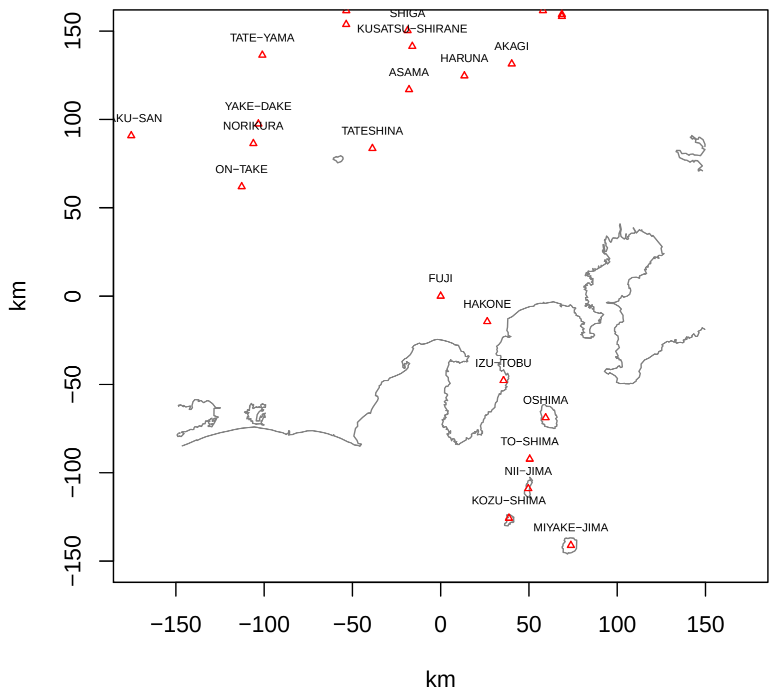
To restrict plotting of specific features in the map database japmap we can pass a selection vector to the plotting program. In this case the Japan map has coastal data and internal prefecture boundaries. The prefecture boundaries are useful for orientation on maps, but they may also clutter a plot if they are not needed. In this case the STROKES in the data have tags labeled either “a” or “i”, where the tag “i” stands for internal.

```
> print(japmap$STROKES$code)
```

```
  [1] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
 [19] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
 [37] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
 [55] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
 [73] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
 [91] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
[109] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
[127] "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a" "a"
[145] "a" "a" "a" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i"
[163] "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i"
[181] "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i"
[199] "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i" "i"
```

if we choose those strokes that are not internal and create a selection vector, we can quickly elliminate the internal boundaries.

```
> isel = which(japmap$STROKES$code != "i")
> plotGEOmapXY(japmap, LIM = FUJIAREA, PROJ = PROJ, SEL = isel,
     xlab = "km", ylab = "km")
> pointsGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, col = "red",
     pch = 2, cex = 0.5)
> textGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, labels = jvolcs$name,
     cex = 0.5, pos = 3)
```



7 Convert from a GMT file

Many earth scientists use the program GMT (Generic Mapping Tools) to make figures for research and publication. GMT is a program that includes plotting routines, a small amount of analysis and numerous cartographic projections. The main output of GMT is postscript figures. One purpose of GEOmap is to replace GMT with a more general mapping platform that produces figures as well is high level statistical analysis.

As a result I show here how one can convert a file used by GMT to a GEOmap data file. Map information in GMT are stored as strokes separated by a flagged marker, typically by the greater than symbol ">". Here we read in a GMT map file that has coordinates of the crude, world, plate-tectonic boundaries.

```
> plates = scan(file = "Plates.gmt", what = "", sep = "\n")
```

This file has separated strokes, but also some more information (meta data) on the separator lines, which can be used to augment the GEOmap database. There are 89 strokes in this data file. These are the first 10 headers:

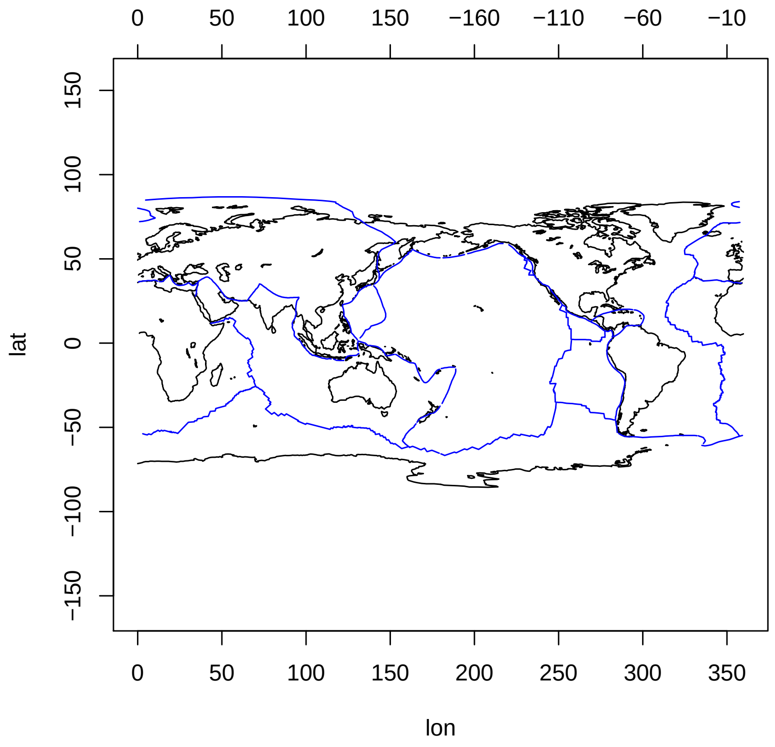
```
> g = grep("^>", plates)
> plates[g[1:10]]

 [1] "> PLT1 13 2 13 p 3.800000 12.500000 93.599998 91.800003"
 [2] "> PLT2 35 2 13 p -9.400000 2.900000 114.900002 94.500000"
 [3] "> PLT3 16 2 13 p 53.090000 59.124100 -142.994995 -164.031006"
 [4] "> PLT4 7 2 13 p 50.610699 52.518600 -165.889999 -178.641998"
 [5] "> PLT5 12 2 13 p 50.633400 55.190498 179.565002 163.968994"
 [6] "> PLT6 4 2 13 p -10.300000 -9.500000 122.400002 116.400002"
 [7] "> PLT7 32 2 13 p 1.900000 34.500000 138.300003 121.599998"
 [8] "> PLT8 11 2 13 p -1.200000 1.200000 136.500000 131.000000"
 [9] "> PLT9 8 2 13 p 17.000000 20.000000 94.099998 93.800003"
[10] "> PLT10 23 2 13 p 3.100000 34.000000 147.300003 132.100006"
```

First we will read in each stroke, extract the LAT-LON information and store in a list.

```
> PLATES = list(STROKES = list(nam = NULL, num = NULL, index = NULL,
     col = NULL, style = NULL, code = NULL), POINTS = list(lat = NULL,
     lon = NULL))
> K = 0
> for (i in 1:length(g)) {
     i1 = g[i] + 1
     i2 = g[i + 1] - 1
     if (i == length(g))
         i2 = length(plates)
     LONLAT = as.numeric(unlist(strsplit(plates[i1:i2], split = " ")))
     lon = LONLAT[seq(from = 1, to = length(LONLAT), by = 2)]
     lat = LONLAT[seq(from = 2, to = length(LONLAT), by = 2)]
     PLATES$POINTS$lat = c(PLATES$POINTS$lat, lat)
     PLATES$POINTS$lon = c(PLATES$POINTS$lon, lon)
     PLATES$STROKES$nam = c(PLATES$STROKES$nam, paste("PLATE",
         i, sep = ""))
     PLATES$STROKES$num = c(PLATES$STROKES$num, length(lat))
     PLATES$STROKES$index = c(PLATES$STROKES$index, K)
     PLATES$STROKES$col = c(PLATES$STROKES$col, "blue")
```

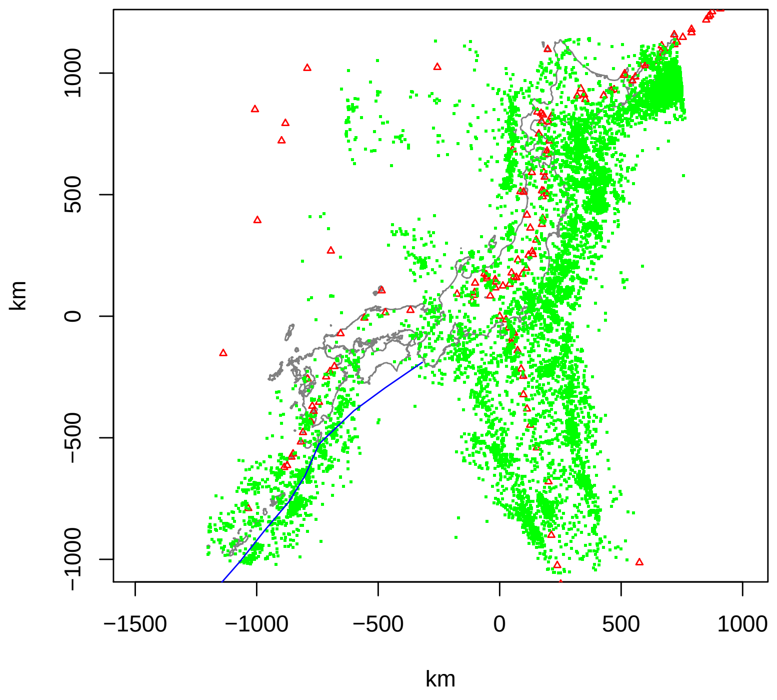
```
    PLATES$STROKES$style = c(PLATES$STROKES$style, 2)
    PLATES$STROKES$code = c(PLATES$STROKES$code, "p")
    K = K + length(lat)
 }
> PLATES$POINTS$lon = fmod(PLATES$POINTS$lon, 360)
> PLATES = boundGEOmap(PLATES, NEGLON = FALSE)
> PLATES$PROJ = PROJ
```

```
> data(worldmap)
> plotGEOmap(worldmap, asp = 1)
> plotGEOmap(PLATES, add = TRUE)
```



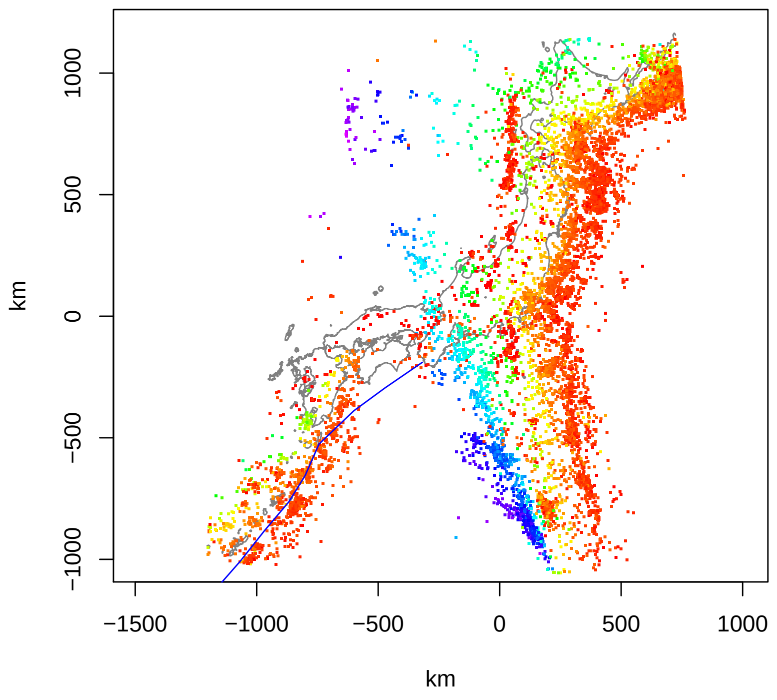
Or to show the map of Japan, projected with volcanoes, earthquakes and plate tectonic boundaries,

```
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "km", ylab = "km")
> pointsGEOmapXY(jvolcs$lat, jvolcs$lon, PROJ = PROJ, col = "red",
    pch = 2, cex = 0.5)
> pointsGEOmapXY(eqs$lat, eqs$lon, PROJ = PROJ, col = "green",
    pch = ".", cex = 2)
> plotGEOmapXY(PLATES, PROJ = PROJ, add = TRUE)
```



Here the earthquakes are plotted as one single color but often we would like to see the events plotted with colors coded according to depth,

```
> rcol = rainbow(120)
> ecol = 1 + floor(99 * (eqs$z - min(eqs$z))/(max(eqs$z) - min(eqs$z)))
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "km", ylab = "km")
> pointsGEOmapXY(eqs$lat, eqs$lon, PROJ = PROJ, pch = ".", cex = 2,
      col = rcol[ecol])
> plotGEOmapXY(PLATES, PROJ = PROJ, add = TRUE)
```

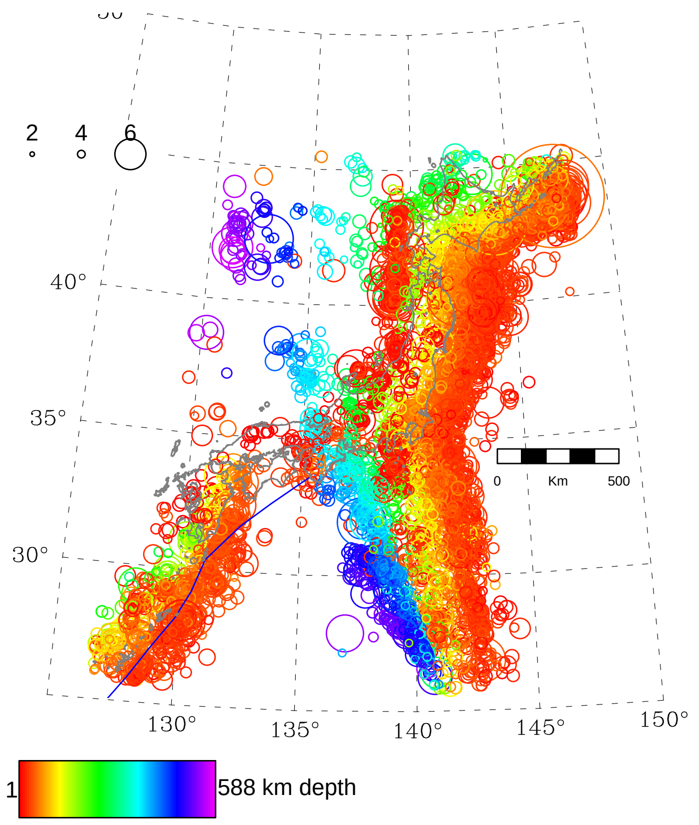


To finish off the plot we had the horizontal scale in km, the size of the earthquakes scaled by magnitude with a small legend at the top, and a horzontal scale showing the colors associated with depth. The following is a short function for plotting the earthquake size scale at the top.

```
> print(sizelegend)

function (se, am, pch = pch)
{
    if (missing(pch))
        pch = 1
    u = par("usr")
    ex = c(u[1] + 0.05 * (u[2] - u[1]), u[1] + 0.2 * (u[2] -
        u[1]))
    why = u[3] + 0.95 * (u[4] - u[3])
    N = length(se)
    rect(u[1], u[3] + 0.9 * (u[4] - u[3]), u[1] + 0.25 * (u[2] -
        u[1]), u[4], col = "white", border = NA, xpd = TRUE)
    points(seq(from = ex[1], to = ex[2], length = N), rep(why,
        length = N), pch = pch, cex = se, xpd = TRUE)
    text(seq(from = ex[1], to = ex[2], length = N), rep(why,
        length = N), labels = am, pos = 3, xpd = TRUE)
}
```

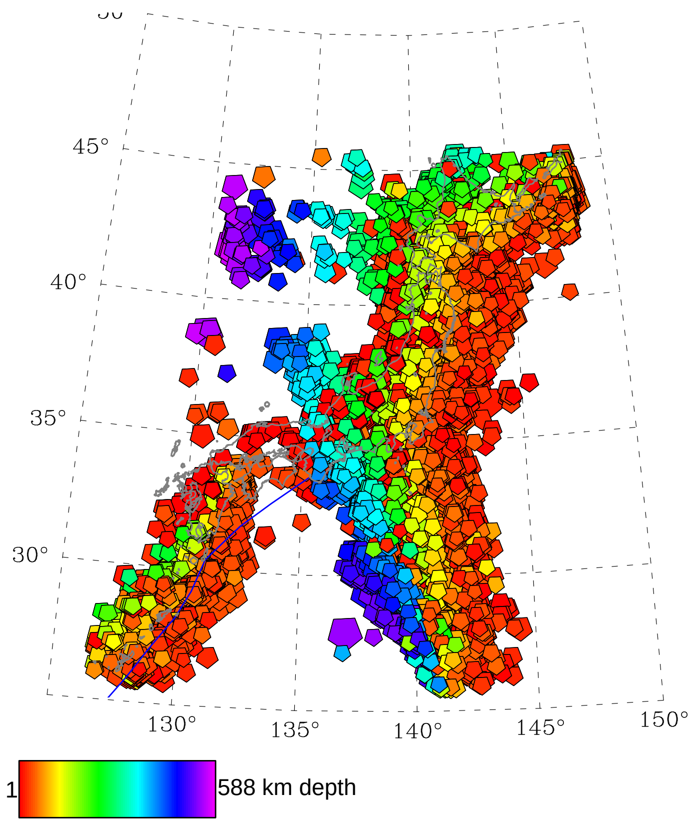
and the figure is constructed by:

```
> esiz = exp(eqs$m)
> rsiz = RESCALE(esiz, 0.4, 10, min(esiz), max(esiz))
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "", ylab = "",
     axes = FALSE)
> PLAT = pretty(eqs$lat)
> PLON = pretty(eqs$lon)
> addLLXY(PLAT, PLON, GRIDcol = "black", LABS = 0, BORDER = 0,
     PROJ = PROJ)
> pointsGEOmapXY(eqs$lat, eqs$lon, PROJ = PROJ, pch = rep(1, length(rsiz)),
     cex = rsiz, col = rcol[ecol])
> plotGEOmapXY(PLATES, PROJ = PROJ, add = TRUE)
> HOZscale(eqs$z, rcol[1:100], units = "km depth", SIDE = 1, s1 = 0.5,
     s2 = 0.95)
> zeb = list()
> zeb$x = c(458.266070479352, 870.677297484252)
> zeb$y = c(-129.768792704472, -12.2491966665725)
> zebra(zeb$x[1], zeb$y[1], 500, 100, 60, lab = "Km", cex = 0.6)
> am = pretty(eqs$m)
> am = am[am > min(eqs$m) & am < max(eqs$m)]
> em = exp(am)
> se = RESCALE(em, 0.4, 10, min(esiz), max(esiz))
> sizelegend(se, am, pch = 1)
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "km", ylab = "km",
     add = TRUE)
```



Next we can plot this in a slightly different way, using a home grown symbol function.

```
> EXY = GLOB.XY(eqs$lat, eqs$lon, PROJ)
> PLAT = pretty(eqs$lat)
> PLON = pretty(eqs$lon)
> esiz = exp(eqs$m)
> rsiz = RESCALE(esiz, 0.04, 0.2, min(esiz), max(esiz))
> ordsiz = order(rsiz, decreasing = TRUE)
> acol = rcol[ecol]
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "", ylab = "",
     axes = FALSE)
> addLLXY(PLAT, PLON, GRIDcol = "black", LABS = 0, BORDER = 0,
     PROJ = PROJ)
> pgon(EXY$x[ordsiz], EXY$y[ordsiz], siz = rsiz[ordsiz], col = acol[ordsiz],
     border = "black", startalph = 60, K = 5, lwd = 0.5, xpd = TRUE)
> plotGEOmapXY(PLATES, PROJ = PROJ, add = TRUE)
> plotGEOmapXY(japmap, PROJ = PROJ, SEL = isel, xlab = "", ylab = "",
     axes = FALSE, add = TRUE)
> HOZscale(eqs$z, rcol[1:100], units = "km depth", SIDE = 1, s1 = 0.5,
s2 = 0.95)
```

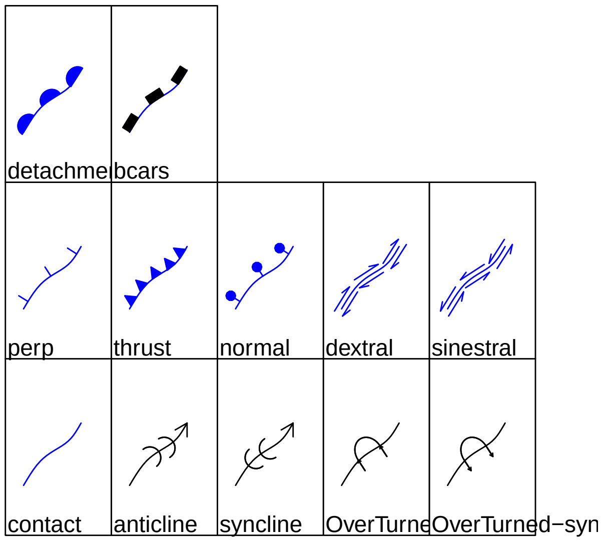


8 Geologic Map Symbols

Geologic maps are often complex figures illustrating large amounts of interconnected information. Numerous line styles have specific meanings indicating geologic structures useful for illustrating relationships of surface and subsurface features.

Several standard geological symbols are available for plotting specific faults on plots. These can be seen by executing the gridded plot of many line dress ups:

```
> GEOsymbols()
```


detachme
bcars
perp
thrust
normal
dextral
sinestral
contact
anticline
syncline
OverTurne
OverTurned−syn