Mamainse_Data_Analysis

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Magmatic activity and plate motion during the "latent stage" of Midcontinent Rift development

Corresponding Author: Nicholas L. Swanson-Hysell (swanson-hysell@berkeley.edu)This notebook contains data analysis used for the paper entitled *Magmatic activity and plate motion during the "latent stage" of Midcontinent Rift development* published in the journal GEOLOGY in 2014.

1 Preamble materials

Import necessary libraries and start the interactive pylab environment. The code below uses the pmag.py and pmagplotlib.py files of the the PmagPy software package (version pmagpy-2.206) authored by Lisa Tauxe (https://github.com/ltauxe/PmagPy) and the IPmag.py function library that modifies some of these functions for use in the IPython environment (https://github.com/Swanson-Hysell/PmagPy_IPython). The check_updates and get_version functions of the PmagPy libraries cause errors in the interactive environment of IPython so the code below calls a slightly modified version of the libraries that are included in the Github repository for this work. The IPmag.py function library is included within the Github repository as well as an archive of the exact code that was used in the analysis.

In [1]:
```
import pandas
from IPython.core.display import HTML
import pmag
import IPmag
import pmagplotlib
```

In [2]:
```
%pylab inline
```

```
Populating the interactive namespace from numpy and matplotlib
```

2 Import Mamainse Point paleomagnetic data

Import the data as a pandas dataframe and display the first 5 rows.

In [3]:
```
Mamainse_Data_all=pandas.read_csv('../Data/Mamainse_Point_data.csv',sep=',')
Mamainse_Data_all.head()
```

Out [3]:
```
  stratigraphic_section section_meter_level  composite_meter_level
site_lat  \
0                 MP101         0.0 to 15.5                     68
47.0988
1                 MP101        15.5 to 16.8                     84
47.0987
2                 MP101        16.8 to 18.7                     85
47.0986
3                 MP101        20.7 to 21.3                     89
47.0986
4                 MP101        21.3 to 21.9                     89
47.0986

   site_long  n  D_geo  I_geo  D_tilt-cor  I_tilt-cor  a_95    k
fit_used
0   -84.7123  6  203.2  -50.3       131.6       -63.2   9.2   54
mag
1   -84.7124  3  225.0  -47.2       146.0       -77.2  13.7   54
mag
2   -84.7124  5  226.7  -52.8       120.3       -77.5   7.4   88
mag
3   -84.7125  4  209.1  -46.8       141.5       -66.4   8.4  121
mag
4   -84.7126  6  218.3  -52.3       126.6       -72.7   4.5  189
mag
```

3 Reversal tests on directional data from the succession

Create a list of unit vectors from the data frame to use for the statistical tests.

In [4]:
```
MP_DIdata=[]
for n in range(0,len(Mamainse_Data_all)):
    Dec=Mamainse_Data_all['D_tilt-cor'][n]
    Inc=Mamainse_Data_all['I_tilt-cor'][n]
    MP_DIdata.append([Dec,Inc,1.])
```

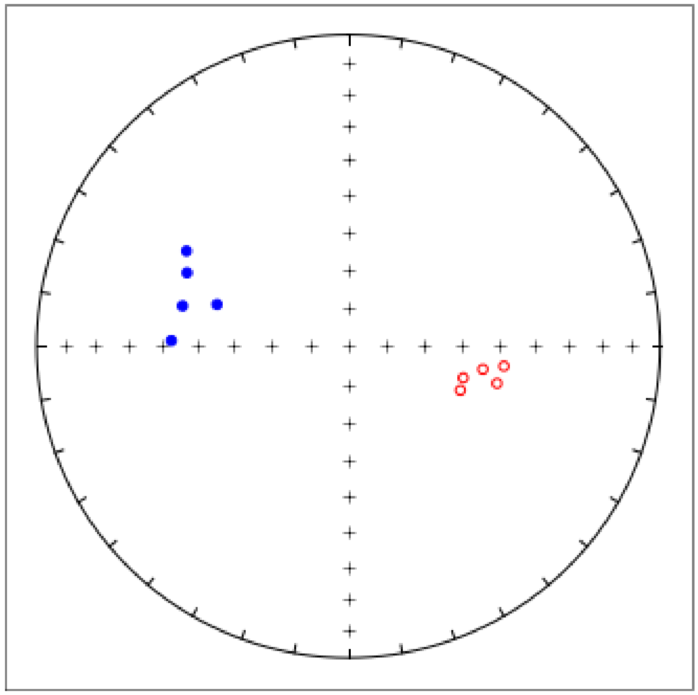
3.1 First reversal

Plot the data from section MP214 which crosses the first reversal in the Mamainse Point stratigraphy and conduct a reversal test between the reversed and normal directions (Watson's V test with simulation and McFadden and McElhinny (1990) classification criteria).

In [5]:
```
MP214r=MP_DIdata[33:38]
MP214n=MP_DIdata[38:43]

fignum = 1 #set the figure number here
pylab.figure(num=fignum,figsize=(8,8),dpi=160) #size and resolution can be changed her
pmagplotlib.plotNET(fignum)
IPmag.iplotDI(MP214r,'r')
```

```
IPmag.iplotDI(MP214n,'b')

#the nested iflip function takes the antipode of the MP214r data to conduct the Watson
IPmag.iWatsonV(IPmag.iflip(MP214r),MP214n)
```

```
Results of Watson V test:

Watson's V:           6.8
Critical value of V:  7.5
"Pass": Since V is less than Vcrit, the null hypothesis
that the two populations are drawn from distributions
that share a common mean direction can not be rejected.

M&M1990 classification:

Angle between data set means: 9.2
Critical angle for M&M1990:   9.7
The McFadden and McElhinny (1990) classification for
this test is: 'B'
```



pmagpy-2.206

3.2 Second reversal

Plot the data from the normal polarity zone below and the reversed polarity zone above the second reversal in the Mamainse Point stratigraphy. Conduct a reversal test between the reversed and normal directions (Watson's V test with simulation and McFadden and McElhinny (1990) classification criteria).

In [6]:
```
MPlowerN=MP_DIdata[38:52]
MPupperR=MP_DIdata[55:65]

fignum = 2 #set the figure number here
pylab.figure(num=fignum,figsize=(8,8),dpi=160) #size and resolution can be changed her
pmagplotlib.plotNET(fignum)
IPmag.iplotDI(MPlowerN,'b')
IPmag.iplotDI(MPupperR,'r')

#the nested iflip function takes the antipode of the MPupperR data to conduct the Wats
IPmag.iWatsonV(IPmag.iflip(MPupperR),MPlowerN)
```

Results of Watson V test:

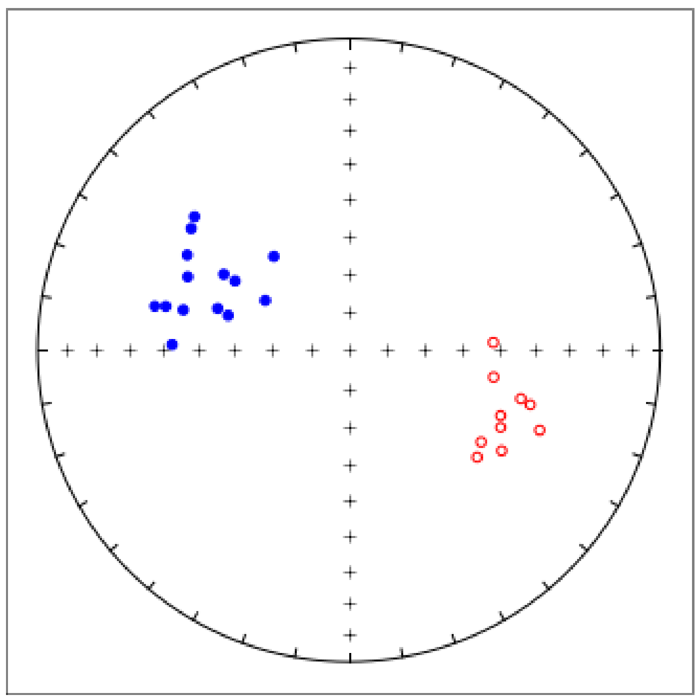
```
Watson's V:           0.9
Critical value of V:  6.3
```

"Pass": Since V is less than Vcrit, the null hypothesis that the two populations are drawn from distributions that share a common mean direction can not be rejected.

M&M1990 classification:

```
Angle between data set means: 3.2
Critical angle for M&M1990:   8.6
```

The McFadden and McElhinny (1990) classification for this test is: 'B'



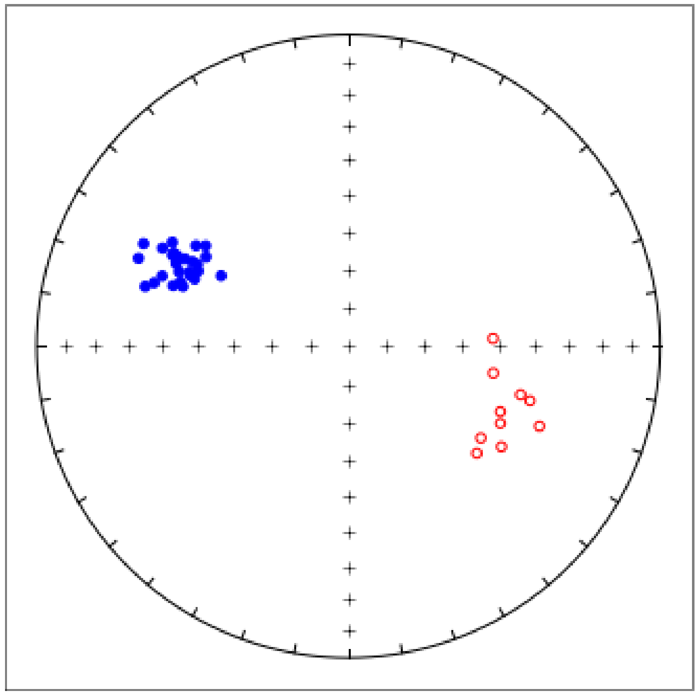
pmagpy-2.206

3.3 Third reversal

Plot the data from the reversed polarity zone below and first 1000 meters of the normal polarity zone above the third reversal in the Mamainse Point stratigraphy. Conduct a reversal test between the reversed and normal directions (Watson's V test with simulation and McFadden and McElhinny (1990) classification criteria).

In [7]:
```
MPupperR=MP_DIdata[55:65]
MPupperN=MP_DIdata[65:92]

fignum = 2 #set the figure number here
pylab.figure(num=fignum,figsize=(8,8),dpi=160) #size and resolution can be changed her
pmagplotlib.plotNET(fignum)
IPmag.iplotDI(MPupperN,'b')
IPmag.iplotDI(MPupperR,'r')

#the nested iflip function takes the antipode of the MPupperR data to conduct the Wats
IPmag.iWatsonV(IPmag.iflip(MPupperR),MPupperN)
```

```
Results of Watson V test:

Watson's V:           5.2
Critical value of V:  6.8
"Pass": Since V is less than Vcrit, the null hypothesis
that the two populations are drawn from distributions
that share a common mean direction can not be rejected.

M&M1990 classification:

Angle between data set means: 5.7
Critical angle for M&M1990:   6.5
The McFadden and McElhinny (1990) classification for
this test is: 'B'
```



pmagpy-2.206

4 Calculate Mamainse Point paleomagnetic poles

Create an empty dataframe that will be populated with pole means.

In [8]:
```
pole_means = pandas.DataFrame(columns=['name','pole_lat','pole_long','A_95','N'], inde
pole_means
```

Out [8]:

	name	pole_lat	pole_long	A_95	N
lower_R1	NaN	NaN	NaN	NaN	NaN
lower_R2	NaN	NaN	NaN	NaN	NaN
lower_N_upper_R	NaN	NaN	NaN	NaN	NaN
upper_N	NaN	NaN	NaN	NaN	NaN
upper_N_woMP306	NaN	NaN	NaN	NaN	NaN

Using the site directional data and site locations within the dataframe calculate the virtual geomagnetic pole positions. Once calculated display the first 5 rows of the now expanded Mamainse_Data_all dataframe.

In [9]:
```
#calculate the paleolatitude/colatitude
Mamainse_Data_all['paleolatitude']=np.degrees(np.arctan(0.5*np.tan(np.radians(Mamainse_
Mamainse_Data_all['colatitude']=90-Mamainse_Data_all['paleolatitude']
#calculate the latitude of the pole
Mamainse_Data_all['pole_lat']=np.degrees(np.arcsin(np.sin(np.radians(Mamainse_Data_all
                                                     np.cos(np.radians(Mamainse_Da
                                                     np.cos(np.radians(Mamainse_Da
                                                     np.sin(np.radians(Mamainse_Da
                                                     np.cos(np.radians(Mamainse_Da
#calculate the longitudinal difference between the pole and the site (beta)
Mamainse_Data_all['beta']=np.degrees(np.arcsin((np.sin(np.radians(Mamainse_Data_all['c
                                    np.sin(np.radians(Mamainse_Data_all['D_tilt-cor'
                                   (np.cos(np.radians(Mamainse_Data_all['pole_lat']))
#generate a boolean array (mask) to use to distinguish between the two possibilities f
#and then calculate pole longitude using the site location and calculated beta
mask = np.cos(np.radians(Mamainse_Data_all['colatitude']))>np.sin(np.radians(Mamainse_
Mamainse_Data_all['pole_long']=np.where(mask,(Mamainse_Data_all['site_long']+Mamainse_
#calculate the antipode of the poles
Mamainse_Data_all['pole_lat_rev']=-Mamainse_Data_all['pole_lat']
Mamainse_Data_all['pole_long_rev']=(Mamainse_Data_all['pole_long']-180.)%360.
Mamainse_Data_all.head()
```

Out [9]:
```
  stratigraphic_section section_meter_level  composite_meter_level
site_lat  \
0                 MP101         0.0 to 15.5                     68
47.0988
1                 MP101        15.5 to 16.8                     84
47.0987
2                 MP101        16.8 to 18.7                     85
47.0986
3                 MP101        20.7 to 21.3                     89
47.0986
4                 MP101        21.3 to 21.9                     89
47.0986

   site_long  n  D_geo  I_geo  D_tilt-cor  I_tilt-cor  a_95    k
fit_used  \
0   -84.7123  6  203.2  -50.3       131.6       -63.2   9.2   54
mag
1   -84.7124  3  225.0  -47.2       146.0       -77.2  13.7   54
mag
2   -84.7124  5  226.7  -52.8       120.3       -77.5   7.4   88
mag
3   -84.7125  4  209.1  -46.8       141.5       -66.4   8.4  121
mag
4   -84.7126  6  218.3  -52.3       126.6       -72.7   4.5  189
mag

   paleolatitude  colatitude   pole_lat       beta  pole_long
pole_lat_rev  \
0     -44.707215  134.707215 -56.775933  75.926276  19.361424
56.775933
1     -65.563482  155.563482 -64.207227  32.116906  63.170694
64.207227
```

```
2     -66.088013  156.088013 -53.985198  36.525485  58.762115
53.985198
3     -48.853737  138.853737 -64.443167  71.706913  23.580587
64.443167
4     -58.079957  148.079957 -56.757528  50.744843  44.542557
56.757528

   pole_long_rev
0     199.361424
1     243.170694
2     238.762115
3     203.580587
4     224.542557
```

Now that the virtual paleomagnetic poles have been calculated from the directional data, calculate mean paleomagnetic poles as the Fisher means of the VGPs in stratigraphic groupings. After these poles are calculated using the fisher_mean function in the pmag.py library, they are added to the pole_means dataframe.

In [10]:

```
MPlowerR1_VGPs=[]
for n in range(0,24):
    Plong,Plat=Mamainse_Data_all['pole_long_rev'][n],Mamainse_Data_all['pole_lat_rev']
    MPlowerR1_VGPs.append([Plong,Plat,1.])
MPlowerR1_mean=pmag.fisher_mean(MPlowerR1_VGPs)


pole_means.loc['lower_R1'] = pandas.Series({'name':'lower R pole 1',
                                       'pole_lat':str(round(MPlowerR1_mean['inc'],1)),
                                       'pole_long':str(round(MPlowerR1_mean['dec'],1)),
                                       'A_95':str(round(MPlowerR1_mean['alpha95'],1)),
                                       'N':str(int(MPlowerR1_mean['n']))})

MPlowerR2_VGPs=[]
for n in range(24,38):
    Plong,Plat=Mamainse_Data_all['pole_long_rev'][n],Mamainse_Data_all['pole_lat_rev']
    MPlowerR2_VGPs.append([Plong,Plat,1.])
MPlowerR2_mean=pmag.fisher_mean(MPlowerR2_VGPs)


pole_means.loc['lower_R2'] = pandas.Series({'name':'lower R pole 2',
                                       'pole_lat':str(round(MPlowerR2_mean['inc'],1)),
                                       'pole_long':str(round(MPlowerR2_mean['dec'],1)),
                                       'A_95':str(round(MPlowerR2_mean['alpha95'],1)),
                                       'N':str(int(MPlowerR2_mean['n']))})

MPlower_N_upper_R_VGPs=[]
for n in range(38,52):
    Plong,Plat=Mamainse_Data_all['pole_long'][n],Mamainse_Data_all['pole_lat'][n]
    MPlower_N_upper_R_VGPs.append([Plong,Plat,1.])
for n in range(55,65):
    Plong,Plat=Mamainse_Data_all['pole_long_rev'][n],Mamainse_Data_all['pole_lat_rev']
    MPlower_N_upper_R_VGPs.append([Plong,Plat,1.])
MPlower_N_upper_R_mean=pmag.fisher_mean(MPlower_N_upper_R_VGPs)

pole_means.loc['lower_N_upper_R'] = pandas.Series({'name':'lower N and upper R',
                                       'pole_lat':str(round(MPlower_N_upper_R_mean['inc'],
                                       'pole_long':str(round(MPlower_N_upper_R_mean['dec']
                                       'A_95':str(round(MPlower_N_upper_R_mean['alpha95'],
                                       'N':str(int(MPlower_N_upper_R_mean['n']))})

MPupper_N_VGPs=[]
for n in range(65,99):
    Plong,Plat=Mamainse_Data_all['pole_long'][n],Mamainse_Data_all['pole_lat'][n]
    MPupper_N_VGPs.append([Plong,Plat,1.])
MPupper_N_mean=pmag.fisher_mean(MPupper_N_VGPs)
```

```
pole_means.loc['upper_N'] = pandas.Series({'name':'upper N',
                                     'pole_lat':str(round(MPupper_N_mean['inc'],1)),
                                     'pole_long':str(round(MPupper_N_mean['dec'],1)),
                                     'A_95':str(round(MPupper_N_mean['alpha95'],1)),
                                     'N':str(int(MPupper_N_mean['n']))})

MPupper_N_woMP306_VGPs=[]
for n in range(65,92):
    Plong,Plat=Mamainse_Data_all['pole_long'][n],Mamainse_Data_all['pole_lat'][n]
    MPupper_N_woMP306_VGPs.append([Plong,Plat,1.])
MPupper_N_woMP306_mean=pmag.fisher_mean(MPupper_N_woMP306_VGPs)

pole_means.loc['upper_N_woMP306'] = pandas.Series({'name':'upper N (w/o MP306)',
                                     'pole_lat':str(round(MPupper_N_woMP306_mean['inc'],
                                     'pole_long':str(round(MPupper_N_woMP306_mean['dec']
                                     'A_95':str(round(MPupper_N_woMP306_mean['alpha95'],
                                     'N':str(int(MPupper_N_woMP306_mean['n']))})

pole_means
```

Out [10]:

	name	pole_lat	pole_long	A_95	N
lower_R1	lower R pole 1	49.5	227.0	5.3	24
lower_R2	lower R pole 2	37.5	205.2	4.5	14
lower_N_upper_R	lower N and upper R	36.1	189.7	4.9	24
upper_N	upper N	31.2	183.2	2.5	34
upper_N_woMP306	upper N (w/o MP306)	33.7	183.1	2.0	27

5 Comparision between Mamainse Point VGPs and other Midcontinent Rift VGPs

5.1 Comparision between Siemens Creek Volcanics VGPs and Mamainse Point lower R pole 1 VGPs

Import data from the Siemens Creek Volcanics (Palmer and Halls, 1986) from sites 15 to 24 which are those that the authors argue come from the panel with the most robust tilt-correction. Tests for a common mean are conducted between these data and data from the lower reversed polarity zone of Mamainse Point (the lowermost 600 meters of stratigraphy; flows used for Mamainse Point lower R pole 1).

In [11]:
```
SCV_VGP=[]
SCV_Plong=[]
SCV_Plat=[]

data_file='../Data/SCV_VGP.txt'
f=open(data_file,'rU')
for line in f.readlines():
    rec=line.split()
    Plong,Plat=float(rec[0]),float(rec[1])
    SCV_VGP.append([Plong,Plat,1.])
    SCV_Plong.append(Plong)
    SCV_Plat.append(Plat)
```

In [12]:
```
#Conduct the Watson V and Bootstrap tests for a common mean
IPmag.iWatsonV(MPlowerR1_VGPs,SCV_VGP)
IPmag.iBootstrap(MPlowerR1_VGPs,SCV_VGP)
```

```
Results of Watson V test:

Watson's V:           5.5
Critical value of V:  6.6
```

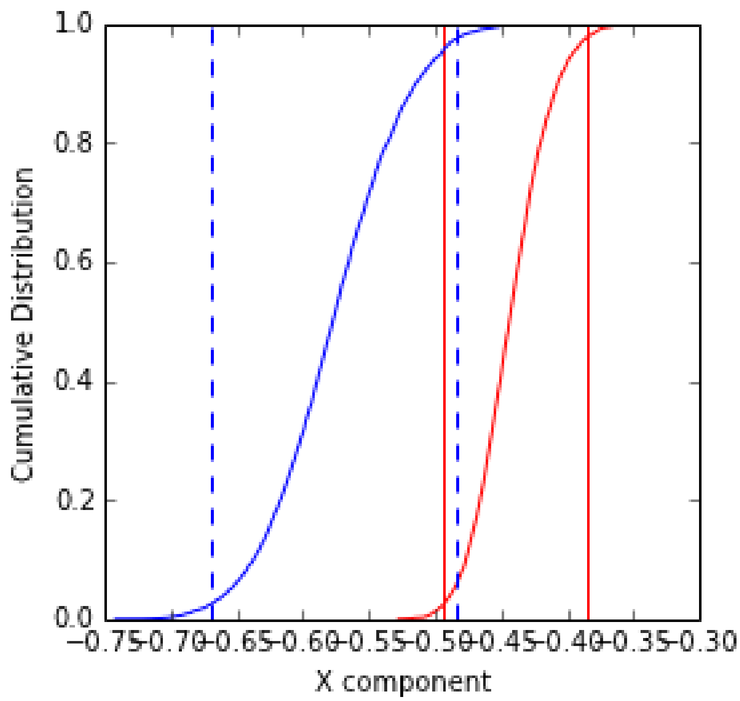
"Pass": Since V is less than Vcrit, the null hypothesis that the two populations are drawn from distributions that share a common mean direction can not be rejected.

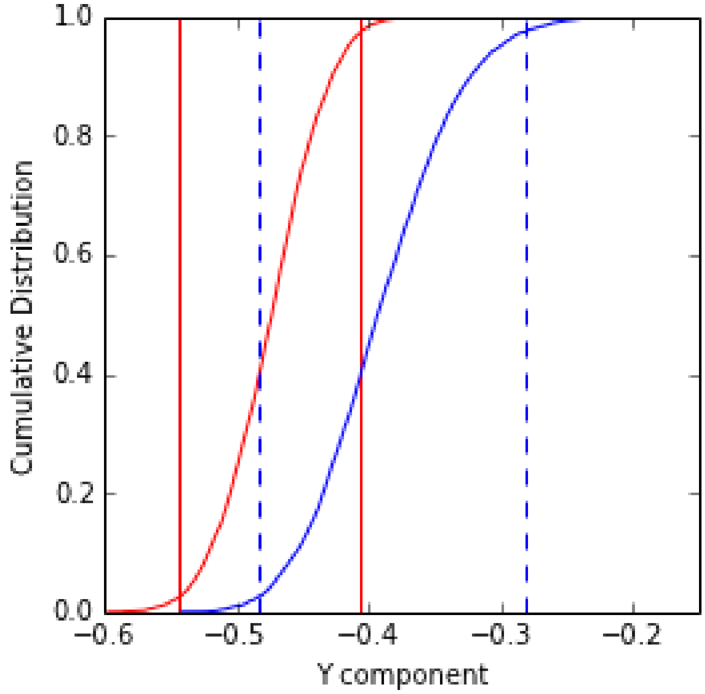
M&M1990 classification:

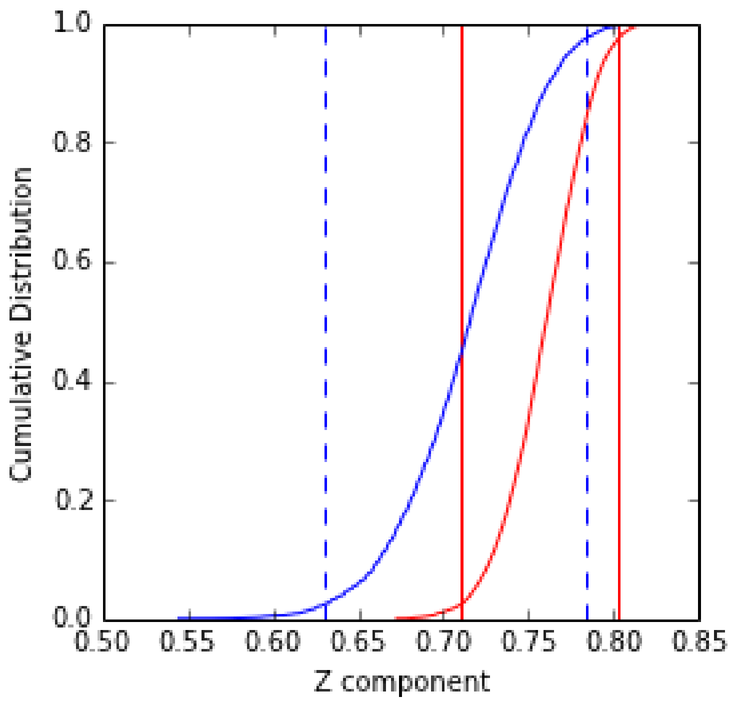
Angle between data set means: 9.5
Critical angle for M&M1990:   10.4
The McFadden and McElhinny (1990) classification for this test is: 'C'

===============

Here are the results of the bootstrap test for a common mean







5.2 Comparision between Osler Volcanic Group VGPs and Mamainse Point lower R pole 2 VGPs

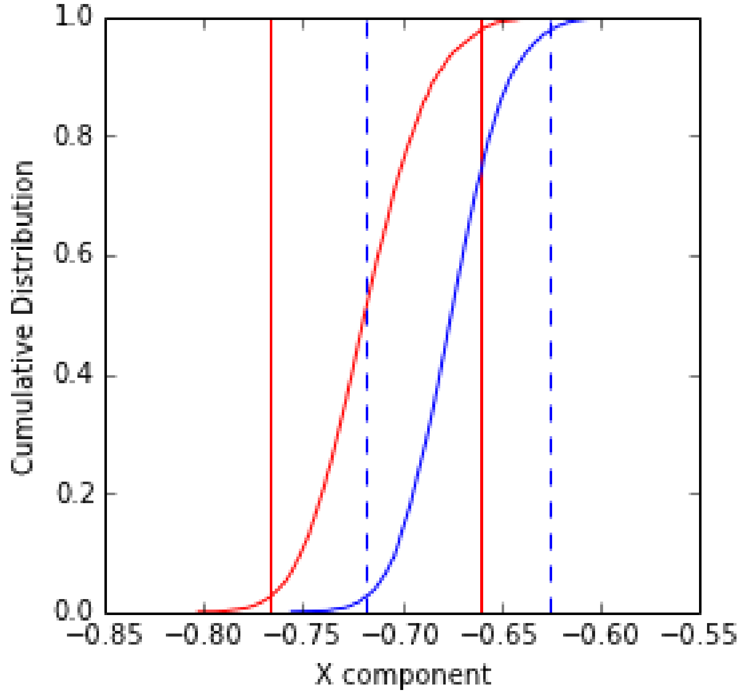
Import data from the upper portion of the stratigraphy of the Osler Volcanics Group (upper third of the Simpson Island stratigraphy; data of Swanson-Hysell et al., in review). Tests for a common mean are conducted between these data and upper portion of the lower reversed polarity zone at Mamainse Point (flows used for Mamainse Point lower R pole

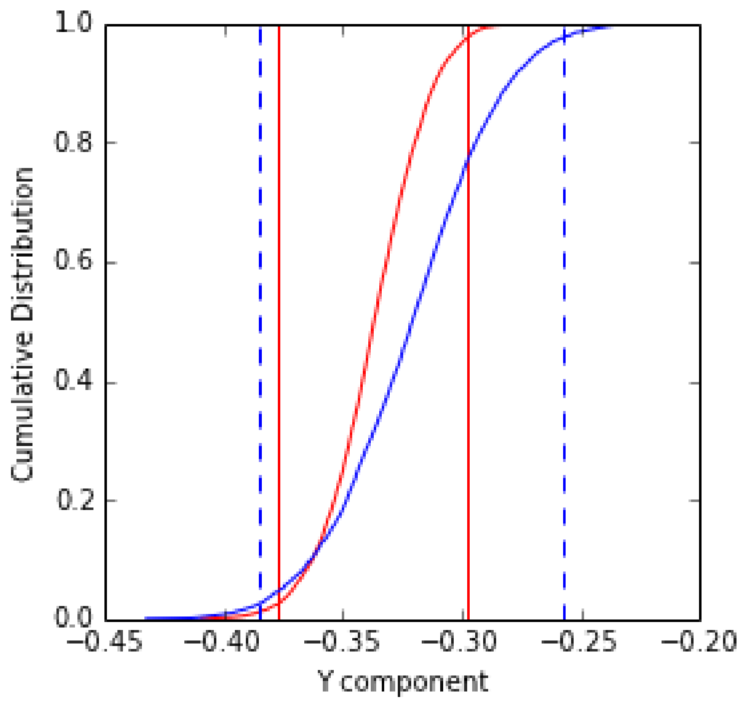
2).

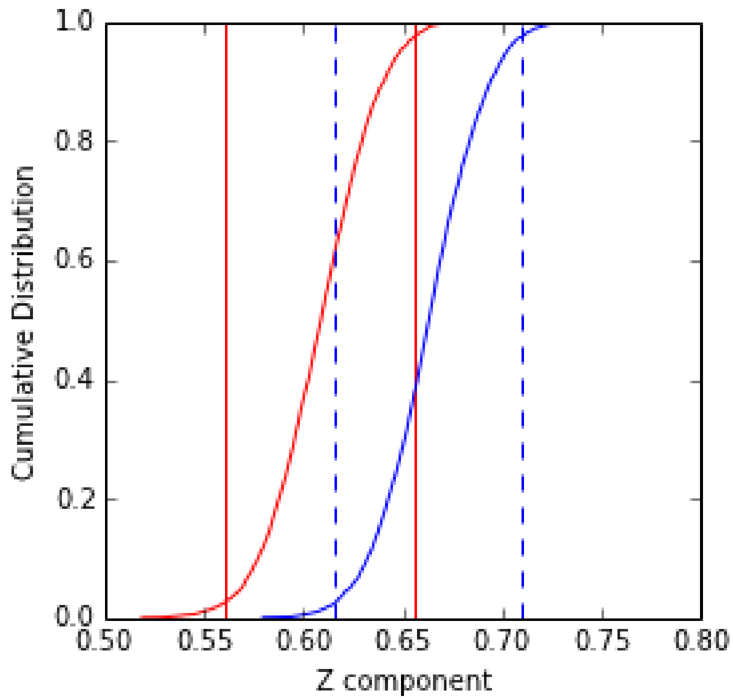
In [13]:
```
Osler_upperthird_VGP=[]
Osler_upperthird_Plong=[]
Osler_upperthird_Plat=[]

data_file='../Data/SI_upperthird_VGP.txt'
f=open(data_file,'rU')
for line in f.readlines():
    rec=line.split()
    Plong,Plat=float(rec[0]),float(rec[1])
    Osler_upperthird_VGP.append([Plong,Plat,1.])
    Osler_upperthird_Plong.append(Plong)
    Osler_upperthird_Plat.append(Plat)
```

In [14]:
```
#Conduct the Watson V and Bootstrap tests for a common mean
IPmag.iWatsonV(MPlowerR2_VGPs,Osler_upperthird_VGP)
IPmag.iBootstrap(MPlowerR2_VGPs,Osler_upperthird_VGP)
```

```
Results of Watson V test:

Watson's V:           2.4
Critical value of V:  6.2
"Pass": Since V is less than Vcrit, the null hypothesis
that the two populations are drawn from distributions
that share a common mean direction can not be rejected.

M&M1990 classification:

Angle between data set means: 4.0
Critical angle for M&M1990:   6.5
The McFadden and McElhinny (1990) classification for
this test is: 'B'

===============

Here are the results of the bootstrap test for a common mean
```


Cumulative Distribution
X component
1.0
0.8
0.6
0.4
0.2
0.0
−0.85
−0.80
−0.75
−0.70
−0.65
−0.60
−0.55


Cumulative Distribution
Y component
1.0
0.8
0.6
0.4
0.2
0.0
−0.45
−0.40
−0.35
−0.30
−0.25
−0.20



5.3 Comparision between SW limb of the North Shore Volcanic Group VGPs and Mamainse Point upper normal polarity zone VGPs

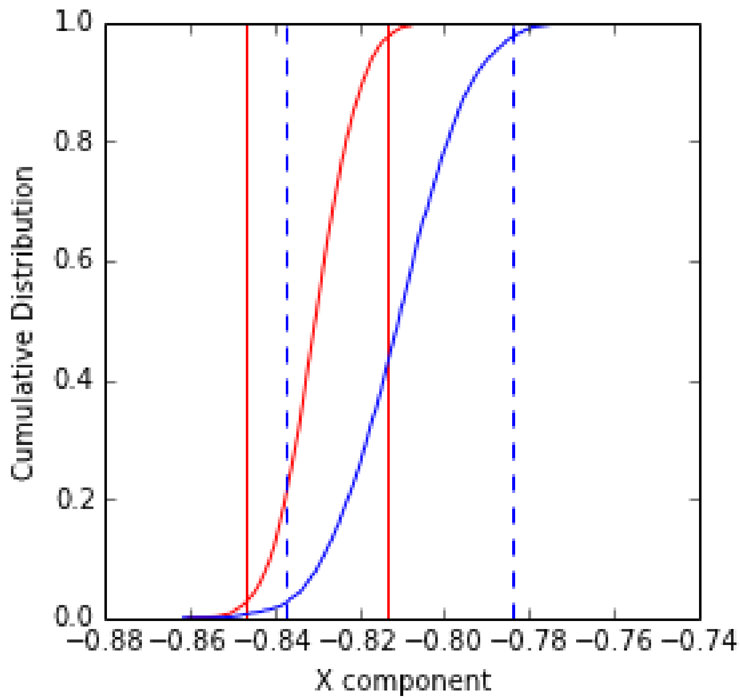
Import VGPs from the North Shore Volcanic Group (Tauxe and Kodama, 2009) from flows on the SW limb that are between the 40th Ave Icelandite and the Palisade Rhyolite. Tests for a common mean are conducted between these data and data from the upper normal polarity at Mamainse Point (VGPs from the 1000 meters above Great Conglomerate; upper N [w/o MP306] pole).

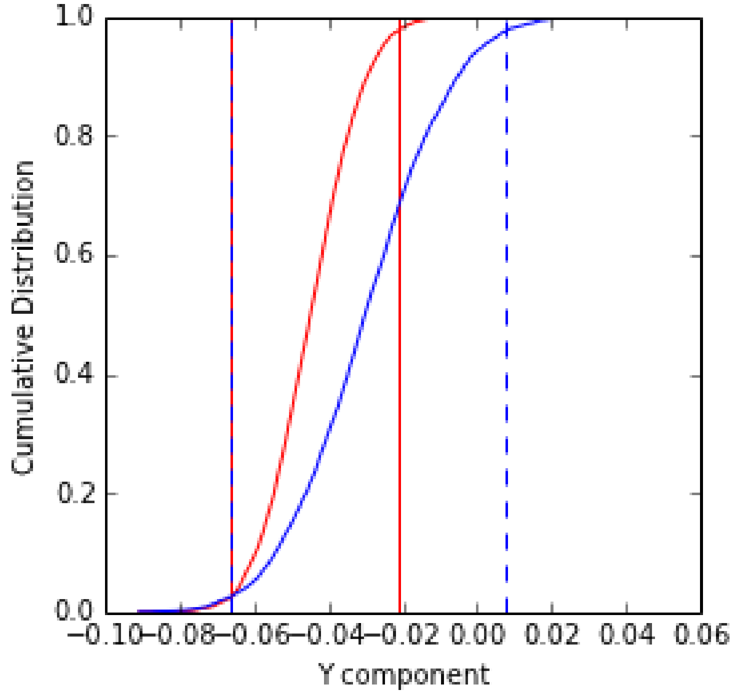
In [15]:
```
NSVG_SWlimb_VGP=[]
NSVG_SWlimb_Plong=[]
NSVG_SWlimb_Plat=[]

data_file='../Data/NSVGsubset_VGP.txt'  #This file contains data from flows on the SW l
f=open(data_file,'rU')
for line in f.readlines():
    rec=line.split()
    Plong,Plat=float(rec[0]),float(rec[1])
    NSVG_SWlimb_VGP.append([Plong,Plat,1.])
    NSVG_SWlimb_Plong.append(Plong)
    NSVG_SWlimb_Plat.append(Plat)
```

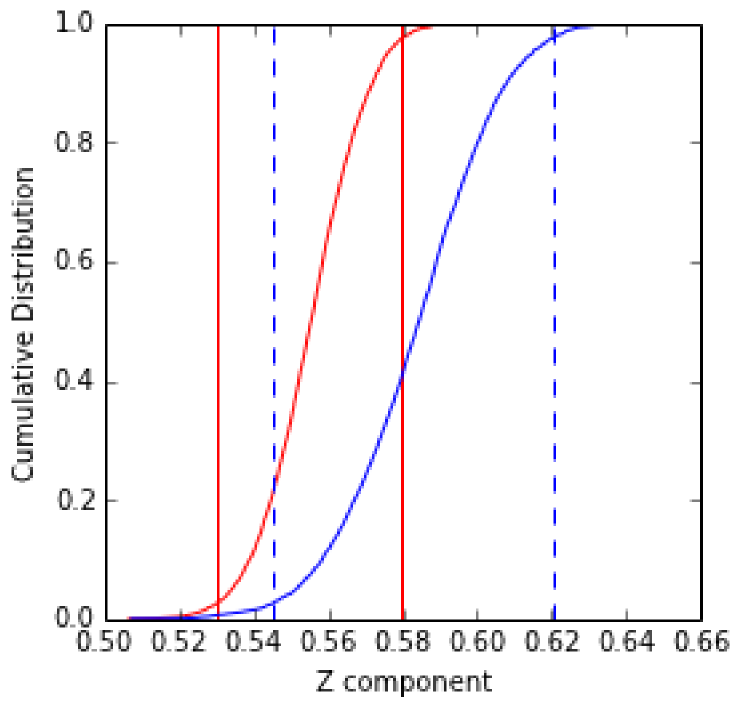
In [16]:
```
#Conduct the Watson V and Bootstrap tests for a common mean
IPmag.iWatsonV(MPupper_N_woMP306_VGPs,NSVG_SWlimb_VGP)
IPmag.iBootstrap(MPupper_N_woMP306_VGPs,NSVG_SWlimb_VGP)
```

```
Results of Watson V test:

Watson's V:           2.2
Critical value of V:  6.1
"Pass": Since V is less than Vcrit, the null hypothesis
that the two populations are drawn from distributions
```

```
that share a common mean direction can not be rejected.

M&M1990 classification:

Angle between data set means: 2.2
Critical angle for M&M1990:   3.7
The McFadden and McElhinny (1990) classification for
this test is: 'A'

===============

Here are the results of the bootstrap test for a common mean
```





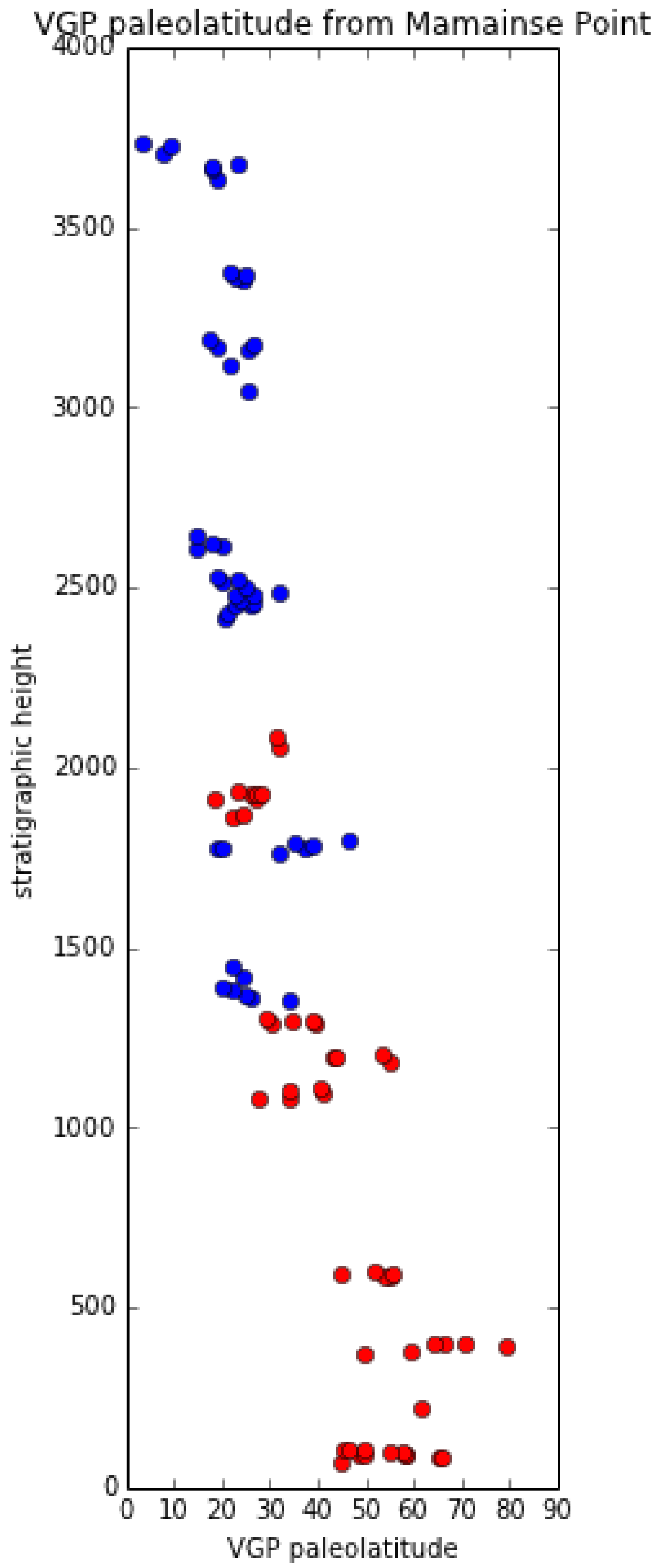


6 Stratigraphic plot of VGP paleolatitude

This code takes the Mamainse Point data and creates a stratigraphic plot of the absolute value of the paleolatitude implied by each virtual geomagnetic pole. This plot was published in the supplementary materials as Figure DR3.

In [17]:
```
strat_height_forplot=[]
abs_paleolatitude_forplot=[]
inclination_forplot=[]

for n in range(0,52):
    strat_height_forplot.append(Mamainse_Data_all['composite_meter_level'][n])
    abs_paleolatitude_forplot.append(numpy.absolute(Mamainse_Data_all['paleolatitude']
    inclination_forplot.append(Mamainse_Data_all['I_tilt-cor'][n])
for n in range(55,99):
    strat_height_forplot.append(Mamainse_Data_all['composite_meter_level'][n])
    abs_paleolatitude_forplot.append(numpy.absolute(Mamainse_Data_all['paleolatitude']
    inclination_forplot.append(Mamainse_Data_all['I_tilt-cor'][n])
```

In [18]:
```
for n in range(0, len(strat_height_forplot)):
    if inclination_forplot[n]>0:
        pylab.plot(abs_paleolatitude_forplot[n],strat_height_forplot[n],'bo')
        #print strat_height[item]
    elif inclination_forplot[n]<0:
        pylab.plot(abs_paleolatitude_forplot[n],strat_height_forplot[n],'ro')

plt.title("VGP paleolatitude from Mamainse Point")
plt.xlabel("VGP paleolatitude")
plt.ylabel("stratigraphic height")
pylab.xlim([0,90])
fig = matplotlib.pyplot.gcf()
fig.set_size_inches(3,10)
savefig('Mamainse_Strat.svg')
```



VGP paleolatitude from Mamainse Point
stratigraphic height
VGP paleolatitude
0
500
1000
1500
2000
2500
3000
3500
4000
0
10
20
30
40
50
60
70
80
90