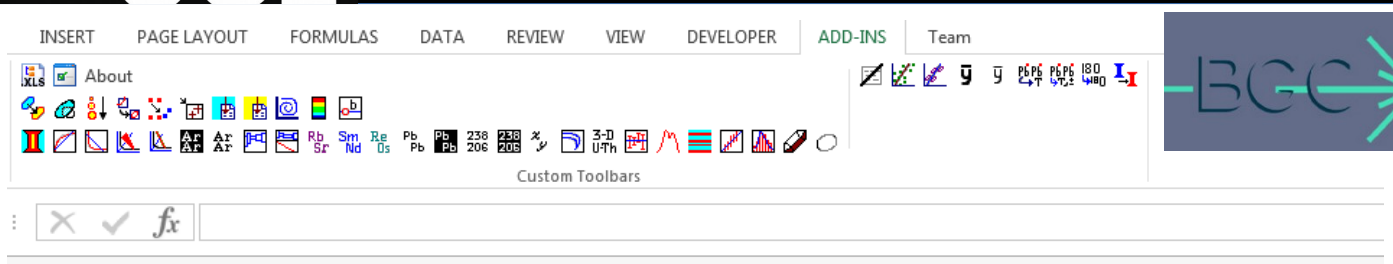
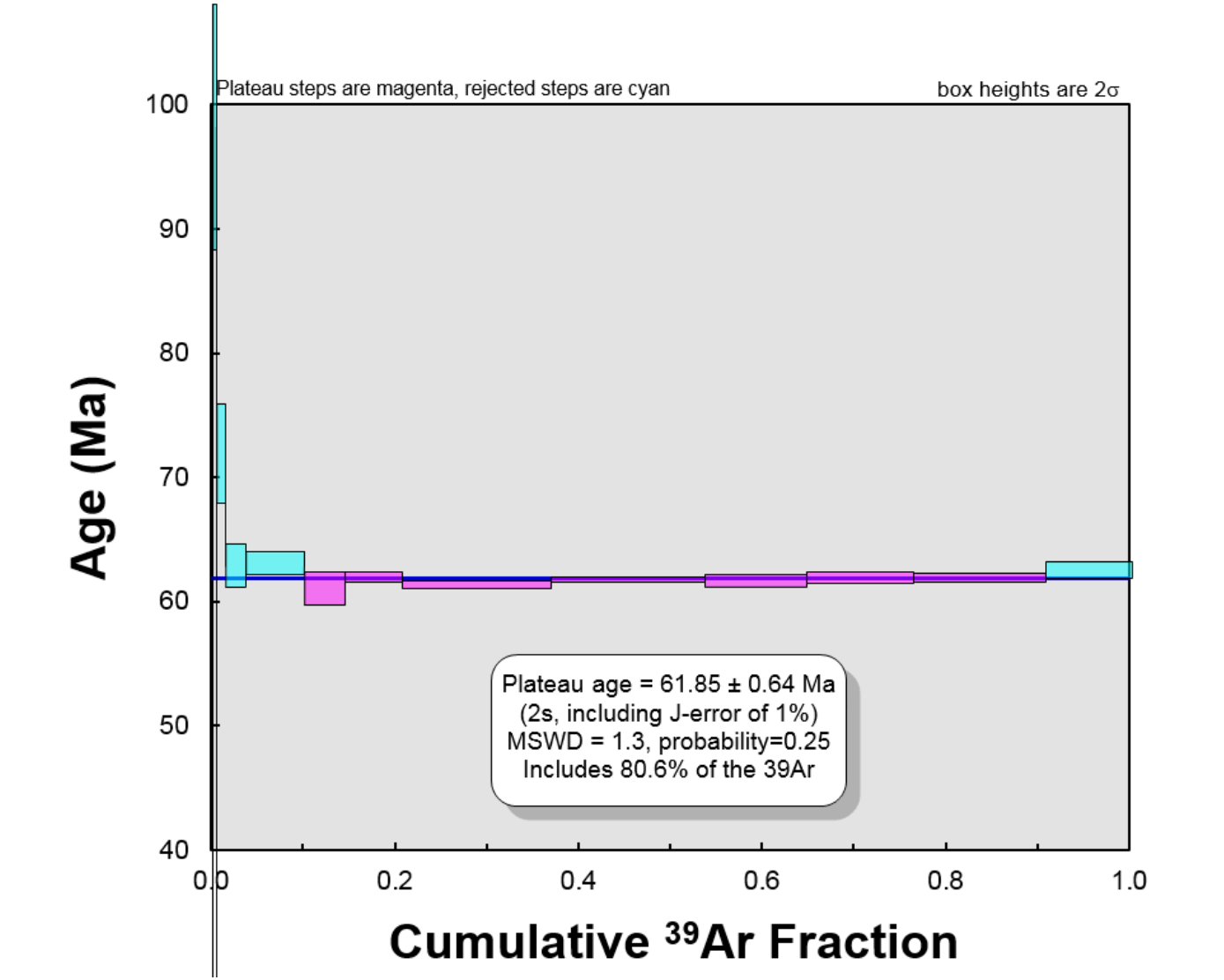
Beyond `Isoplot`: new software for better geochronology

Pieter Vermeesch

London Geochronology Centre
University College London
p.vermeesch@ucl.ac.uk



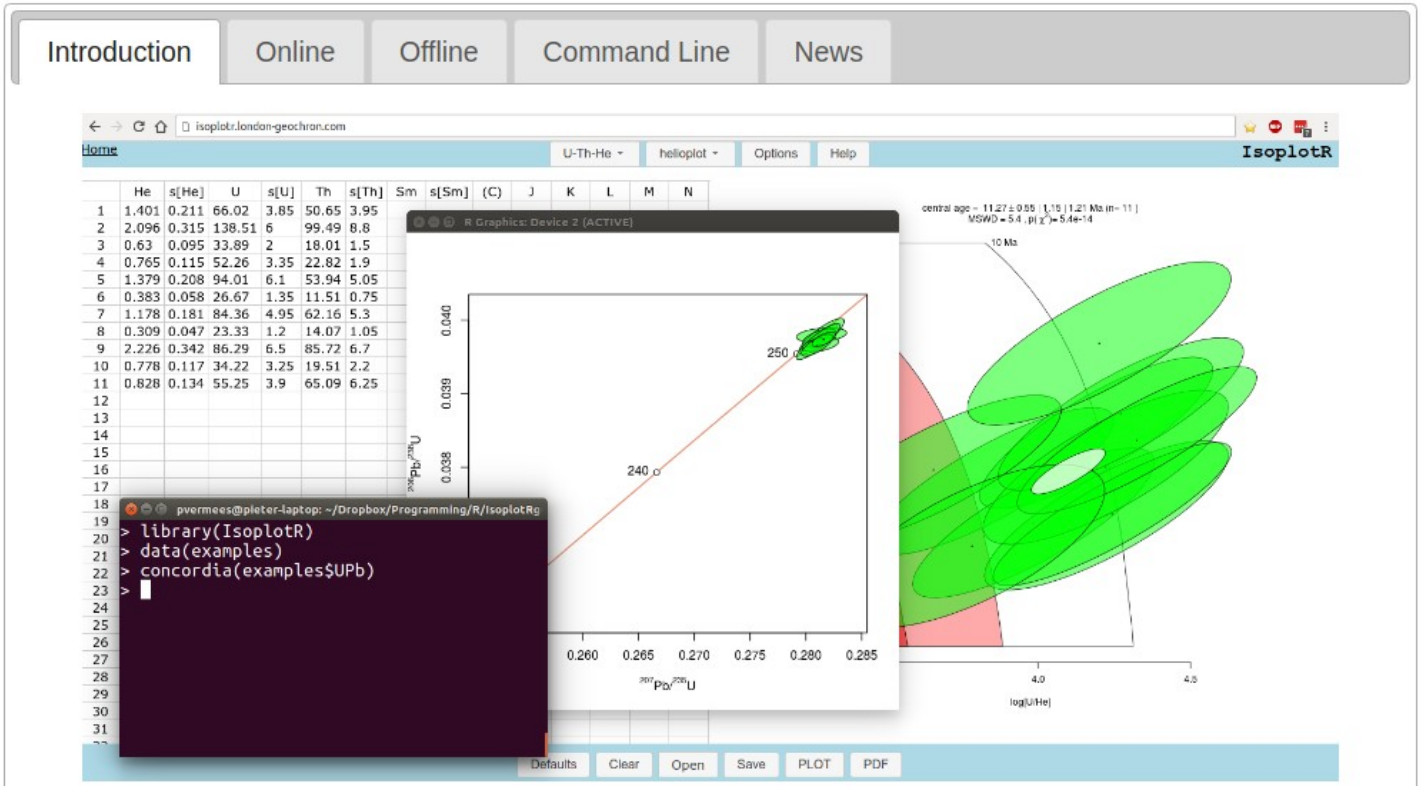


Berkeley Geochronology Center

Isoplot 3 is not compatible with either *Excel 2007* or *Excel 2010*. If you must use *Excel 2007* or *Excel 2010*, request a copy *Isoplot 4*, which is compatible with *Excel 2007/2010* only. *Isoplot 4* has no more functionality than *Isoplot 3.7*, and somewhat less flexibility. Expect a speed penalty of up to a factor of 10 when using *Excel 2007/2010*.

There are no versions of *Isoplot* compatible with native Macintosh versions of *Excel*, including *Excel* 2011. To run *Isoplot* on the Macintosh, you will need to acquire a Windows-enabling program (*Fusion* will work, but not *Crossover* nor *Parallels*). Despite expectations on my part, *Excel 2011* is not *Isoplot*-compatible

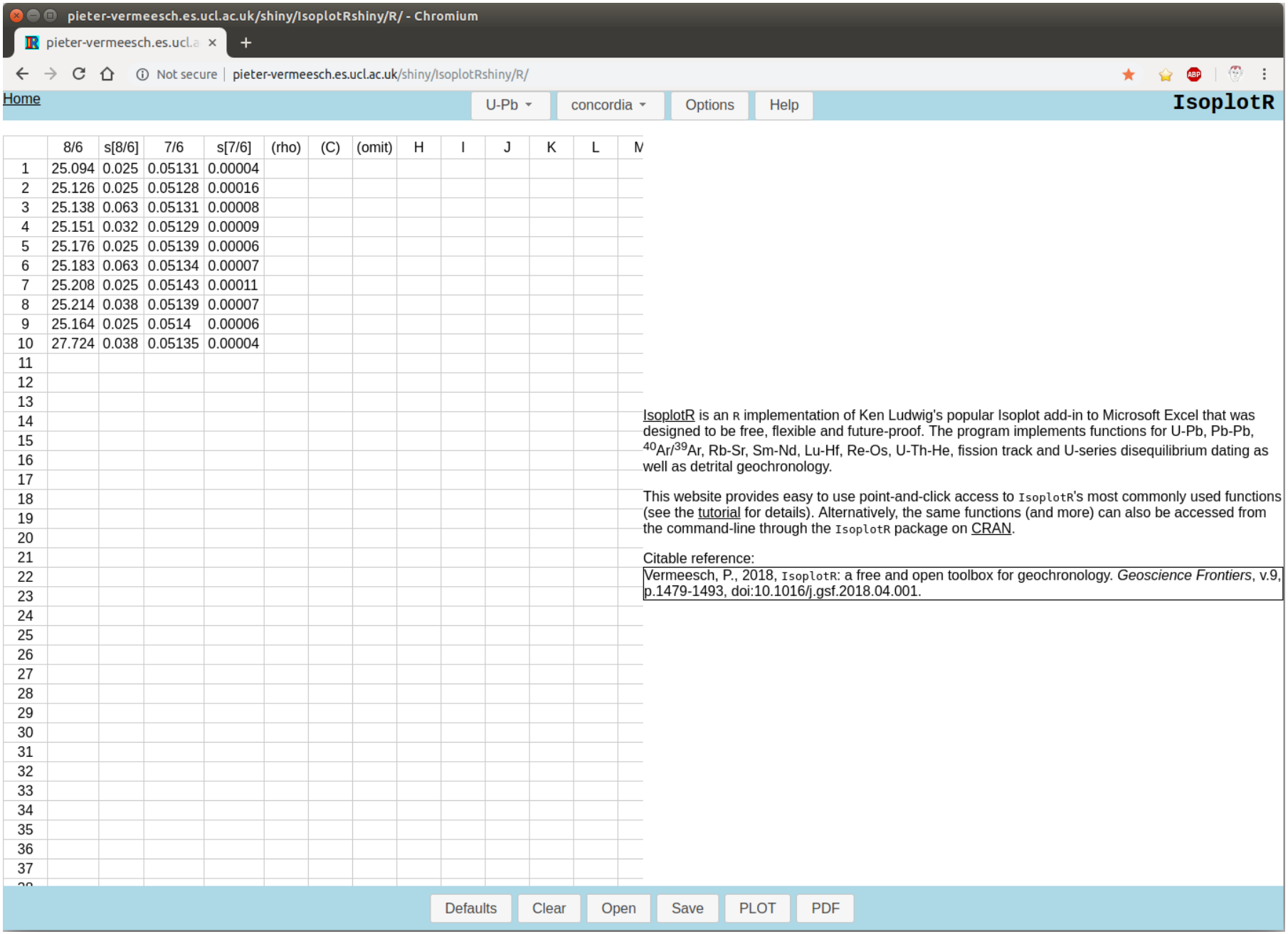
IsoplotR: a free and extendable toolbox for geochronology



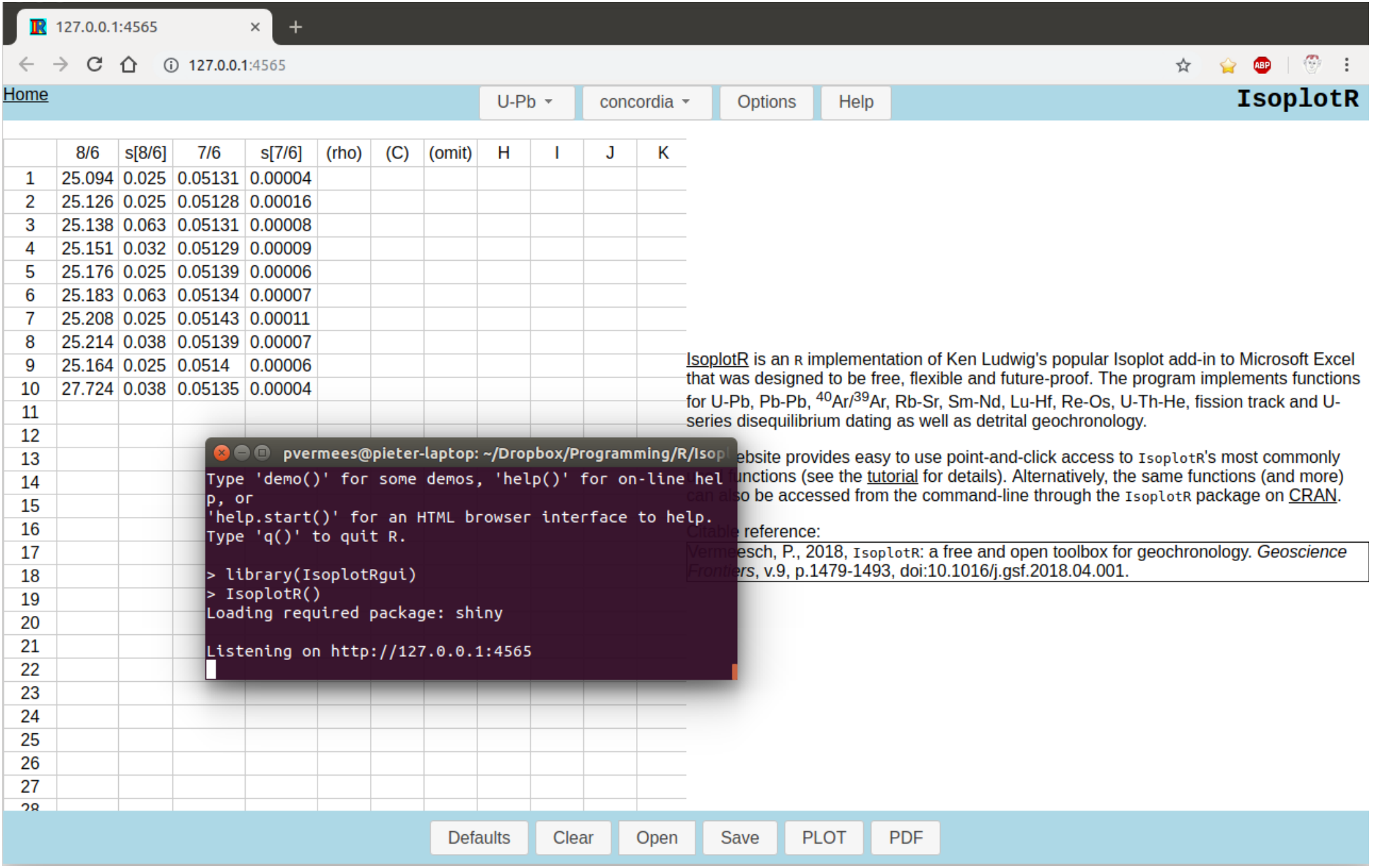
IsoplotR is a free and open-source substitute for Kenneth Ludwig's popular *Isoplot* add-in to Microsoft *Excel*. *IsoplotR* is programmed in *R* and can be run in three different modes:

1. Online: A user-friendly Graphical User Interface (GUI) that runs in a web browser on any internet-connected device.
2. Offline: The GUI can be run natively on any computer that has *R* installed on it. *R* is free software that is available on Windows, Mac and Linux/Unix.
3. Command Line: Advanced users can access the full functionality of *IsoplotR* from *R*'s command line. This enables *IsoplotR* to be extended and incorporated into automation scripts.

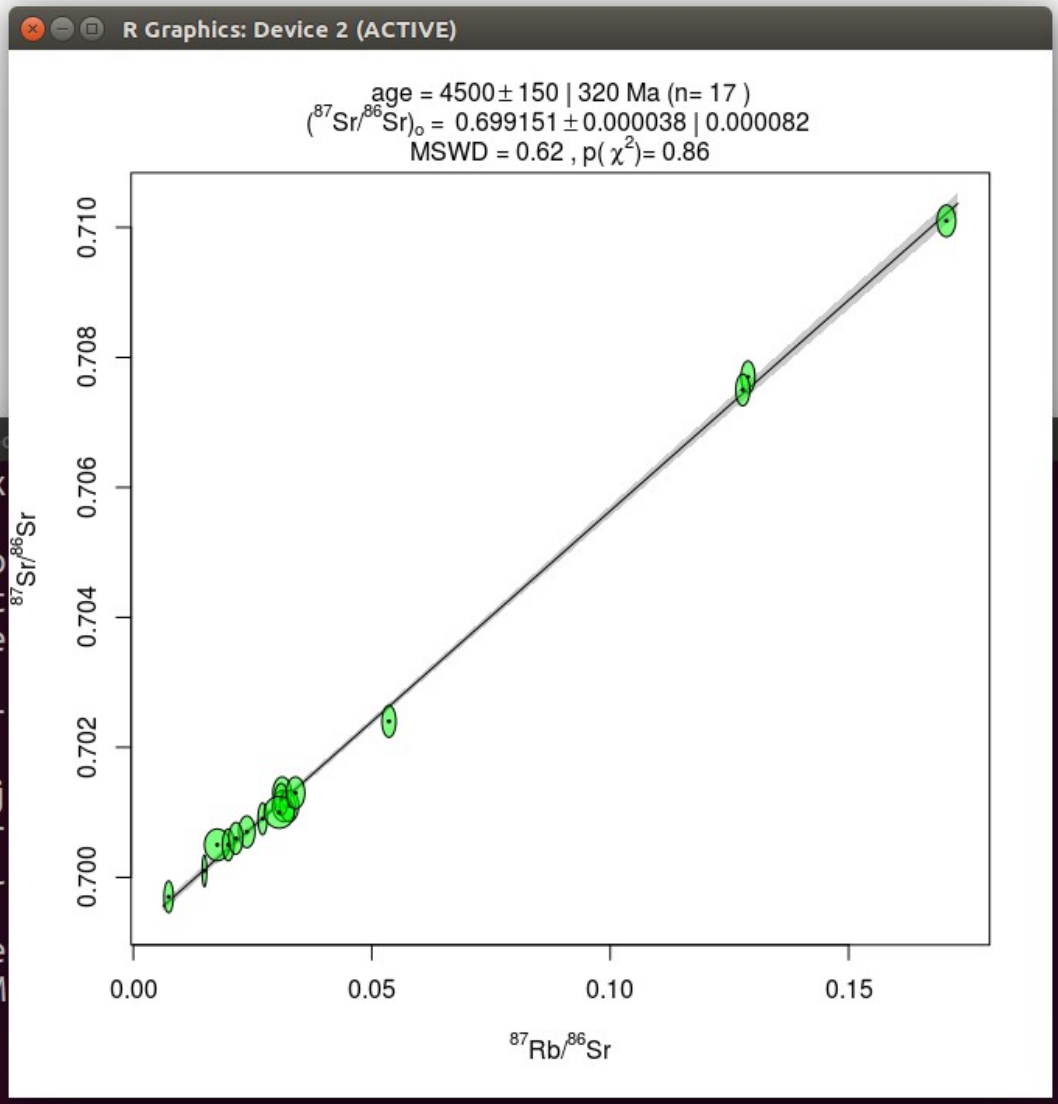
Citable reference:
Vermeesch, P., 2018, `IsoplotR`: a free and open toolbox for geochronology. *Geoscience Frontiers*, v.9, p.1479-1493, doi: 10.1016/j.gsf.2018.04.001.



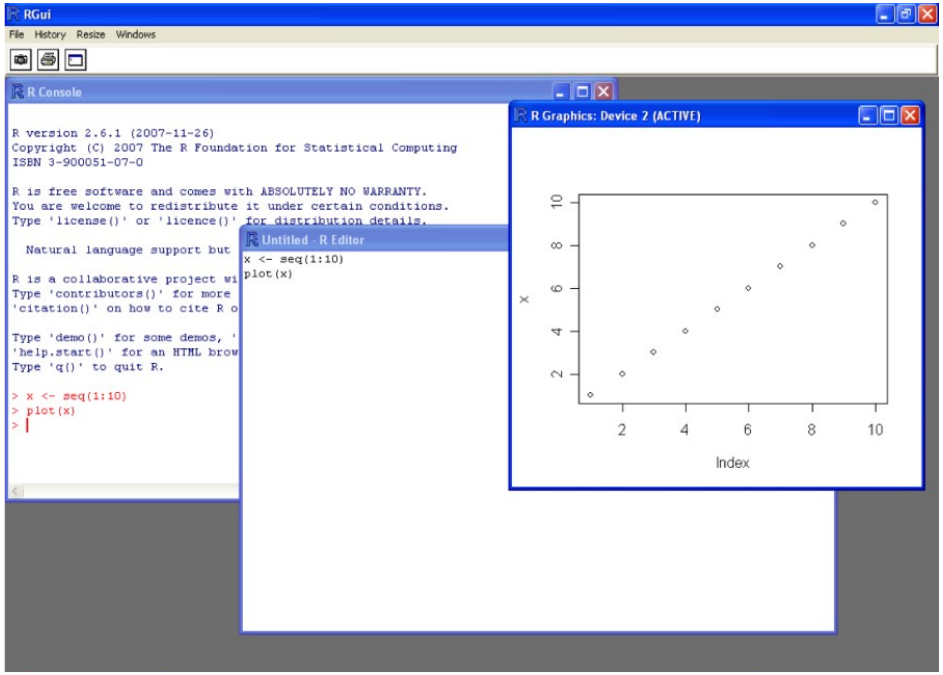
	8/6	s[8/6]	7/6	s[7/6]	(rho)	(C)	(omit)	H	I	J	K	L	M
1	25.094	0.025	0.05131	0.00004									
2	25.126	0.025	0.05128	0.00016									
3	25.138	0.063	0.05131	0.00008									
4	25.151	0.032	0.05129	0.00009									
5	25.176	0.025	0.05139	0.00006									
6	25.183	0.063	0.05134	0.00007									
7	25.208	0.025	0.05143	0.00011									
8	25.214	0.038	0.05139	0.00007									
9	25.164	0.025	0.0514	0.00006									
10	27.724	0.038	0.05135	0.00004									
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
32													
33													
34													
35													
36													
37													

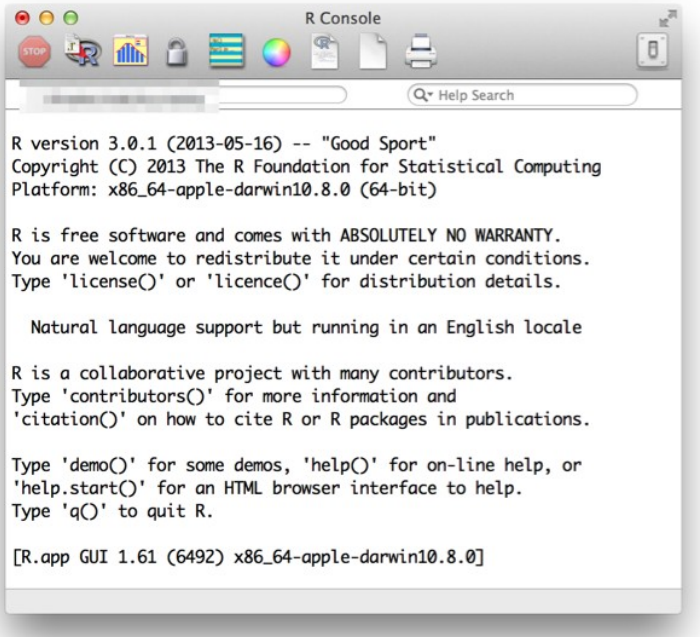


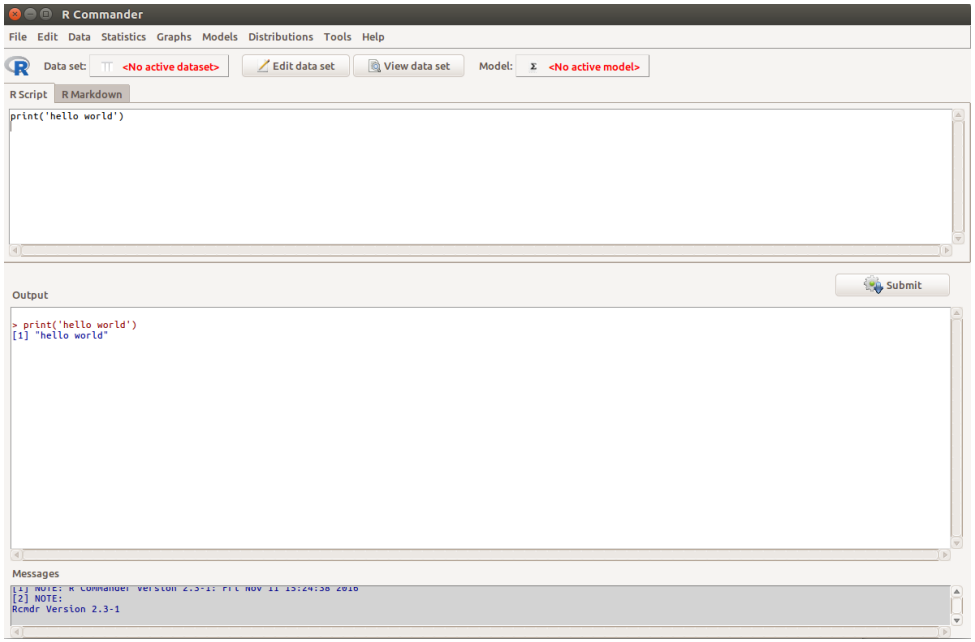
	8/6	s[8/6]	7/6	s[7/6]	(rho)	(C)	(omit)	H	I	J	K
1	25.094	0.025	0.05131	0.00004							
2	25.126	0.025	0.05128	0.00016							
3	25.138	0.063	0.05131	0.00008							
4	25.151	0.032	0.05129	0.00009							
5	25.176	0.025	0.05139	0.00006							
6	25.183	0.063	0.05134	0.00007							
7	25.208	0.025	0.05143	0.00011							
8	25.214	0.038	0.05139	0.00007							
9	25.164	0.025	0.0514	0.00006							
10	27.724	0.038	0.05135	0.00004							
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											
26											
27											
28											

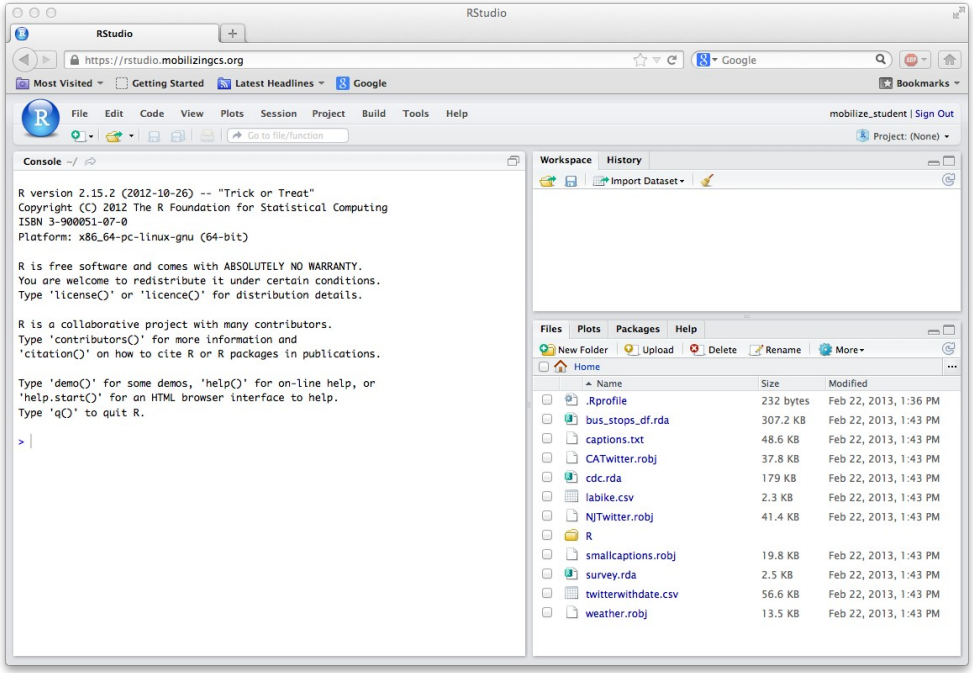



```
pvermees@pieter-laptop: ~/Dropb
Platform: x86_64-pc-linux

R is free software and co
You are welcome to redist
Type 'license()' or 'lice

  Natural language suppor

R is a collaborative proj
Type 'contributors()' for
'citation()' on how to ci

Type 'demo()' for some de
'help.start()' for an HTM
Type 'q()' to quit R.

> library(IsoplotR)
> RbSr <- read.data('RbSr1.csv',method='Rb-Sr',format=1)
> isochron(RbSr)
>
```

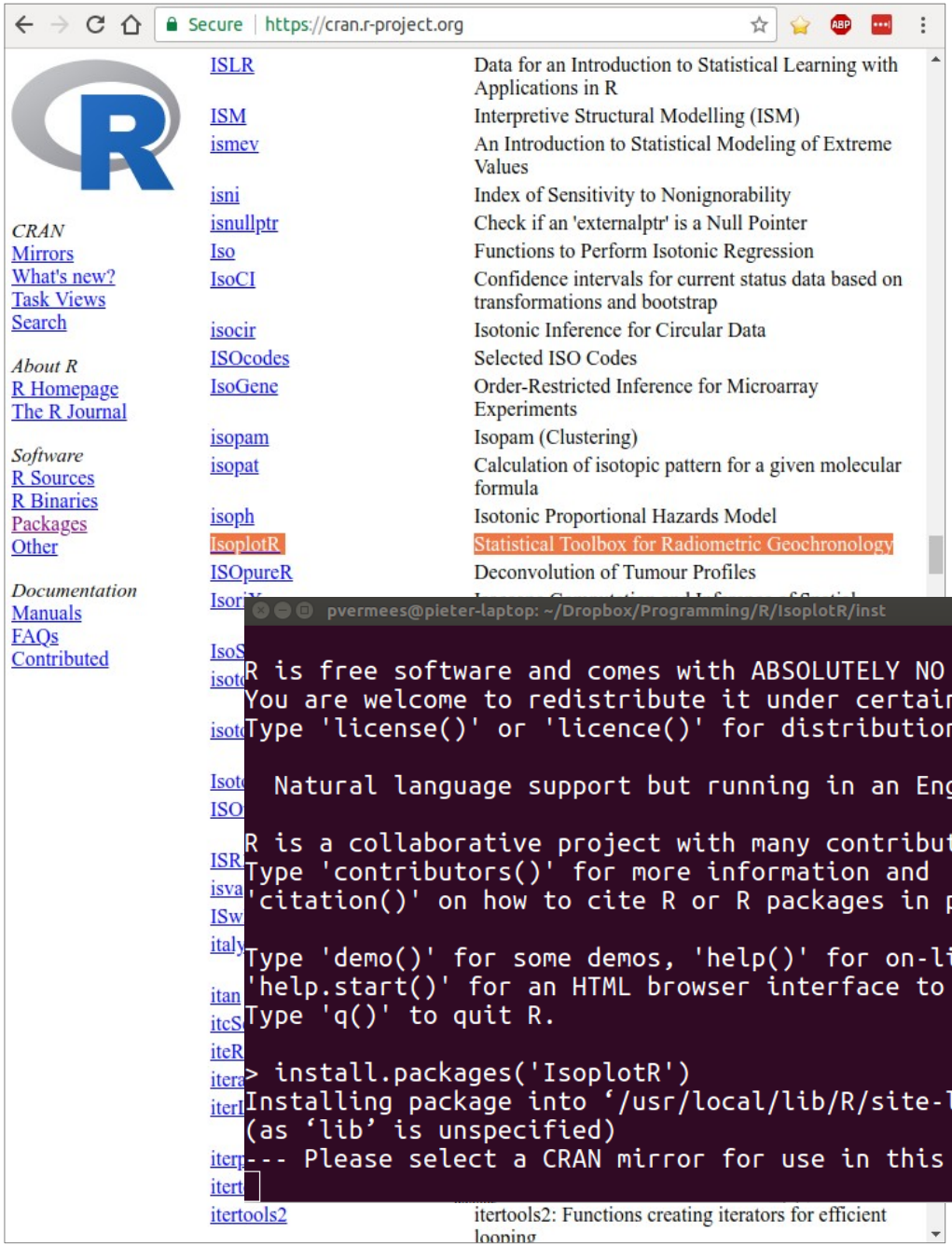

RGui
File History Resize Windows
R Console
R version 2.6.1 (2007-11-26)
Copyright (C) 2007 The R Foundation for Statistical Computing
ISBN 3-900051-07-0
R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.
Natural language support but
R is a collaborative project wi
Type 'contributors()' for more
'citation()' on how to cite R o
Type 'demo()' for some demos,
'help.start()' for an HTML brow
Type 'q()' to quit R.
> x <- seq(1:10)
> plot(x)
R Graphics: Device 2 (ACTIVE)
Untitled - R Editor
x <- seq(1:10)
plot(x)
Index

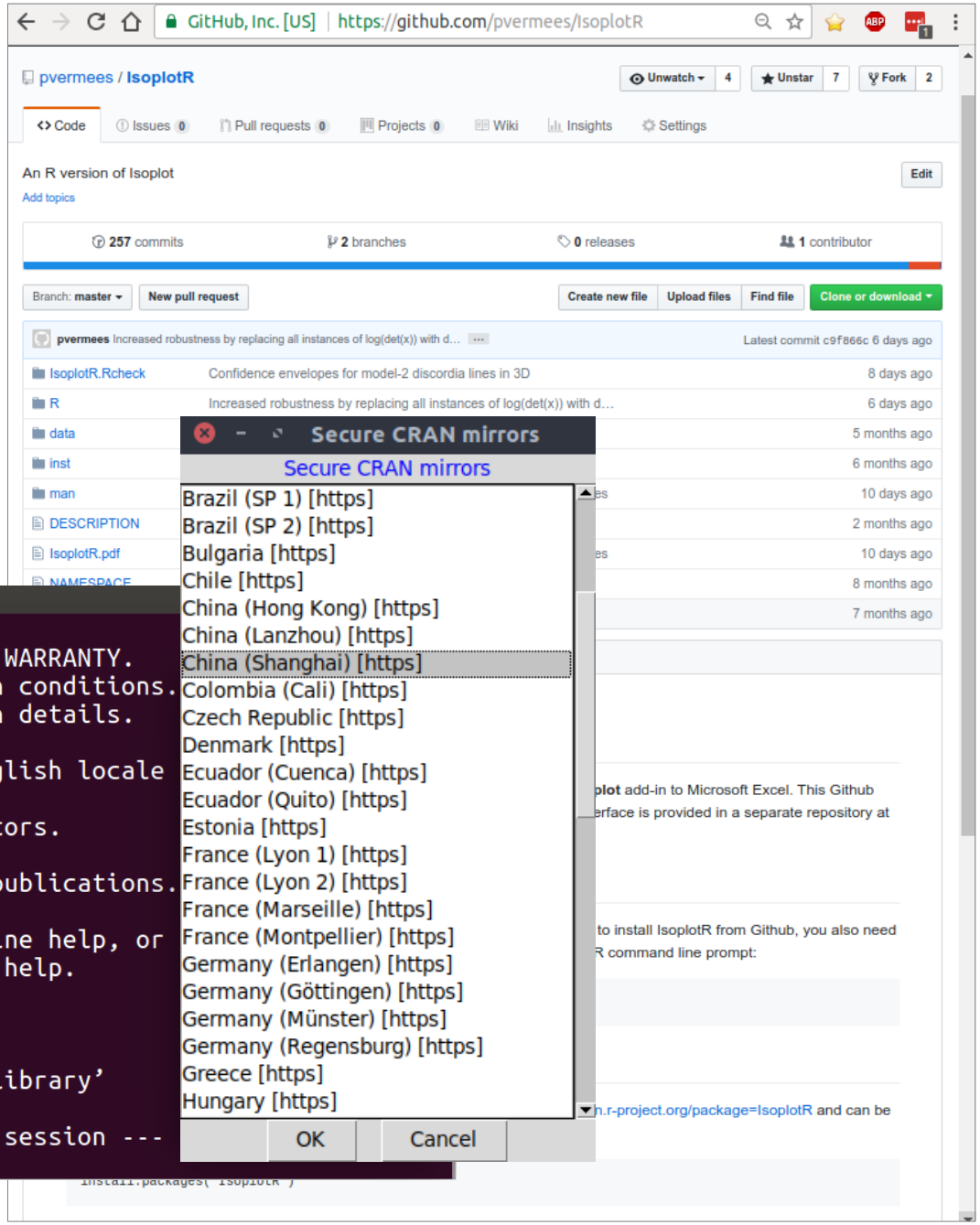

R Console
Help Search
R version 3.0.1 (2013-05-16) -- "Good Sport"
Copyright (C) 2013 The R Foundation for Statistical Computing
Platform: x86_64-apple-darwin10.8.0 (64-bit)
R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.
Natural language support but running in an English locale
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
[R.app GUI 1.61 (6492) x86_64-apple-darwin10.8.0]


R Commander
File Edit Data Statistics Graphs Models Distributions Tools Help
Data set: <No active dataset>
Edit data set
View data set
Model: <No active model>
R Script R Markdown
print('hello world')
Submit
Output
> print('hello world')
[1] "hello world"
Messages
[2] NOTE:
Rcmdr Version 2.3-1

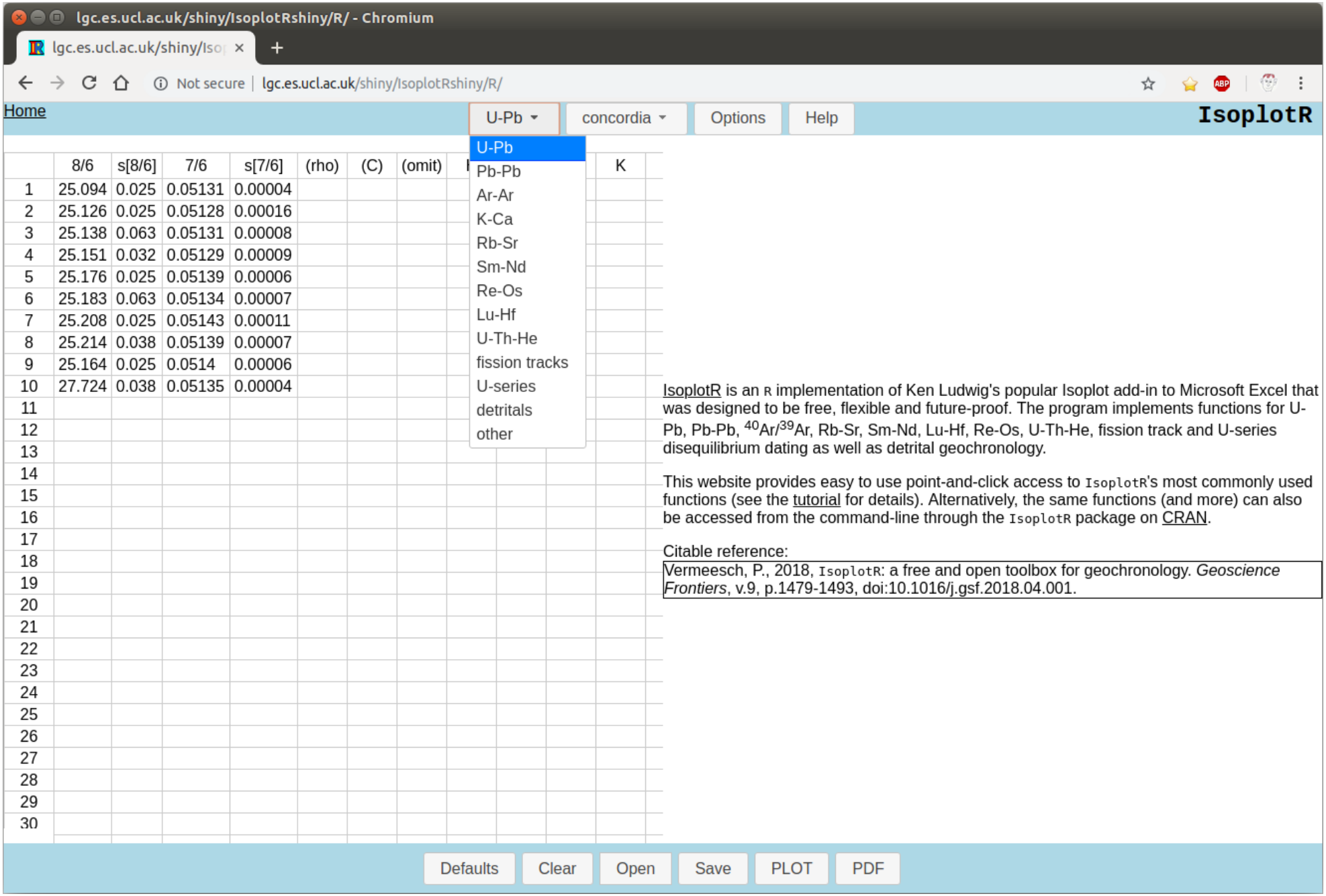

RStudio
https://rstudio.mobilizingcs.org
File Edit Code View Plots Session Project Build Tools Help
Console ~/
R version 2.15.2 (2012-10-26) -- "Trick or Treat"
Copyright (C) 2012 The R Foundation for Statistical Computing
ISBN 3-900051-07-0
Platform: x86_64-pc-linux-gnu (64-bit)
R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
Workspace History
Import Dataset
Files Plots Packages Help
New Folder Upload Delete Rename More
Home
Name Size Modified
.Rprofile 232 bytes Feb 22, 2013, 1:36 PM
bus_stops_df.rda 307.2 KB Feb 22, 2013, 1:43 PM
captions.txt 48.6 KB Feb 22, 2013, 1:43 PM
CATwitter.robj 37.8 KB Feb 22, 2013, 1:43 PM
cdc.rda 179 KB Feb 22, 2013, 1:43 PM
labike.csv 2.3 KB Feb 22, 2013, 1:43 PM
NJTwitter.robj 41.4 KB Feb 22, 2013, 1:43 PM
R
smallcaptions.robj 19.8 KB Feb 22, 2013, 1:43 PM
survey.rda 2.5 KB Feb 22, 2013, 1:43 PM
twitterwithdate.csv 56.6 KB Feb 22, 2013, 1:43 PM
weather.robj 13.5 KB Feb 22, 2013, 1:43 PM

IsoplotR can be downloaded from CRAN or GitHub





IsoplotR currently implements 13 geochronological methods

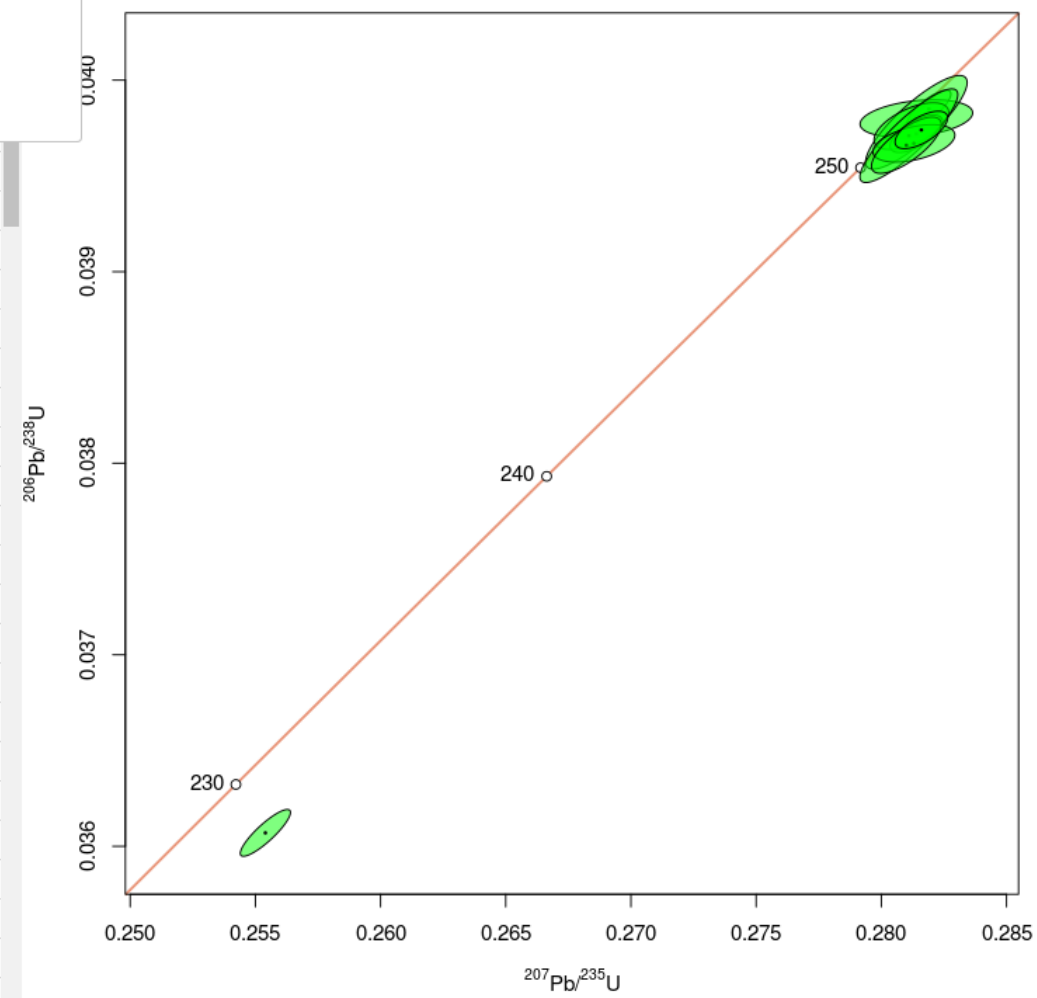


pieter-vermeesch.es.ucl.ac.uk/shiny/IsoplotRshiny/R/

Home | U-Pb | concordia | Options | Help | IsoplotR

concordia
radial plot
weighted mean
KDE
CAD
ages

	X=7/5	s[7/5]	Y=6/8	s[6/8]	Z=7/6	s[7/6]
1	0.2819	0.00036	0.03985	0.00004	0.05131	0.00004
2	0.2814	0.00092	0.0398	0.00004	0.05128	0.00016
3	0.2814	0.00083	0.03978	0.0001	0.05131	0.00008
4	0.2812	0.00061	0.03976	0.00005	0.05129	0.00009
5	0.2814	0.00043	0.03972	0.00004	0.05139	0.00006
6	0.2811	0.0008	0.03971	0.0001	0.05134	0.00007
7	0.2813	0.00067	0.03967	0.00004	0.05143	0.00011
8	0.281	0.00057	0.03966	0.00006	0.05139	0.00007
9	0.2816	0.00043	0.03974	0.00004	0.0514	0.00006
10	0.2554	0.00041	0.03607	0.00005	0.05135	0.00004
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						



Defaults | Clear | Open | Save | PLOT | PDF

pieter-vermeesch.es.ucl.ac.uk/shiny/IsoplotRshiny/R/

Home | U-Pb | concordia | Options | Help | IsoplotR

	X=7/5	s[7/5]	Y=6/8	s[6/8]	Z=7/6	s[7/6]	(rhoXY)	(rhoYZ)	(C)	J
1	0.2819	0.00036	0.03985	0.00004	0.05131	0.00004				
2	0.2814	0.00092	0.0398	0.00004	0.05128	0.00016				
3	0.2814	0.00083	0.03978	0.0001	0.05131	0.00008				
4	0.2812	0.00061	0.03976	0.00005	0.05129	0.00009				
5	0.2814	0.00043	0.03972	0.00004	0.05139	0.00006				
6	0.2811	0.0008	0.03971	0.0001	0.05134	0.00007				
7	0.2813	0.00067	0.03967	0.00004	0.05143	0.00011				
8	0.281	0.00057	0.03966	0.00006	0.05139	0.00007				
9	0.2816	0.00043	0.03974	0.00004	0.0514	0.00006				
10	0.2554	0.00041	0.03607	0.00005	0.05135	0.00004				
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										
37										

Input:

7/5: Measured $^{207}Pb/^{235}U$-ratios.
s[7/5]: Standard error of the $^{207}Pb/^{235}U$-ratios.
6/8: Measured $^{206}Pb/^{238}U$-ratios.
s[6/8]: Standard error of the $^{206}Pb/^{238}U$-ratios.
7/6: Measured $^{207}Pb/^{206}Pb$-ratios.
s[7/6]: Standard error of the $^{207}Pb/^{206}Pb$-ratios.
(rhoXY): Error correlation between the $^{207}Pb/^{235}U$- and $^{206}Pb/^{238}U$-ratios (optional).
(rhoYZ): Error correlation between the $^{238}U/^{206}Pb$- and $^{207}Pb/^{206}Pb$-ratios (optional). The same assumption applies as for `rhoYZ`
(rhoYZ): Error correlation between the $^{238}U/^{206}Pb$- and $^{207}Pb/^{206}Pb$-ratios (optional).
(C): Optional variable to be used as fill colours in concordia and radial plots.

If `rhoXY`, `rhoXZ` or `rhoYZ` are omitted, then their value will be inferred from the redundancy between the three sets of standard errors (`s[X]`, `s[Y]` and `s[Z]`). This inference assumes that these errors are based on the same number of data points. If some data has been rejected from one ratio but not another, because of isobaric interferences, instrument issues, outlier rejection, or any other reason, then this method will not work.

Output:

The concordia diagram is a graphical means of assessing the internal consistency of U-Pb data. It sets out the measured $^{206}Pb/^{238}U$- and $^{207}Pb/^{235}$-ratios against each other ('Wetherill' diagram) or, equivalently, the $^{207}Pb/^{206}Pb$- and $^{207}Pb/^{235}U$-ratios ('Tera-Wasserburg' diagram). The space of concordant isotopic compositions is marked by a curve, the 'concordia line'. Isotopic ratio measurements are shown as 100(1-α)% confidence ellipses, where α is set in the `Options` menu. Concordant samples plot near to, or overlap with, the concordia line. They represent the pinnacle of geochronological robustness. Samples that plot away from the concordia line but are aligned along a linear trend form an isochron (or 'discordia' line) that can be used to infer the composition of the non-radiogenic ('common') lead or to constrain the timing of prior lead loss.

References:

Ludwig, K.R., 1998. On the treatment of concordant uranium-lead ages. *Geochimica et Cosmochimica Acta*, 62(4), pp.665-676.

Defaults | Clear | Open | Save | PLOT | PDF

pieter-vermeesch.es.ucl.ac.uk/shiny/IsoplotRshiny/R/

Home | U-Pb | concordia | Options | Help | IsoplotR

	X=7/5	s[7/5]	Y=6/8	s[6/8]	Z=7/6	s[7/6]	(rhoXY)	(rho
1	0.2819	0.00036	0.03985	0.00004	0.05131	0.00004		
2	0.2814	0.00092	0.0398	0.00004	0.05128	0.00016		
3	0.2814	0.00083	0.03978	0.0001	0.05131	0.00008		
4	0.2812	0.00061	0.03976	0.00005	0.05129	0.00009		
5	0.2814	0.00043	0.03972	0.00004	0.05139	0.00006		
6	0.2811	0.0008	0.03971	0.0001	0.05134	0.00007		
7	0.2813	0.00067	0.03967	0.00004	0.05143	0.00011		
8	0.281	0.00057	0.03966	0.00006	0.05139	0.00007		
9	0.2816	0.00043	0.03974	0.00004	0.0514	0.00006		
10	0.2554	0.00041	0.03607	0.00005	0.05135	0.00004		
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								

Input format: [7/5], [6/8], [7/6]

Common Pb correction: none

$^{238}U/^{235}U$ ratio: 137.818 ± 0.0225

^{238}U decay constant: 0.000155125 ± 8.3e-8 Myr^{-1}

^{235}U decay constant: 0.00098485 ± 6.7e-7 Myr^{-1}

☐ Plot as Tera-Wasserburg?

Calculate no age

Minimum t: auto

Maximum t: auto

Minimum X: auto

Maximum X: auto

Minimum Y: auto

Maximum Y: auto

Probability cutoff: 0.05

Significant digits: 2

Ellipse colour 1: rgb(0,1,0,0.5)

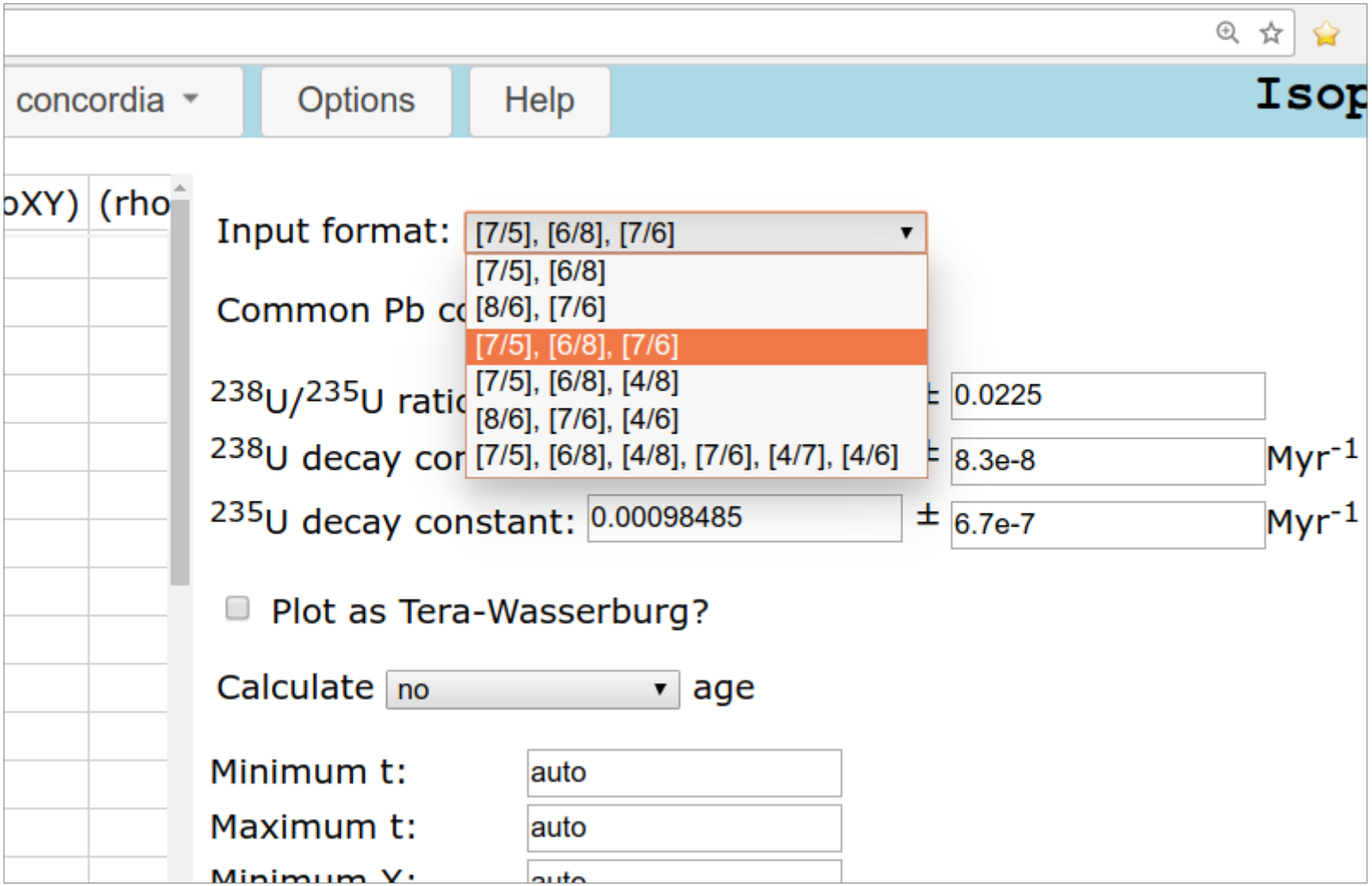
Ellipse colour 2: rgb(1,0,0,0.5)

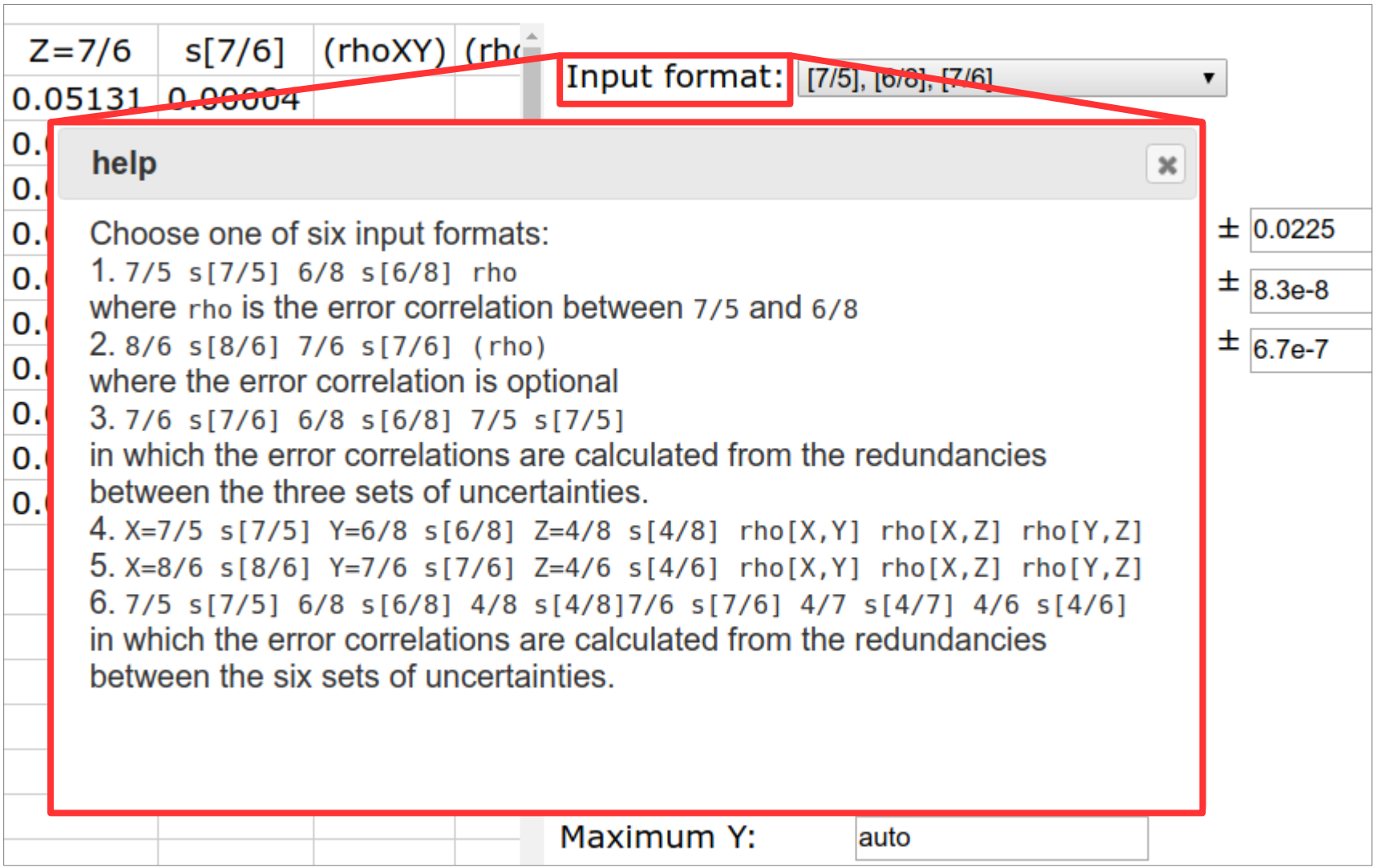
Colour label:

☐ Show decay constant and $^{238}U/^{235}U$-uncertainties?

☐ Add sample numbers to error ellipses?

Defaults | Clear | Open | Save | PLOT | PDF


concordia
Options
Help
Isop
Input format: [7/5], [6/8], [7/6]
[7/5], [6/8]
[8/6], [7/6]
[7/5], [6/8], [7/6]
[7/5], [6/8], [4/8]
[8/6], [7/6], [4/6]
[7/5], [6/8], [4/8], [7/6], [4/7], [4/6]
Common Pb c
238U/235U ratio
± 0.0225
238U decay cor
± 8.3e-8 Myr-1
235U decay constant: 0.00098485 ± 6.7e-7 Myr-1
Plot as Tera-Wasserburg?
Calculate no age
Minimum t: auto
Maximum t: auto


Z=7/6
s[7/6]
(rhoXY)
0.05131
Input format:
[7/5], [6/8], [7/6]
help
Choose one of six input formats:
1. 7/5 s[7/5] 6/8 s[6/8] rho
where rho is the error correlation between 7/5 and 6/8
2. 8/6 s[8/6] 7/6 s[7/6] (rho)
where the error correlation is optional
3. 7/6 s[7/6] 6/8 s[6/8] 7/5 s[7/5]
in which the error correlations are calculated from the redundancies between the three sets of uncertainties.
4. X=7/5 s[7/5] Y=6/8 s[6/8] Z=4/8 s[4/8] rho[X,Y] rho[X,Z] rho[Y,Z]
5. X=8/6 s[8/6] Y=7/6 s[7/6] Z=4/6 s[4/6] rho[X,Y] rho[X,Z] rho[Y,Z]
6. 7/5 s[7/5] 6/8 s[6/8] 4/8 s[4/8]7/6 s[7/6] 4/7 s[4/7] 4/6 s[4/6]
in which the error correlations are calculated from the redundancies between the six sets of uncertainties.
± 0.0225
± 8.3e-8
± 6.7e-7
Maximum Y:
auto

官方网站 | U-Pb | concordia | 选项 | 帮助 | 中文 | **IsoplotR**

	X=38/06	err[X]	Y=07/06	err[Y]	(rho)	(C)	(omit)	H	I	J
1	25.094	0.025	0.05131	0.00004						
2	25.126	0.025	0.05128	0.00016						
3	25.138	0.063	0.05131	0.00008						
4	25.151	0.032	0.05129	0.00009						
5	25.176	0.025	0.05139	0.00006						
6	25.183	0.063	0.05134	0.00007						
7	25.208	0.025	0.05143	0.00011						
8	25.214	0.038	0.05139	0.00007						
9	25.164	0.025	0.0514	0.00006						
10	27.724	0.038	0.05135	0.00004						
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										

输入误差: 1se (abs)

输入格式: [38/06], [07/06]

常规铅校正: none

不平衡校正?

$^{238}U/^{235}U$ 比: 137.818 ± 0.0225

^{238}U 裂变常数: 0.000155125 ± 8.3e-8 Myr^{-1}

^{235}U 裂变常数: 0.00098485 ± 6.7e-7 Myr^{-1}

谐和线类型: Wetherill

计算 空 年龄

最小值 t: auto

最大值 t: auto

最小值 X: auto

最大值 X: auto

最小值 Y: auto

最大值 Y: auto

概率截止: 0.05

有效数字: 2

椭圆颜色: c(rgb(0,1,0,0.5),rgb(1,0,0,0.5))

字体放大: 1

颜色标签:

年龄限制: auto

传播系统的不确定性?

重置设置 | 清空数据 | 打开 | 保存文件 | 生成投图 | PDF

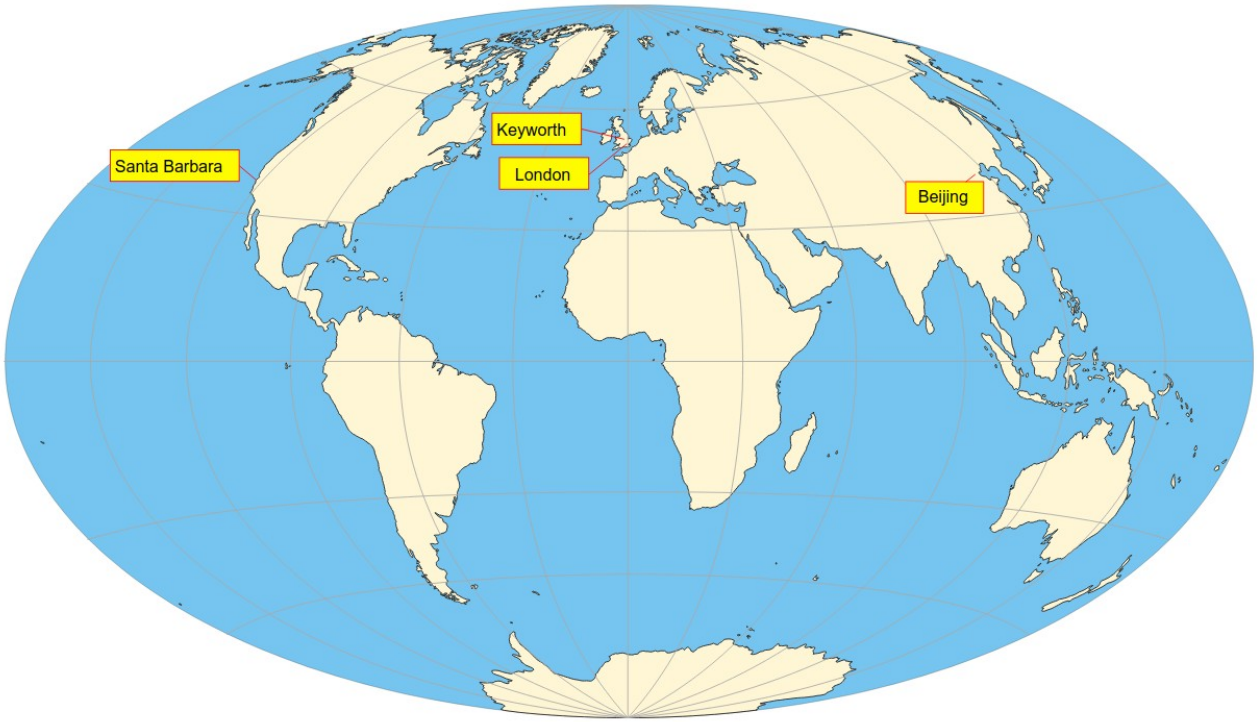
IsoplotR: a free and extendable toolbox for geochronology

Introduction | Online | Offline | Command Line | News | Contribute

An online GUI is hosted by the following international collaborators:

1. Beijing: Qiuye Yu (China University of Geosciences Beijing)
2. Keyworth: Ian Millar (British Geological Survey)
3. London: Pieter Vermeesch (University College London)
4. Santa Barbara: John Cottle (University of California)

Click on one of the yellow boxes below to select a nearby mirror. Otherwise you will be automatically directed to the London server in **2 seconds** ...



If you would like to make your own `IsoplotR` mirror available to the world via this website, then please get in touch with me at *p.vermeesch [at] ucl.ac.uk*.

Synchronizing Rock Clocks of Earth History

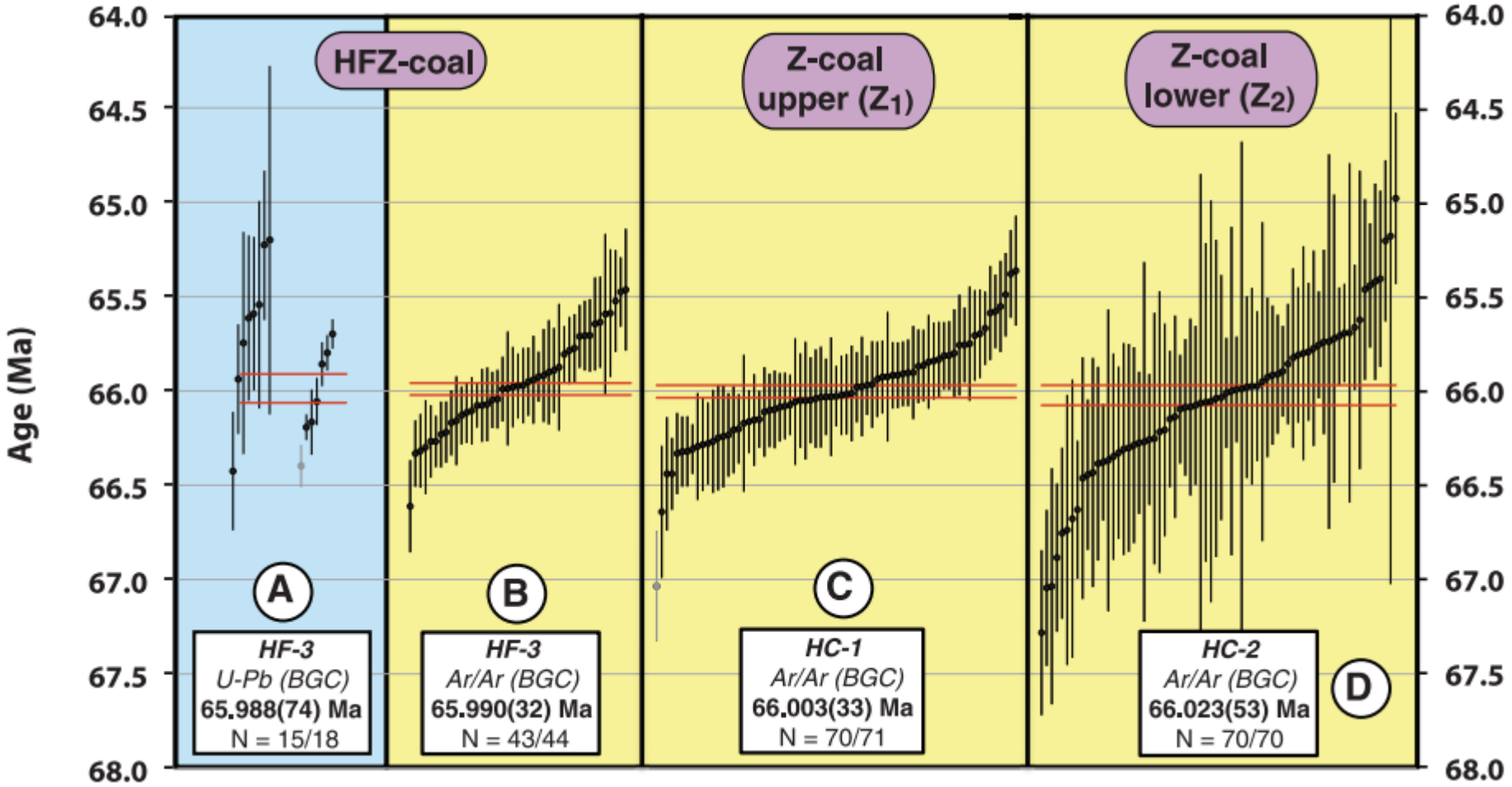
K. F. Kuiper,[1,2] A. Deino,[3] F. J. Hilgen,[1] W. Krijgsman,[1] P. R. Renne,[3,4] J. R. Wijbrans[2]

25 APRIL 2008 VOL 320 SCIENCE

Time Scales of Critical Events Around the Cretaceous-Paleogene Boundary

Paul R. Renne,[1,2]* Alan L. Deino,[1]† Frederik J. Hilgen,[3]† Klaudia F. Kuiper,[4]† Darren F. Mark,[5]† William S. Mitchell III,[2,6]† Leah E. Morgan,[5]† Roland Mundil,[1]† Jan Smit[4]†

8 FEBRUARY 2013 VOL 339 SCIENCE



Geochimica et Cosmochimica Acta 171 (2015) 325–337

ELSEVIER

Revised error propagation of $^{40}Ar/^{39}Ar$ data, including covariances

Pieter Vermeesch

Department of Earth Sciences, University College London, United Kingdom

Received 14 May 2015; accepted in revised form 14 September 2015; available online 25 September 2015

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

1. Isotopic measurements are compositional data

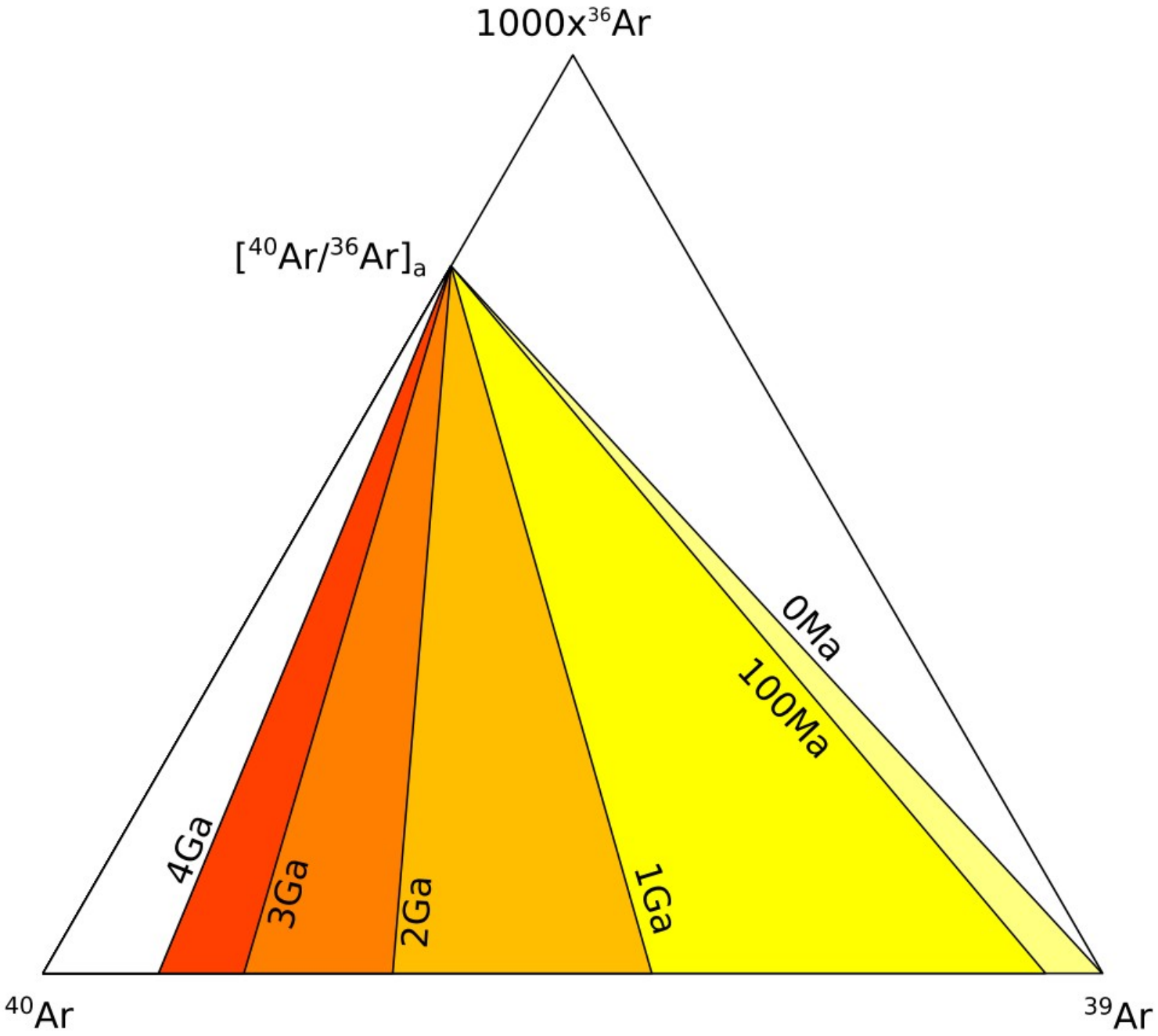
2. Error correlations are commonplace in geochronology

$$^{39}_{19}K + ^{1}_{0}n = ^{39}_{18}Ar + ^{1}_{1}H + Q$$

stable	radioactive

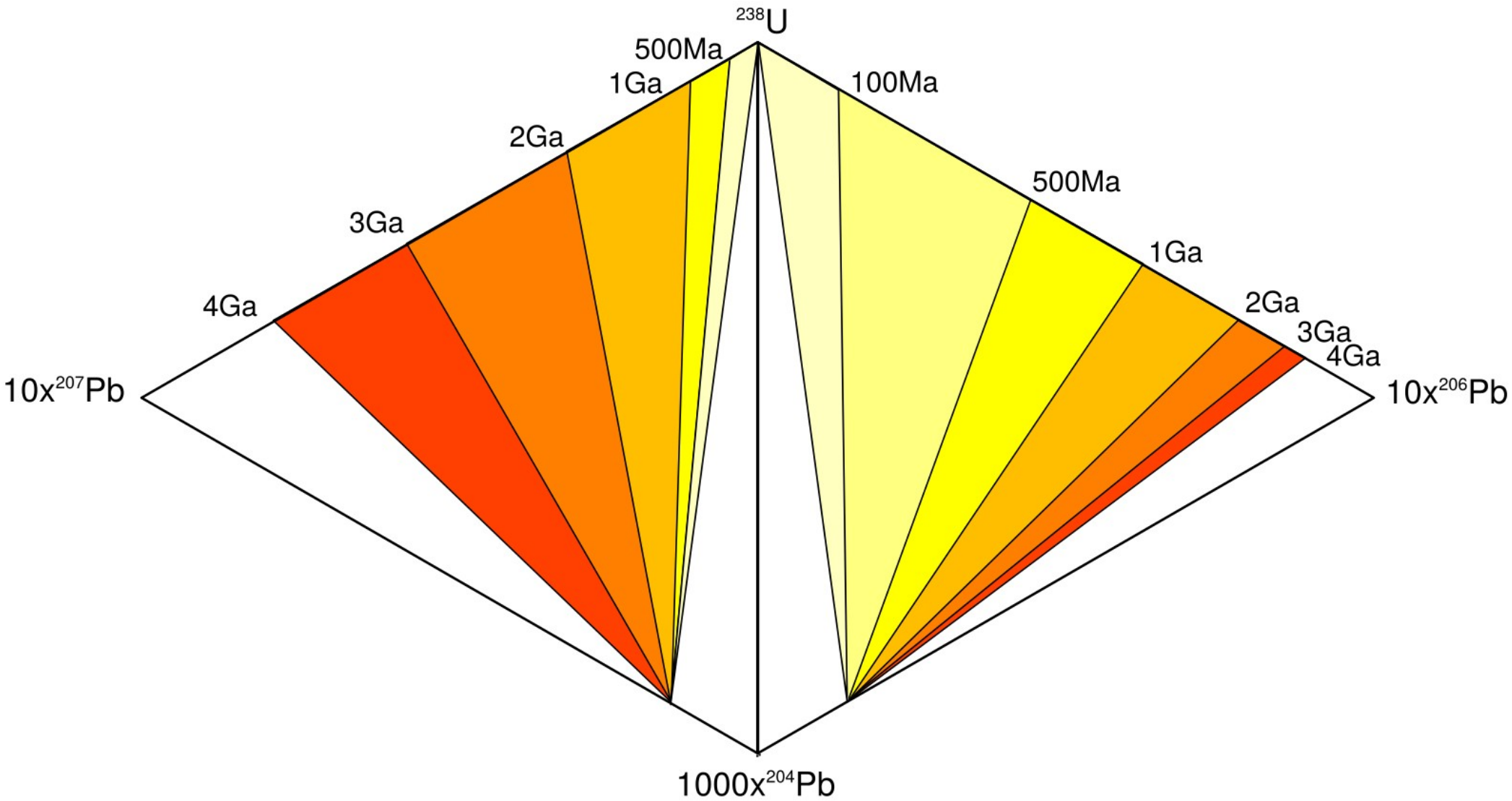
^{38}Ca Z=20,N=18 $t_{1/2}$ =440ms	^{39}Ca Z=20,N=19 $t_{1/2}$ =860ms	^{40}Ca Z=20,N=20 $t_{1/2}$ = ∞	^{41}Ca Z=20,N=21 $t_{1/2}$ =10kyr	^{42}Ca Z=20,N=22 $t_{1/2}$ =∞
^{37}K Z=19,N=18 $t_{1/2}$ =1.2s	^{38}K Z=19,N=19 $t_{1/2}$ =7.6m	^{39}K Z=19,N=20 $t_{1/2}$ = ∞	^{40}K Z=19,N=21 $t_{1/2}$ =1.25Gyr	^{41}K Z=19,N=22 $t_{1/2}$ =∞
^{36}Ar Z=18,N=18 $t_{1/2}$ =∞	^{37}Ar Z=18,N=19 $t_{1/2}$ =35d	^{38}Ar Z=18,N=20 $t_{1/2}$ = ∞	^{39}Ar Z=18,N=21 $t_{1/2}$ =269yr	^{40}Ar Z=18,N=22 $t_{1/2}$ =∞

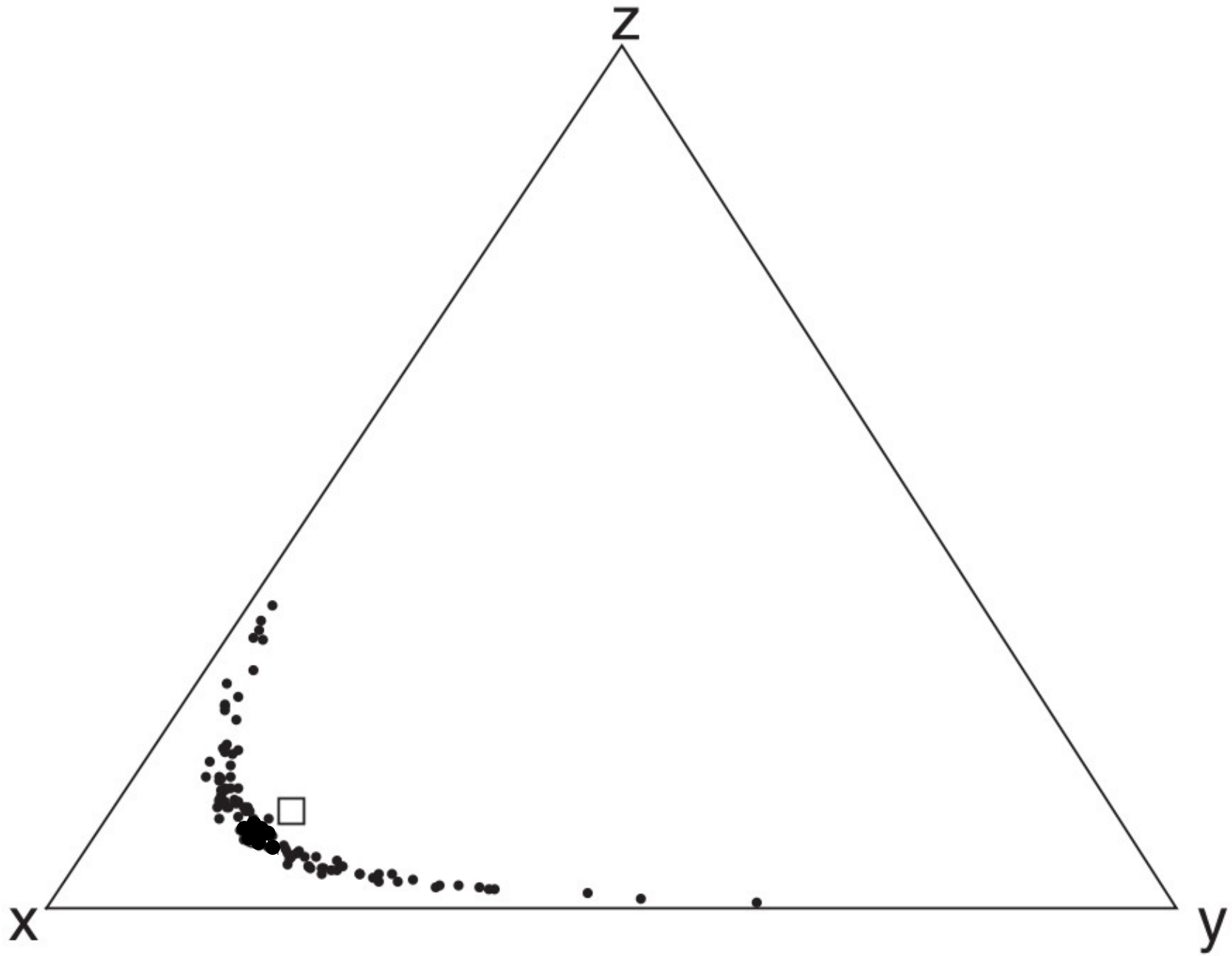
$$t = \frac{1}{\lambda} ln \left[1 + J \left(\frac{^{40}Ar}{^{39}Ar} - 298.56 \frac{^{36}Ar}{^{39}Ar} \right) \right]$$

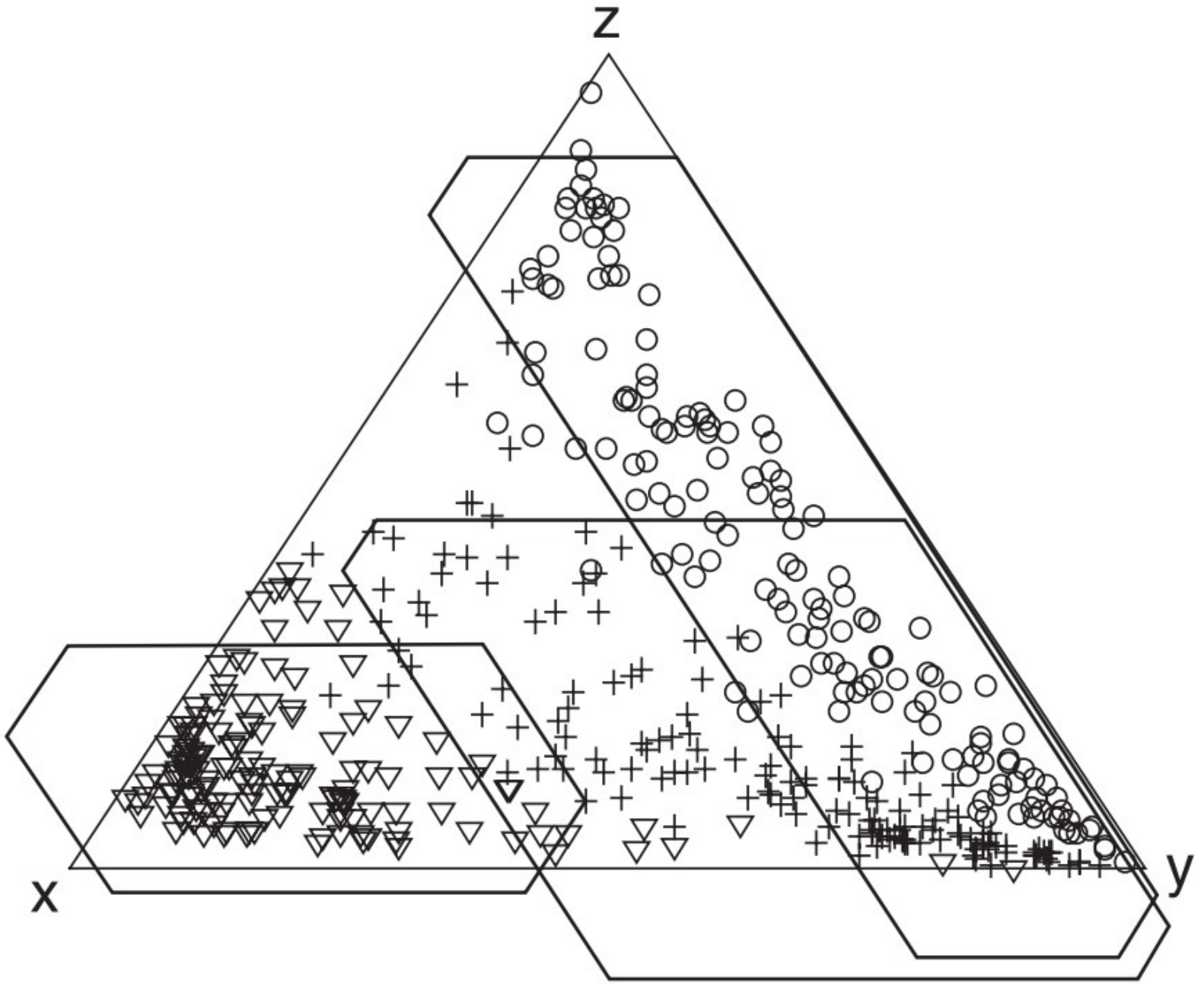

1000x^{36}Ar
[^{40}Ar/^{36}Ar]$_a$
4Ga
3Ga
2Ga
1Ga
100Ma
0Ma
^{40}Ar
^{39}Ar

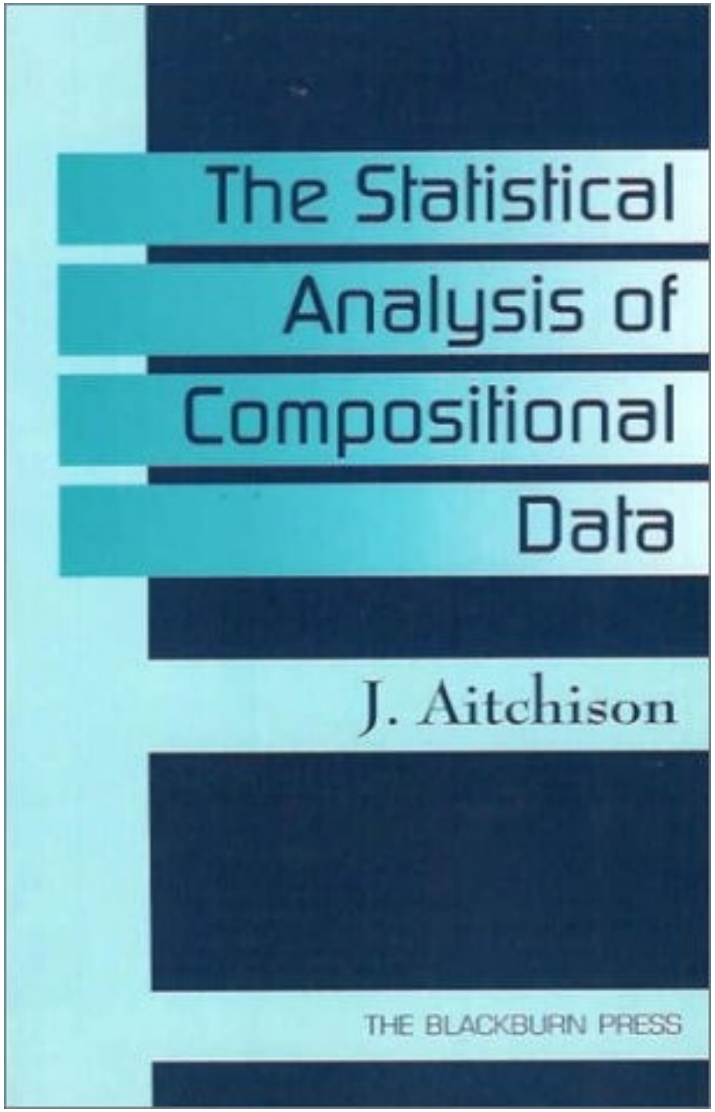
$$t = \frac{1}{\lambda_{238}} \ln \left(\frac{\left(\frac{^{206}Pb}{^{204}Pb}\right) - \left(\frac{^{206}Pb}{^{204}Pb}\right)_\circ}{\frac{^{238}U}{^{204}Pb}} + 1 \right)$$

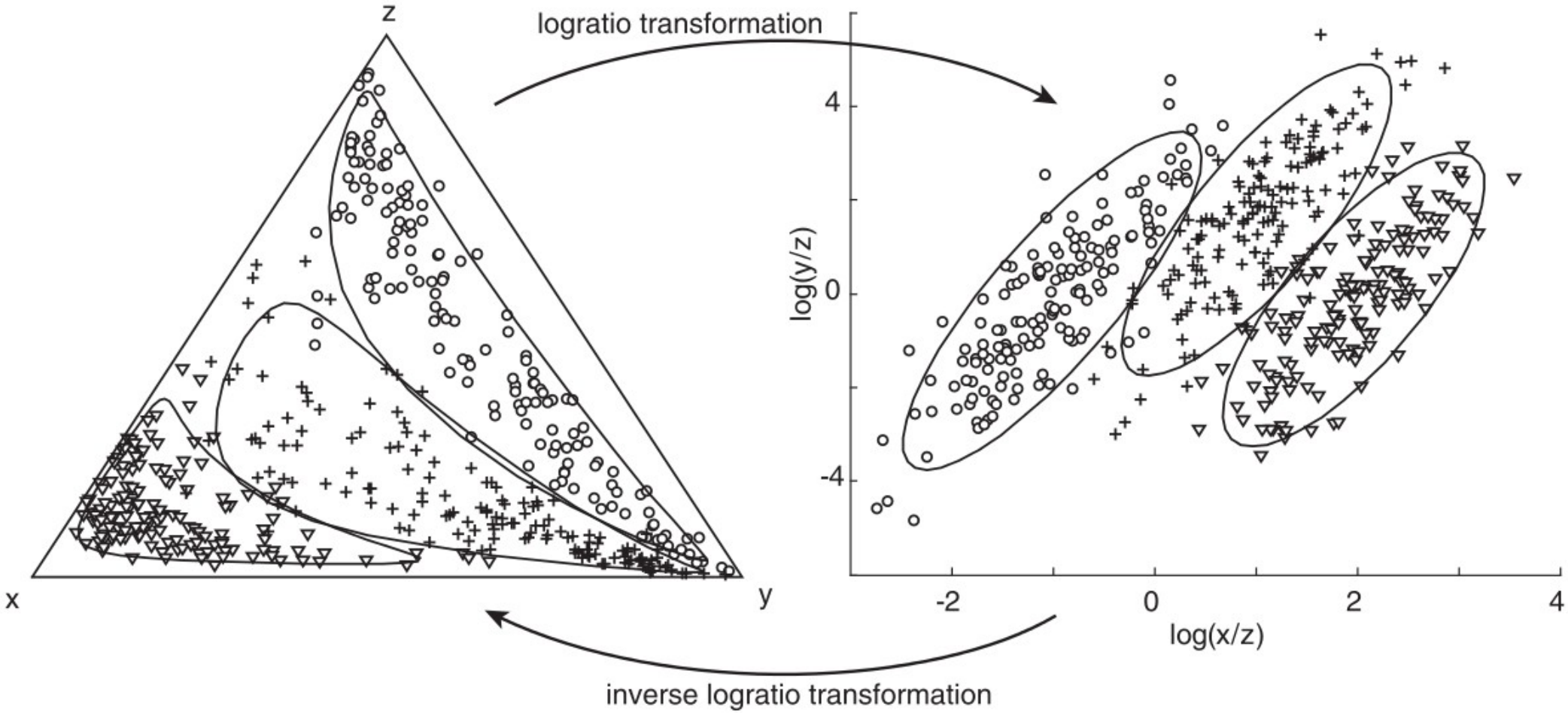
$$t = \frac{1}{\lambda_{235}} \ln \left(\frac{\left(\frac{^{207}Pb}{^{204}Pb}\right) - \left(\frac{^{207}Pb}{^{204}Pb}\right)_\circ}{137.818\,\frac{^{238}U}{^{204}Pb}} + 1 \right)$$

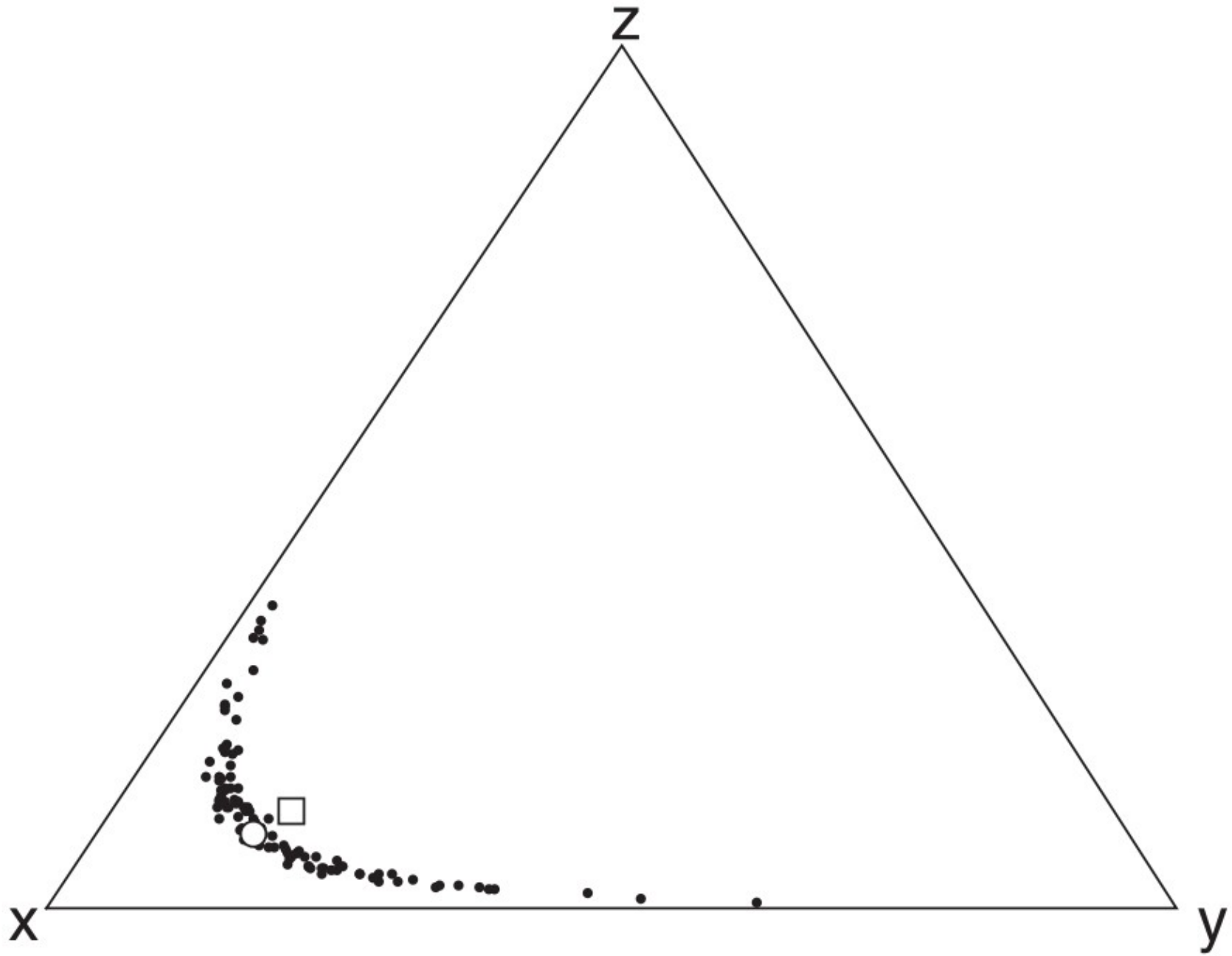

^{238}U
500Ma
1Ga
2Ga
3Ga
4Ga
100Ma
500Ma
1Ga
2Ga
3Ga
4Ga
10x^{207}Pb
10x^{206}Pb
1000x^{204}Pb

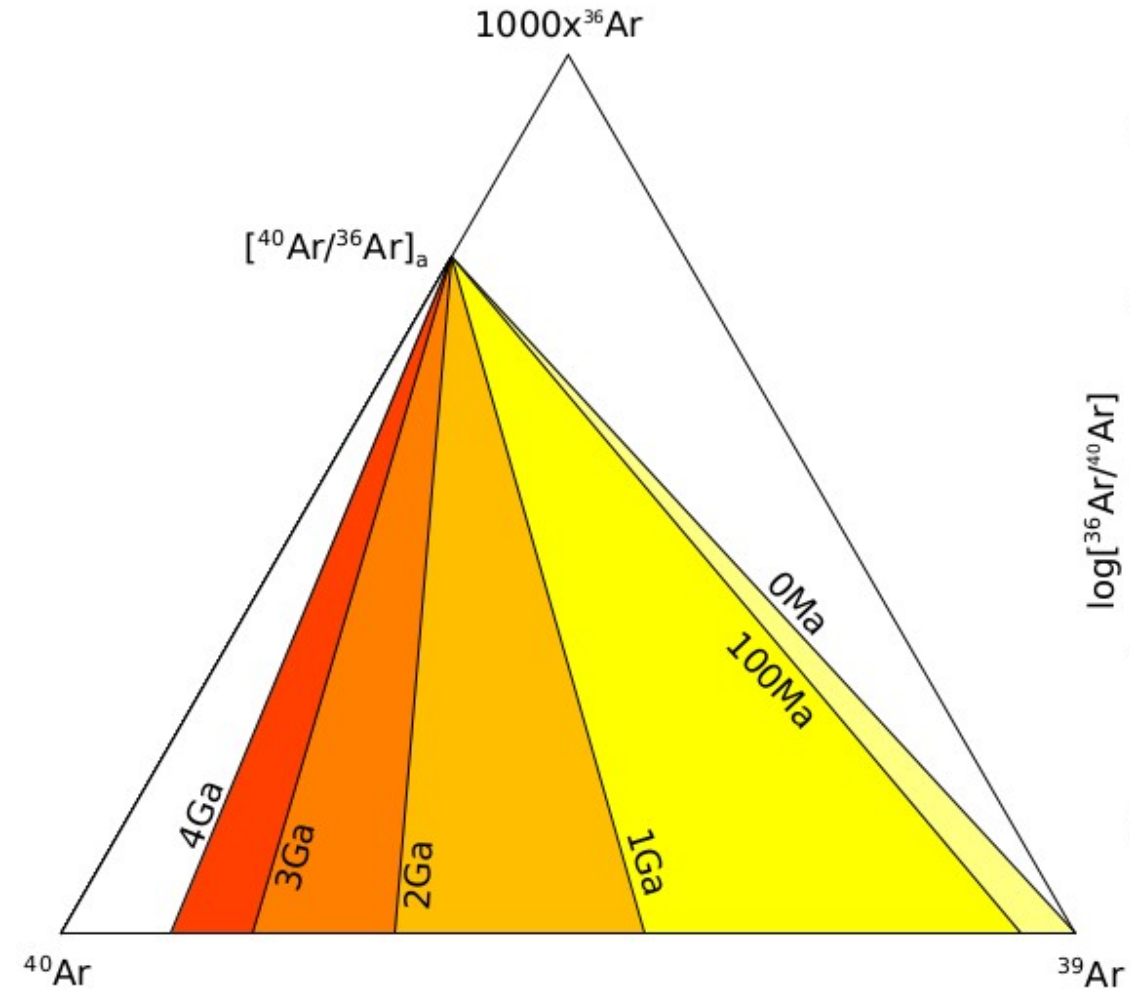

z
x
y

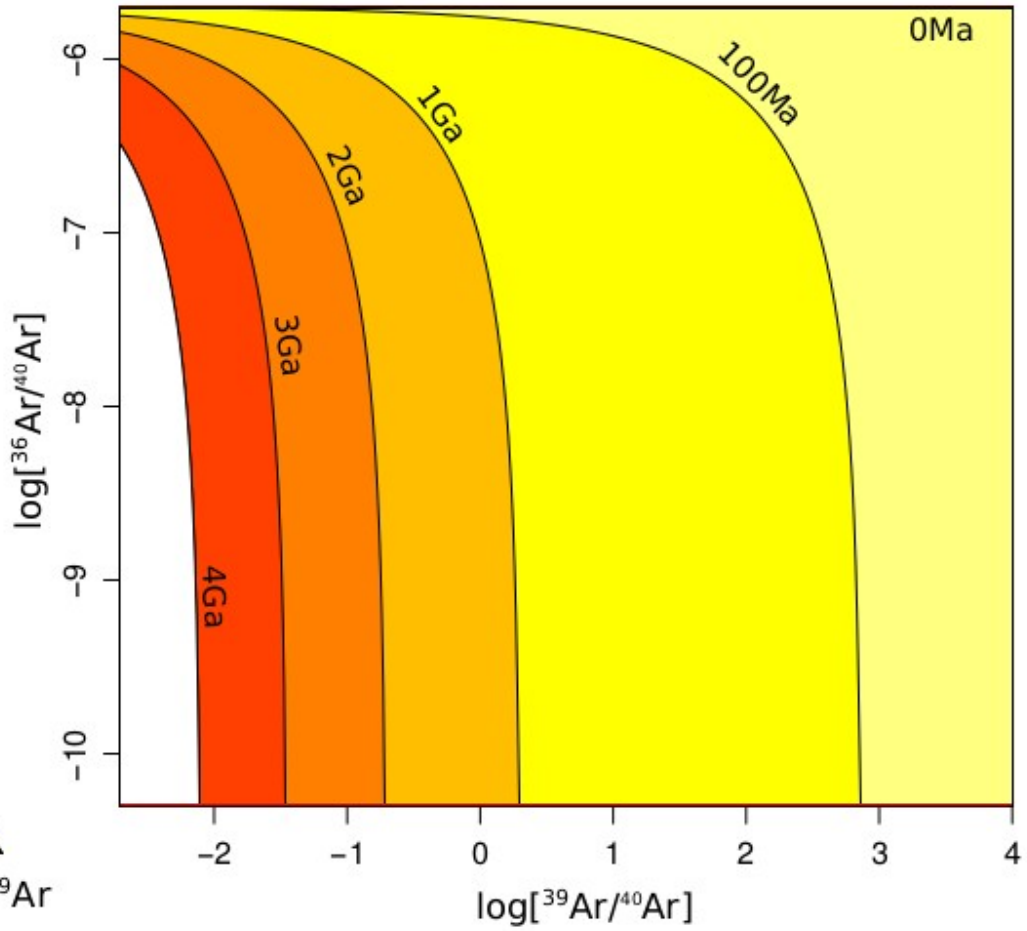

z
x
y

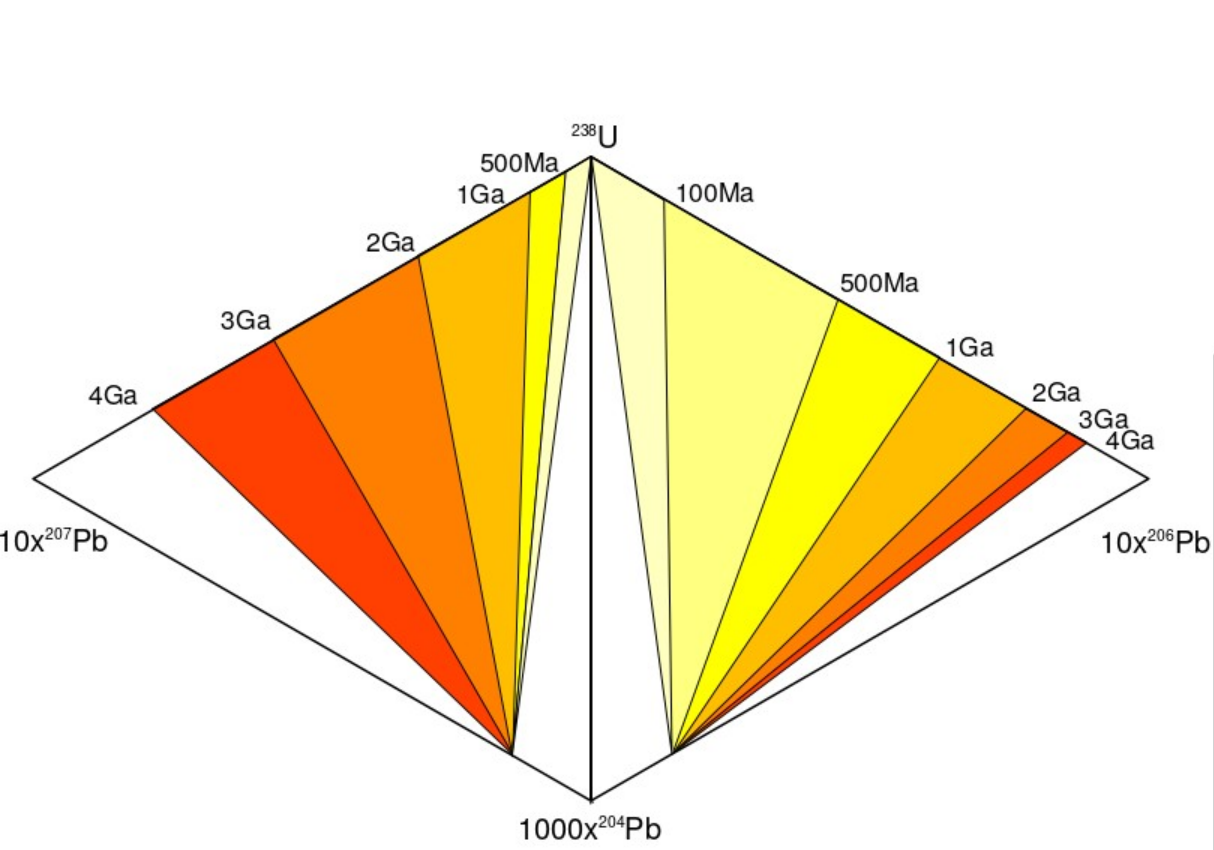

The Statistical
Analysis of
Compositional
Data
J. Aitchison
THE BLACKBURN PRESS

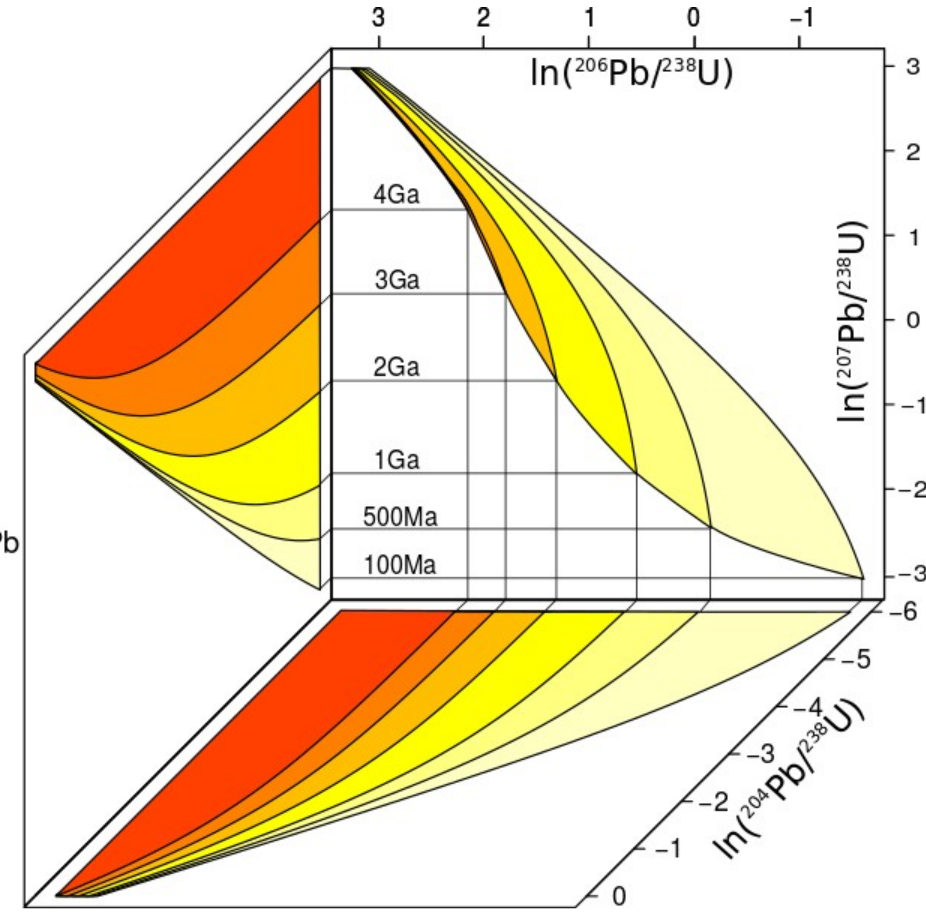

z
x
y
logratio transformation
inverse logratio transformation
log(y/z)
log(x/z)
4
0
-4
-2
0
2
4


z
x
y


1000x^{36}Ar
[^{40}Ar/^{36}Ar]$_a$
4Ga
3Ga
2Ga
1Ga
0Ma
100Ma
^{40}Ar
^{39}Ar


0Ma
100Ma
1Ga
2Ga
3Ga
4Ga
log[^{36}Ar/^{40}Ar]
log[^{39}Ar/^{40}Ar]
−6
−7
−8
−9
−10
−2
−1
0
1
2
3
4

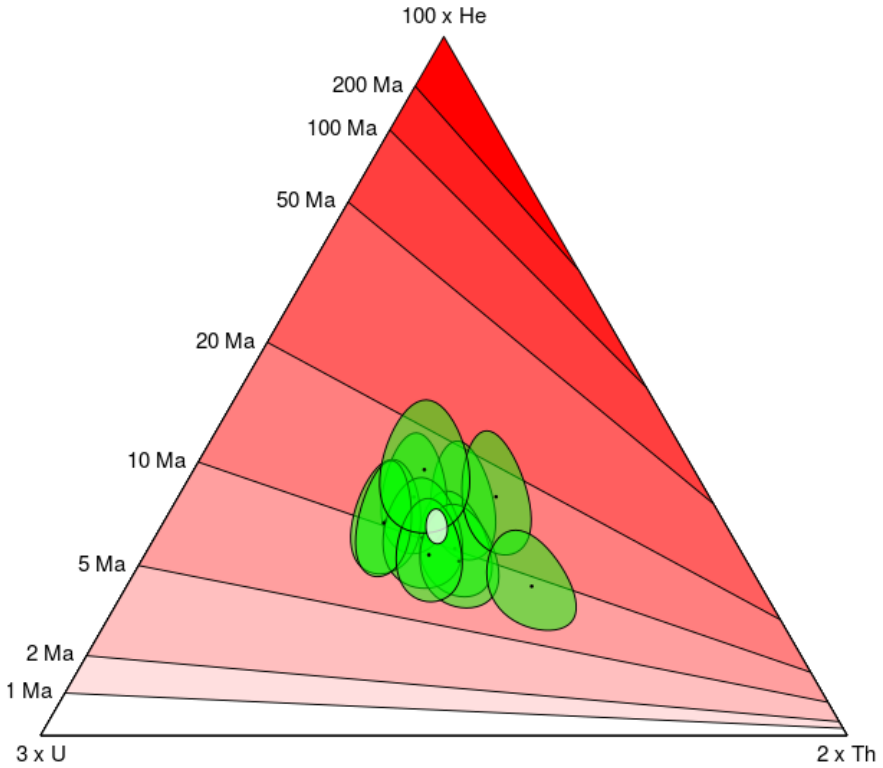

238U
500Ma
1Ga
2Ga
3Ga
4Ga
100Ma
500Ma
1Ga
2Ga
3Ga
4Ga
10x207Pb
10x206Pb
1000x204Pb


3
2
1
0
−1
ln(206Pb/238U)
4Ga
3Ga
2Ga
1Ga
500Ma
100Ma
ln(207Pb/238U)
−6
−5
−4
−3
−2
−1
0
ln(204Pb/238U)

Home | U-Th-He | helioplot | Options | Help | English | IsoplotR

	He	err[He]	U	err[U]	Th	err[Th]	Sm	err[Sm]	(C)	(omit)
1	1.401	0.211	66.02	3.85	50.65	3.95				
2	2.096	0.315	138.51	6.0	99.49	9.0				
3	0.63	0.095	33.89	2.0	18.01	1.5				
4	0.765	0.115	52.26	3.35	22.82	1.9				
5	1.379	0.208	94.01	6.0	53.94	5.05				
6	0.383	0.060	26.67	1.35	11.51	0.75				
7	1.178	0.181	84.36	4.95	62.16	5.5				
8	0.309	0.047	23.33	1.2	14.07	1.05				
9	2.226	0.342	86.29	6.5	85.72	6.5				
10	0.778	0.117	34.22	3.25	19.51	2.2				
11	0.828	0.134	55.25	3.9	65.09	6.25				
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										

central age = 11.27 ± 0.55 | 1.15 | 1.22 Ma (n=11)
MSWD = 5.4 , $p(\chi^2)$ = 4.9e-14



Defaults | Clear | Open | Save | PLOT | PDF

Geochimica et Cosmochimica Acta 171 (2015) 325–337

ELSEVIER

Revised error propagation of $^{40}Ar/^{39}Ar$ data, including covariances

Pieter Vermeesch

Department of Earth Sciences, University College London, United Kingdom

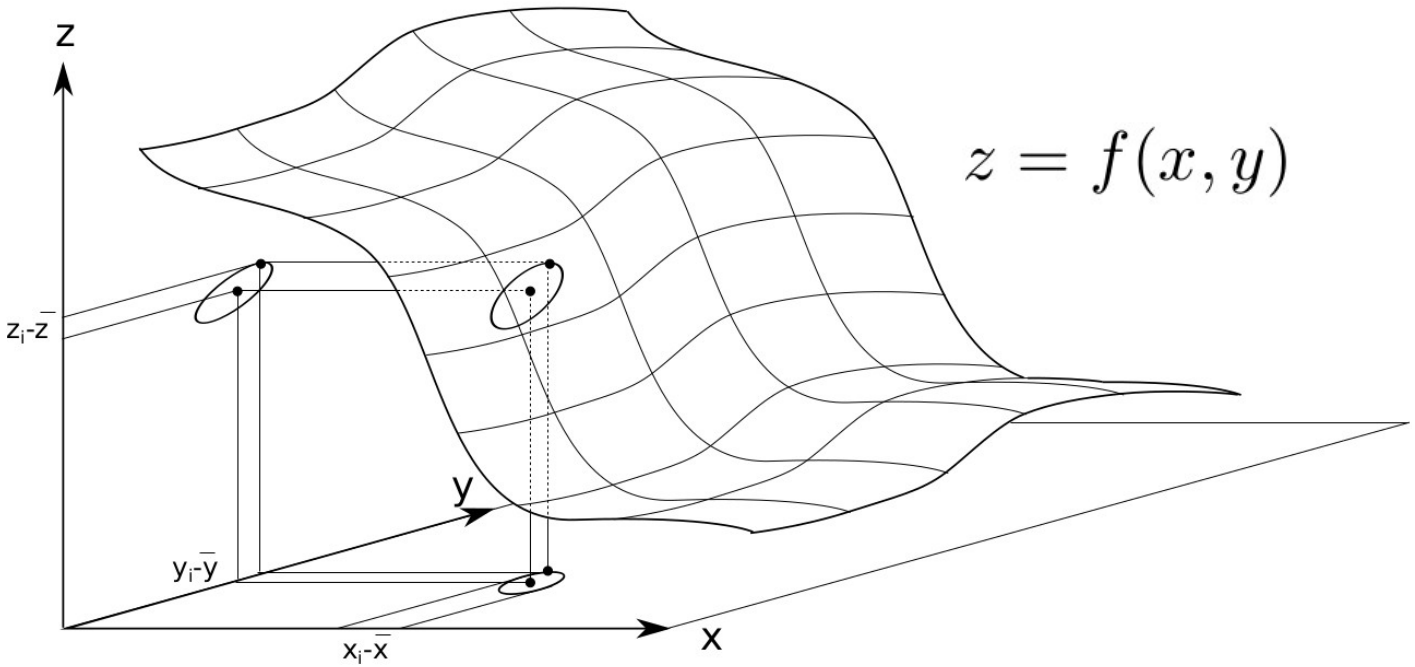
Received 14 May 2015; accepted in revised form 14 September 2015; available online 25 September 2015

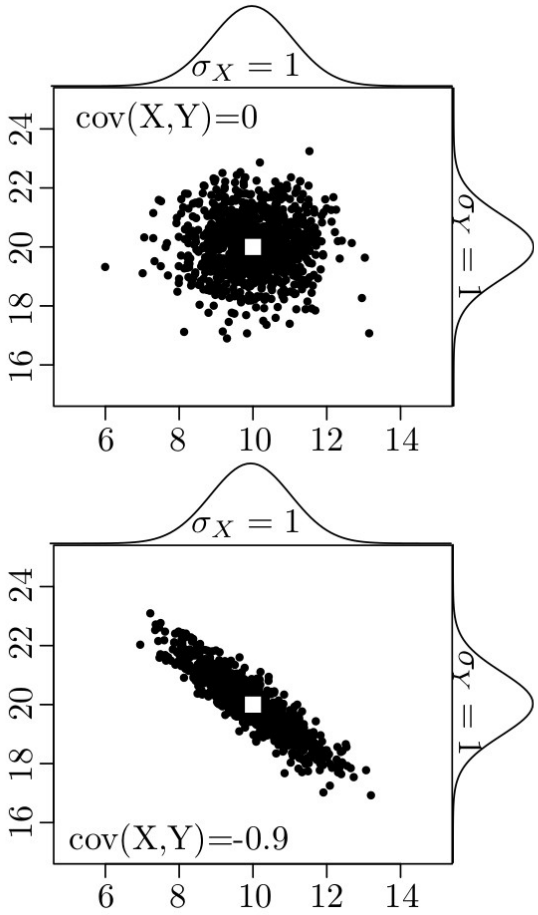
Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

1. Isotopic measurements are compositional data

2. **Error correlations are commonplace in geochronology**





$$\sigma_z^2 = \left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2 + 2\frac{\partial f}{\partial x}\frac{\partial f}{\partial y} cov(x,y)$$

$$\sigma_z^2 = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \begin{bmatrix} \sigma_x^2 & cov(x,y) \\ cov(x,y) & \sigma_y^2 \end{bmatrix} \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

Jacobian matrix

Covariance matrix

Transpose of the Jacobian matrix

$$z = f(x, y)$$

$$\sigma_z^2 = \left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2 + 2\frac{\partial f}{\partial x}\frac{\partial f}{\partial y} cov(x, y)$$

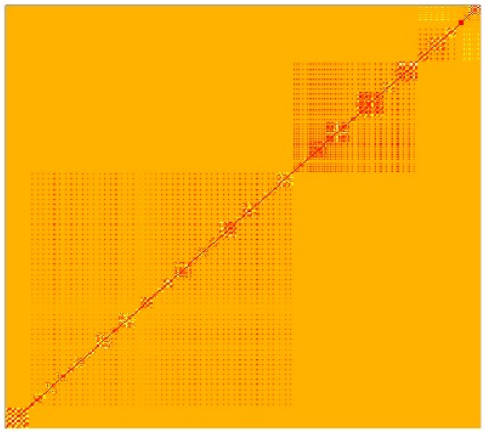
$$\sigma_z^2 = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \begin{bmatrix} \sigma_x^2 & 0 \\ 0 & \sigma_y^2 \end{bmatrix} \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

$$t = \frac{1}{\lambda} ln\left(1 + JR\right)$$

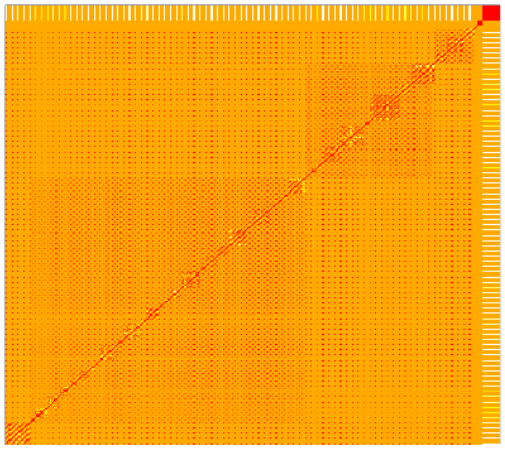
$$\sigma_t^2 = \frac{J^2\sigma_R^2 + R^2\sigma_J^2}{\lambda^2(1 + RJ)}$$

(e.g., McDougall & Harrison, 1999)

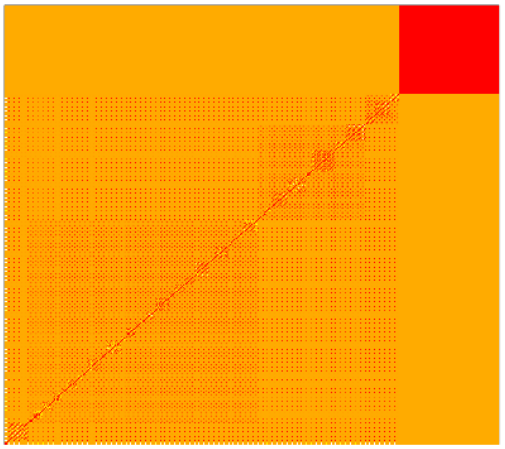
$$\sigma_z^2 = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix} \begin{bmatrix} \sigma_x^2 & cov(x,y) \\ cov(x,y) & \sigma_y^2 \end{bmatrix} \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$



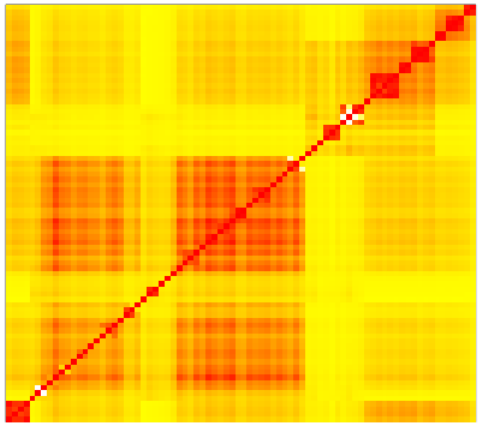
Blank correction



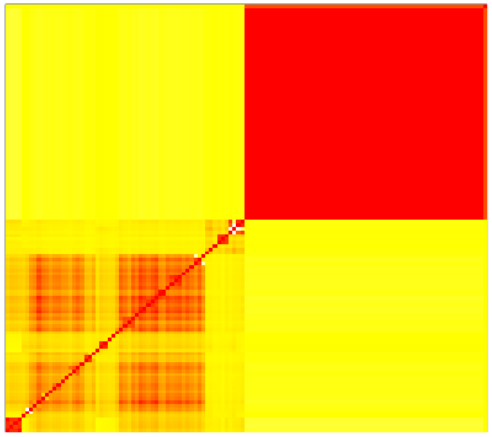
Regression to t_0



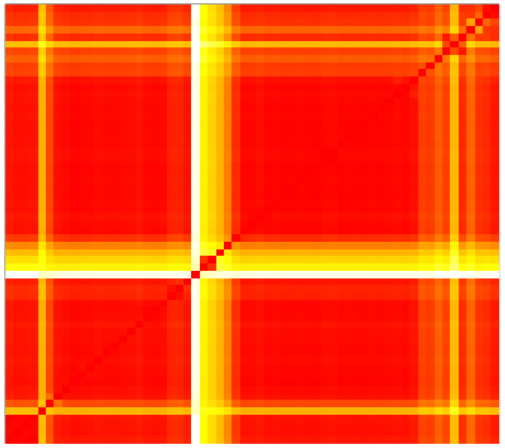
Decay correction



Interference correction



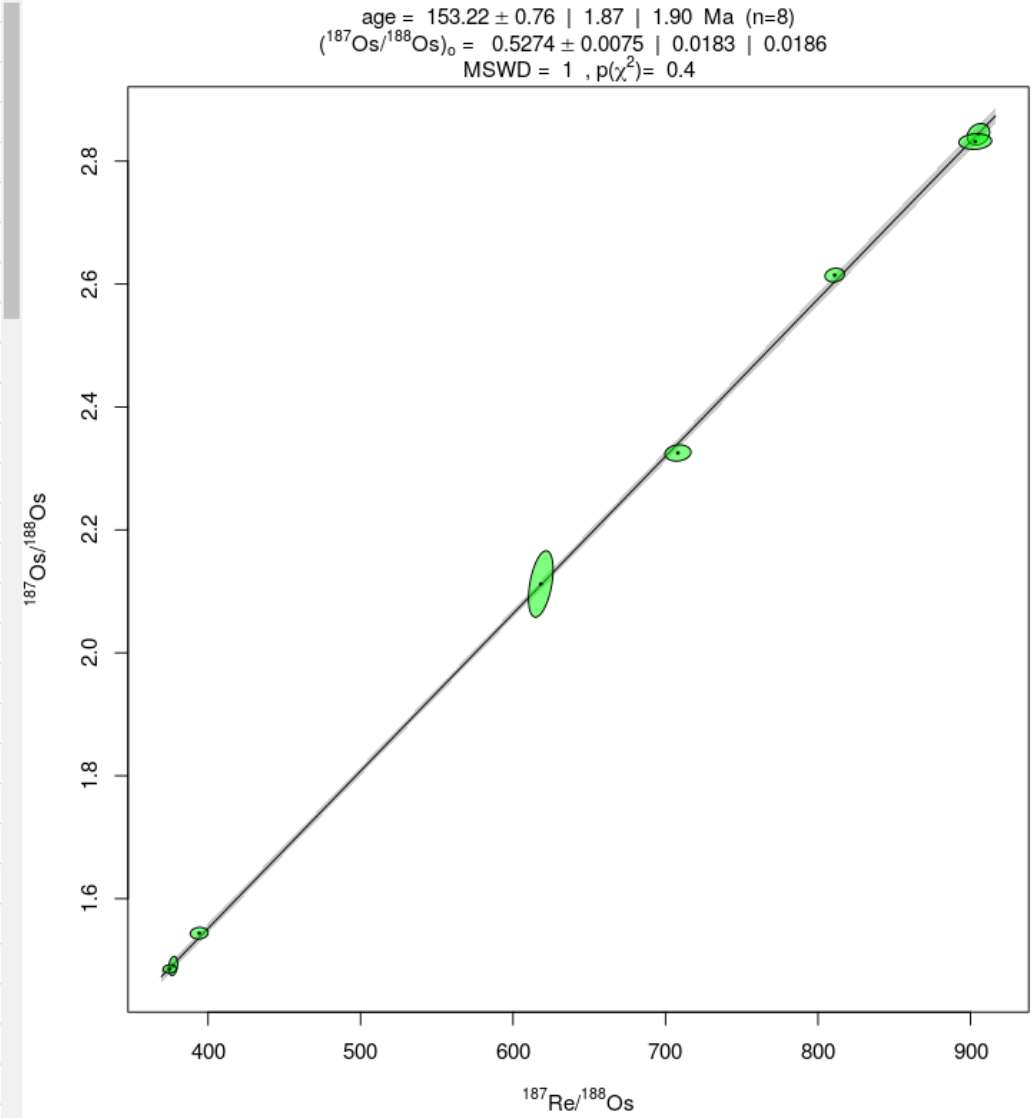
J-factor



40Ar*/39Ar

Home | Re-Os | isochron | Options | Help | English | IsoplotR

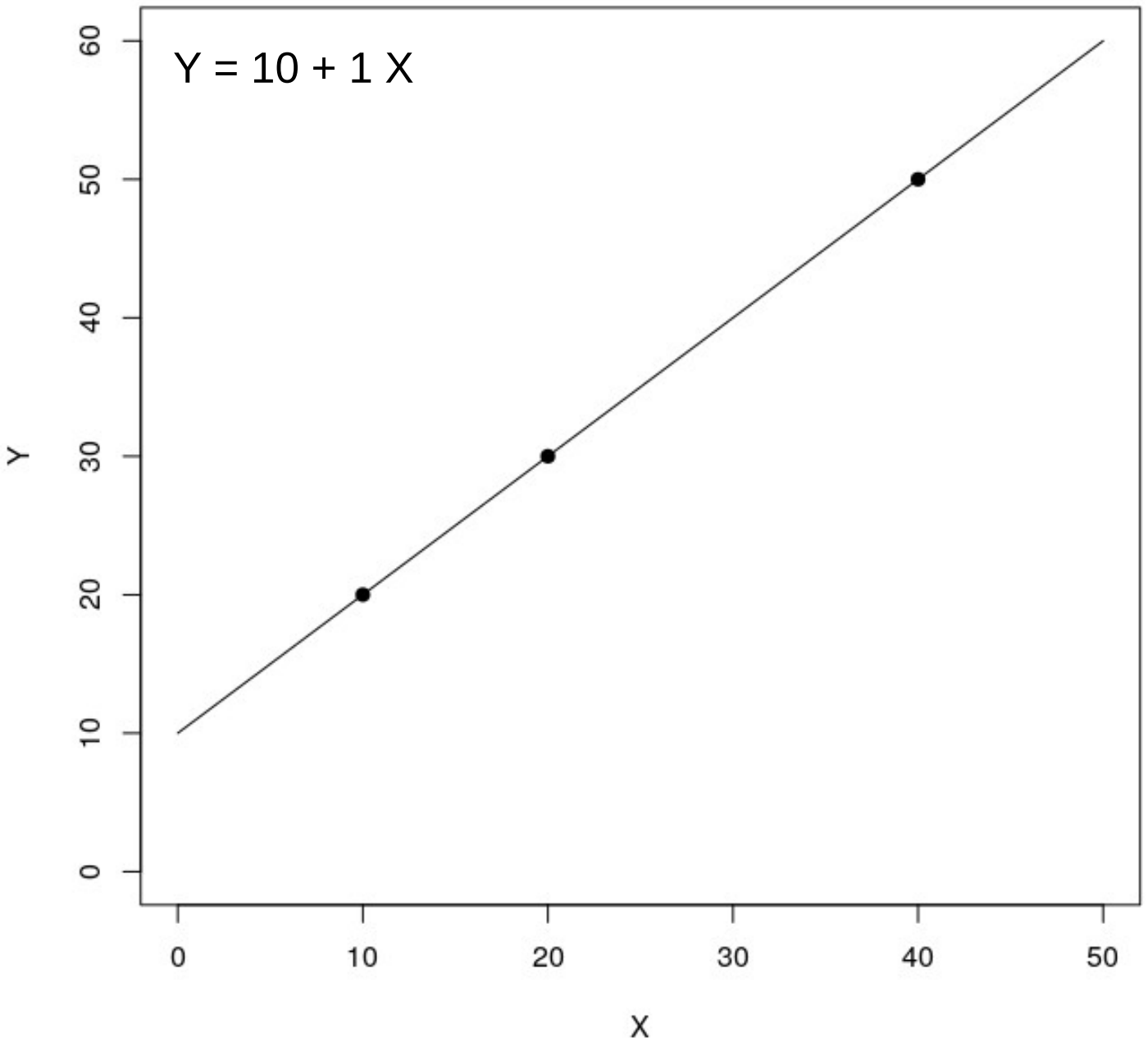
	Re187/Os188	err[Re	Os187/Os188	err[Os18	(rho)	(C)	(omit)	H
1	394.2	2.4	1.5438	0.0039	0.073			
2	377.1	1.2	1.4904	0.0064	0.23			
3	374.8	1.8	1.4856	0.0028	0.067			
4	708.1	3.5	2.3252	0.0054	0.113			
5	618.2	3.3	2.112	0.0221	0.434			
6	810.9	2.6	2.6146	0.0046	0.143			
7	905.2	3	2.8436	0.0072	0.215			
8	903.1	4.4	2.8319	0.0052	0.104			
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								



Defaults | Clear | Open | Save | PLOT | PDF

$Y = a + b\,X$

X	Y
10	20
20	30
40	50

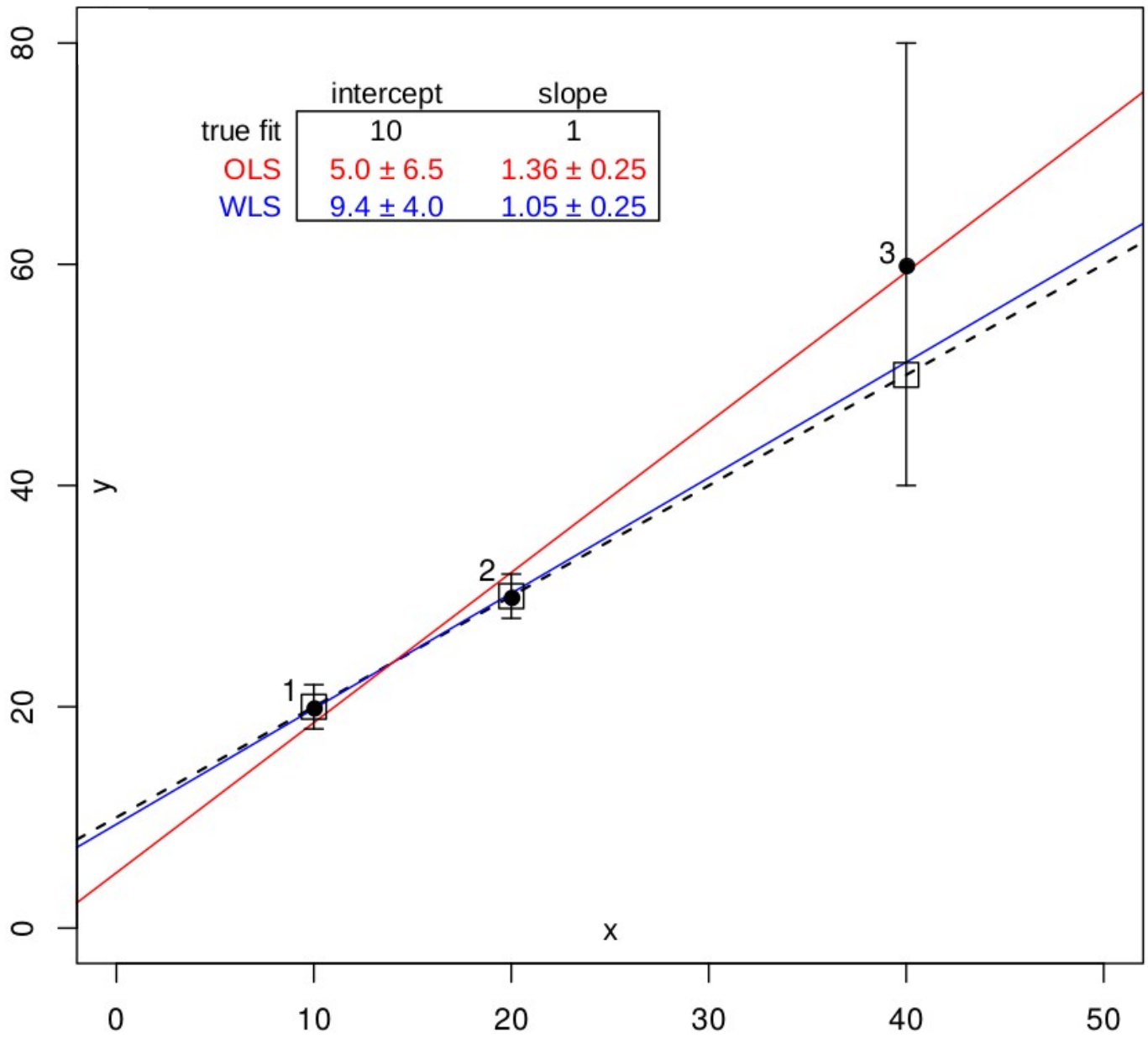


true values (squares):

x	y	s[y]
10	20	1
20	30	1
40	50	10

measurements (circles):

X	Y	s[Y]
10	20	1
20	30	1
40	60	10

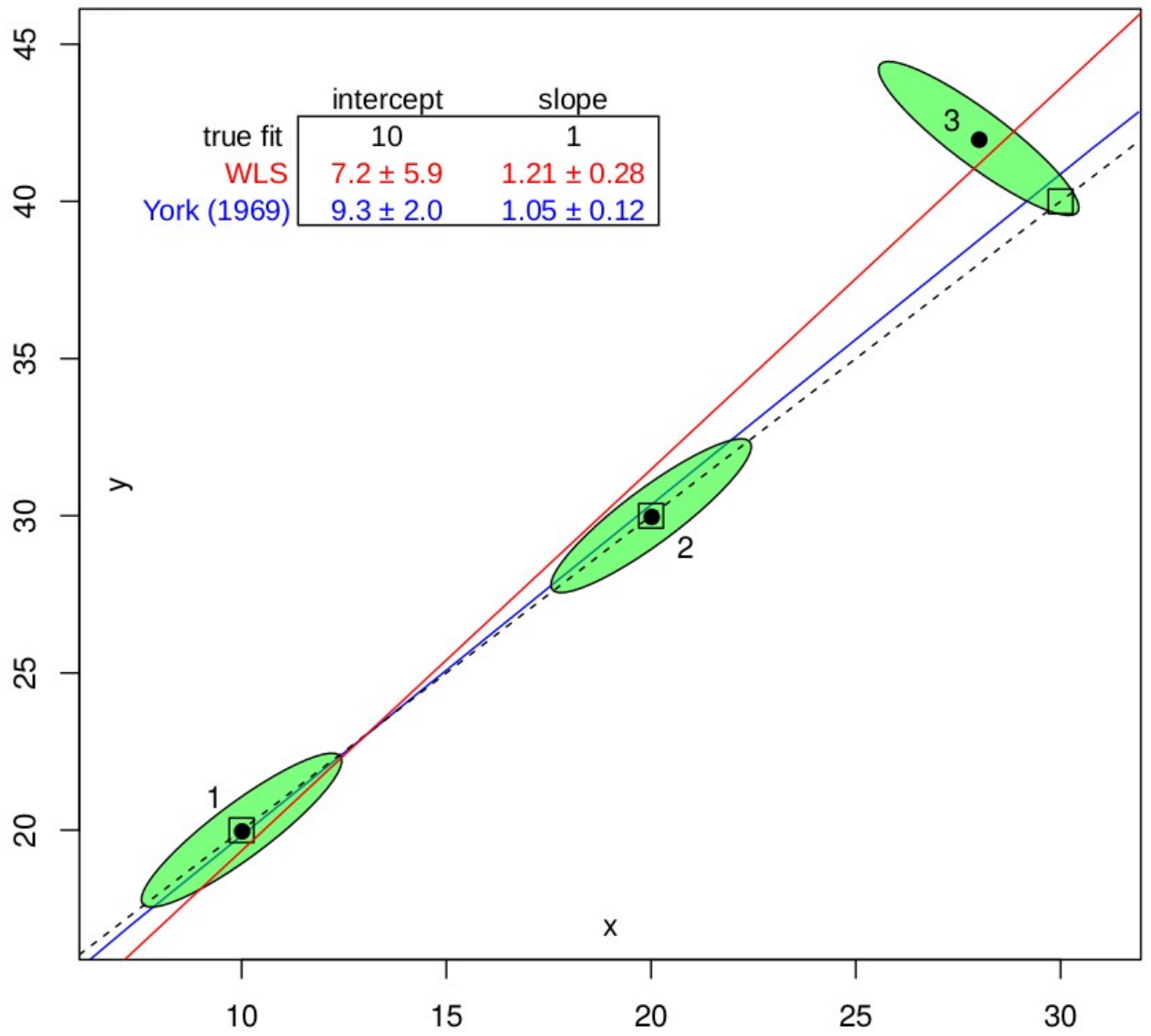


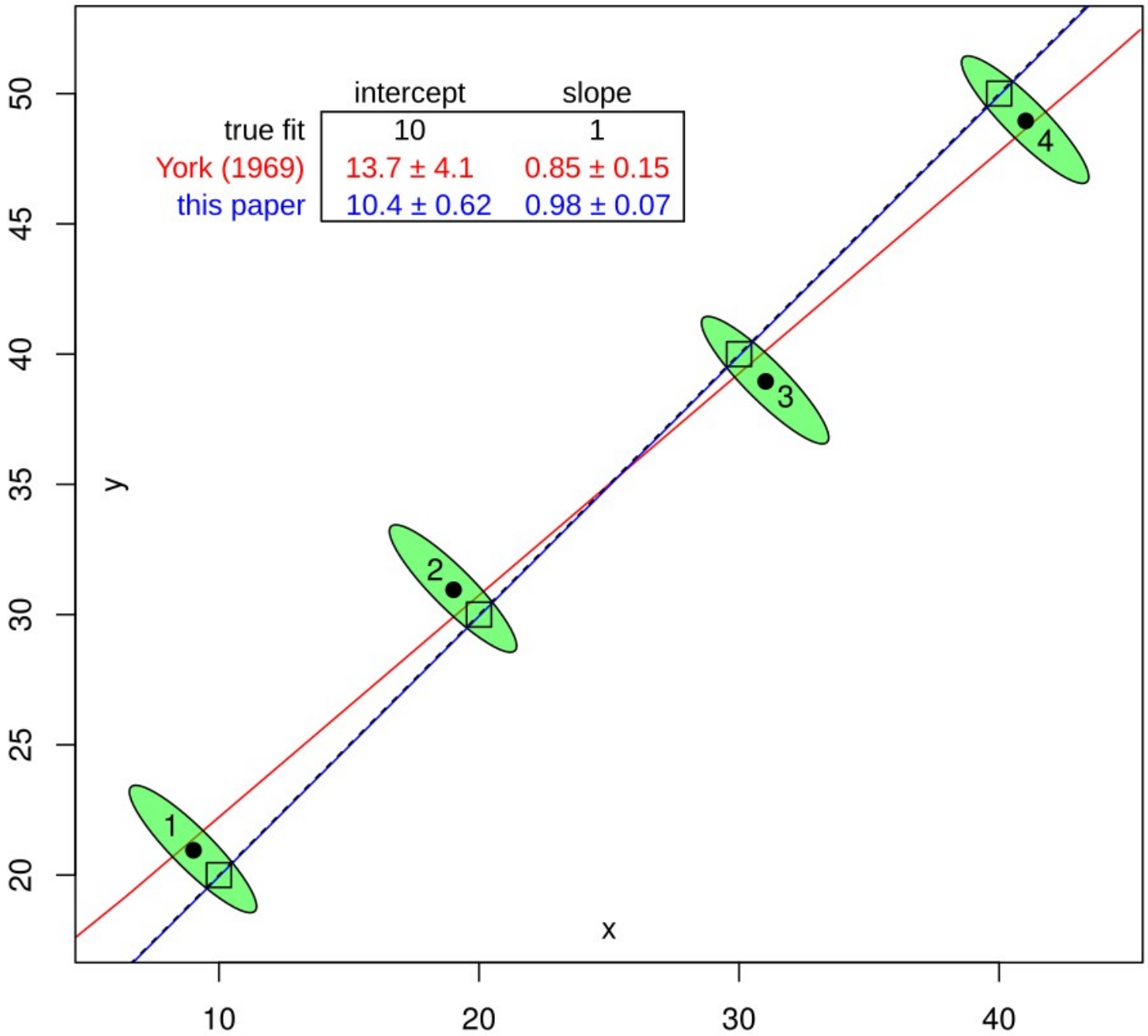
true values (squares):

x	s[x]	y	s[y]	cov[x,y]
10	1	20	1	0.9
20	1	30	1	0.9
30	1	40	1	-0.9

measurements (circles):

X	s[X]	X	s[Y]	cov[X,Y]
10	1	20	1	0.9
20	1	30	1	0.9
28	1	42	1	-0.9

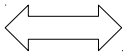



intercept
slope
true fit
10
1
York (1969)
13.7 ± 4.1
0.85 ± 0.15
this paper
10.4 ± 0.62
0.98 ± 0.07
1
2
3
4
y
x
20
25
30
35
40
45
50
10
20
30
40

true values		measure-ments		covariance matrix							
				X1	X2	X3	X4	Y1	Y2	Y3	Y4
x1	10	X1	9	1	0.99	0	0	-0.9	-0.9	0	0
x2	20	X2	19	0.99	1	0	0	-0.9	-0.9	0	0
x3	30	X3	31	0	0	1	0.99	0	0	-0.9	-0.9
x4	40	X4	41	0	0	0.99	1	0	0	-0.9	-0.9
y1	20	Y1	21	-0.9	-0.9	0	0	1	0.99	0	0
y2	30	Y2	31	-0.9	-0.9	0	0	0.99	1	0	0
y3	40	Y3	39	0	0	-0.9	-0.9	0	0	1	0.99
y4	50	Y4	49	0	0	-0.9	-0.9	0	0	0.99	1

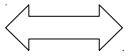
flat table

X	Y	s[Y]
10	20	1
20	30	1
40	60	10



vector of means		covariance matrix					
		X1	X2	X3	Y1	Y2	Y3
X1	10	0	0	0	0	0	0
X2	20	0	0	0	0	0	0
X3	40	0	0	0	0	0	0
Y1	20	0	0	0	1	0	0
Y2	30	0	0	0	0	1	0
Y3	60	0	0	0	0	0	100

X	s[X]	X	s[Y]	cov[X,Y]
10	1	20	1	0.9
20	1	30	1	0.9
28	1	42	1	-0.9



		X1	X2	X3	Y1	Y2	Y3
X1	20	1	0	0	0.9	0	0
X2	30	0	1	0	0	0.9	0
X3	43	0	0	1	0	0	-0.9
Y1	20	0.9	0	0	1	0	0
Y2	30	0	0.9	0	0	1	0
Y3	42	0	0	-0.9	0	0	1

$^{40}Ar/^{39}Ar$

Ar40/Ar39[1]	a1	s[a1]^2	s[a1,b1]	s[a1,a2]	s[a1,b2]	…	s[a1,an]	s[a1,bn]	s[a1,l4]	s[a1,l8]	s[a1,l5]
Ar40/Ar36[1]	b1	s[b1,a1]	s[b1]^2	s[b1,a2]	s[b1,b2]	…	s[b1,an]	s[b1,bn]	s[b1,l4]	s[b1,l8]	s[b1,l5]
Ar40/Ar39[2]	a2	s[a2,a1]	s[a2,b1]	s[a2]^2	s[a2,b2]	…	s[a2,an]	s[a2,bn]	s[a2,l4]	s[a2,l8]	s[a2,l5]
Ar40/Ar36[2]	b2	s[b2,a1]	s[b2,b1]	s[b2,a2]	s[b2]^2	…	s[b2,an]	s[b2,bn]	s[b2,l4]	s[b2,l8]	s[b2,l5]
…	…	…	…	…	…	…	…	…	…	…	…
Ar40/Ar39[n]	an	s[an,a1]	s[an,b1]	s[an,a2]	s[an,b2]	…	s[an]^2	s[an,bn]	s[an,l4]	s[an,l8]	s[an,l5]
Ar40/Ar36[n]	bn	s[bn,a1]	s[bn,b1]	s[bn,a2]	s[bn,b2]	…	s[a1,an]	s[bn]^2	s[bn,l4]	s[bn,l8]	s[bn,l5]
Lambda[40]	l4	s[l4,a1]	s[l4,b1]	s[l4,a2]	s[l4,b2]	…	s[l4,an]	s[l4,bn]	s[l4]^2	s[l4,l8]	s[l4,l5]
Lambda[238]	l8	s[l8,a1]	s[l8,b1]	s[l8,a2]	s[l8,b2]	…	s[l8,an]	s[l8,bn]	s[l8,l4]	s[l8]^2	s[l8,l5]
Lambda[235]	l5	s[l5,a1]	s[l5,b1]	s[l5,a2]	s[l5,b2]	…	s[l5,an]	s[l5,bn]	s[l5,l4]	s[l5,l8]	s[l5]^2

U-Pb

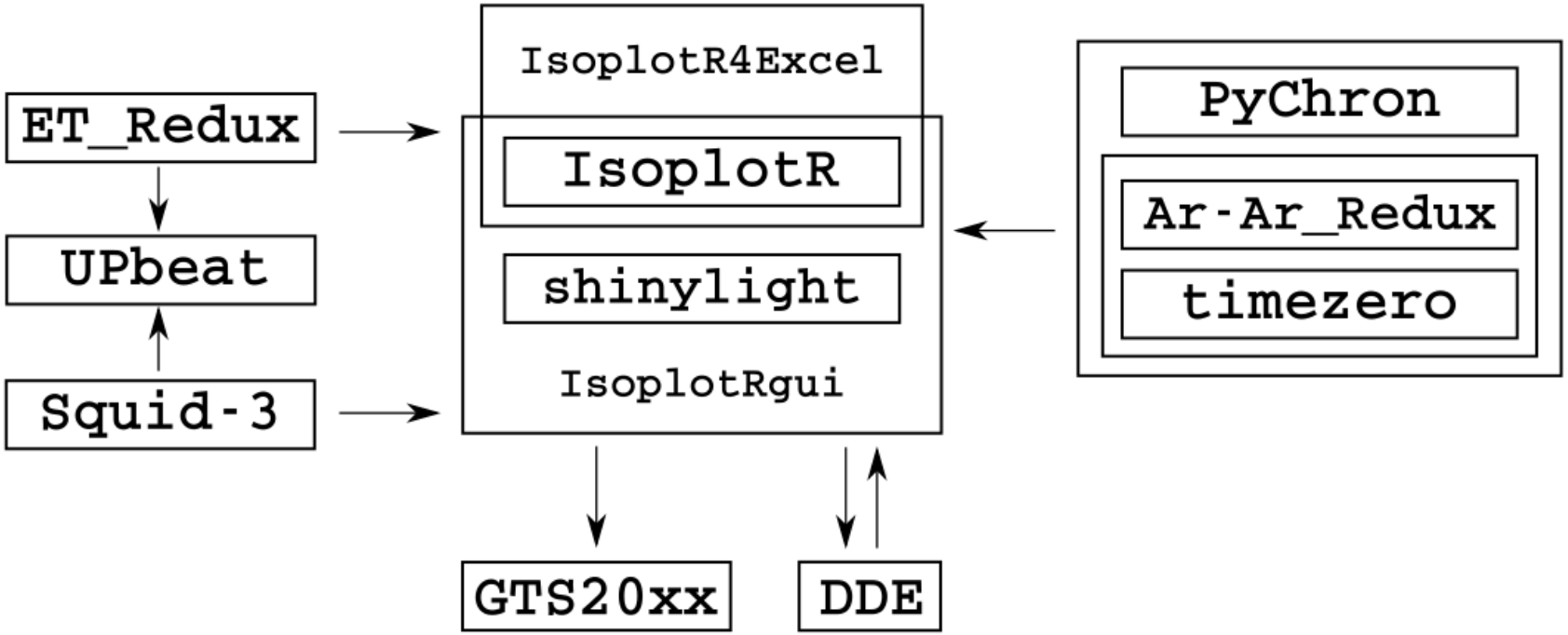
Lambda[40]	l4	s[l4]^2	s[l4,l8]	s[l4,l5]	s[l4,c1]	s[l4,d1]	s[l4,c2]	s[l4,d2]	…	s[l4,cn]	s[l4,dn]
Lambda[238]	l8	s[l8,l4]	s[l8]^2	s[l8,l5]	s[l8,c1]	s[l8,d1]	s[l8,c2]	s[l8,d2]	…	s[l8,cn]	s[l8,dn]
Lambda[235]	l5	s[l5,l4]	s[l5,l8]	s[l5]^2	s[l5,c1]	s[l5,d1]	s[l5,c2]	s[l5,d2]	…	s[l5,cn]	s[l5,dn]
Pb206/U238[1]	c1	s[c1,l4]	s[c1,l8]	s[c1,l5]	s[c1]^2	s[c1,d1]	s[c1,c2]	s[c1,d2]	…	s[c1,cn]	s[c1,dn]
Pb207/U235[1]	d1	s[d1,l4]	s[d1,l8]	s[d1,l5]	s[d1,c1]	s[d1]^2	s[d1,c2]	s[d1,d2]	…	s[d1,cn]	s[d1,dn]
Pb206/U238[2]	c2	s[c2,l4]	s[c2,l8]	s[c2,l5]	s[c2,c1]	s[c2,d1]	s[c2]^2	s[c2,d2]	…	s[c2,cn]	s[c2,dn]
Pb207/U235[2]	d2	s[d2,l4]	s[d2,l8]	s[d2,l5]	s[d2,c1]	s[d2,d1]	s[d2,c2]	s[d2]^2	…	s[d2,cn]	s[d2,dn]
…		…	…	…	…	…	…	…	…	…	…
Pb206/U238[m]	cm	s[cm,l4]	s[cm,l8]	s[cm,l5]	s[cn,c1]	s[cn,d1]	s[cn,c2]	s[cn,d2]	…	s[cn]^2	s[cn,dn]
Pb207/U235[m]	dm	s[dm,l4]	s[dm,l8]	s[dm,l5]	s[dn,c1]	s[dn,d1]	s[dn,c2]	s[dn,d2]	…	s[c1,cn]	s[dn]^2

Combining $^{40}Ar/^{39}Ar$ and U-Pb data

$^{40}Ar/^{39}Ar$

Ar40/Ar39[1]	a1	s[a1]^2	s[a1,b1]	s[a1,a2]	s[a1,b2]	…	s[a1,an]	s[a1,bn]	s[a1,l4]	s[a1,l8]	s[a1,l5]	s[a1,c1]	s[a1,d1]	s[a1,c2]	s[a1,d2]	…	s[a1,cn]	s[a1,dn]
Ar40/Ar36[1]	b1	s[b1,a1]	s[b1]^2	s[b1,a2]	s[b1,b2]	…	s[b1,an]	s[b1,bn]	s[b1,l4]	s[b1,l8]	s[b1,l5]	s[b1,c1]	s[b1,d1]	s[b1,c2]	s[b1,d2]	…	s[b1,cn]	s[b1,dn]
Ar40/Ar39[2]	a2	s[a2,a1]	s[a2,b1]	s[a2]^2	s[a2,b2]	…	s[a2,an]	s[a2,bn]	s[a2,l4]	s[a2,l8]	s[a2,l5]	s[a2,c1]	s[a2,d1]	s[a2,c2]	s[a2,d2]	…	s[a2,cn]	s[a2,dn]
Ar40/Ar36[2]	b2	s[b2,a1]	s[b2,b1]	s[b2,a2]	s[b2]^2	…	s[b2,an]	s[b2,bn]	s[b2,l4]	s[b2,l8]	s[b2,l5]	s[b2,c1]	s[b2,d1]	s[b2,c2]	s[b2,d2]	…	s[b2,cn]	s[b2,dn]
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
Ar40/Ar39[n]	an	s[an,a1]	s[an,b1]	s[an,a2]	s[an,b2]	…	s[an]^2	s[an,bn]	s[an,l4]	s[an,l8]	s[an,l5]	s[an,c1]	s[an,d1]	s[an,c2]	s[a2,d2]	…	s[an,cn]	s[an,dn]
Ar40/Ar36[n]	bn	s[bn,a1]	s[bn,b1]	s[bn,a2]	s[bn,b2]	…	s[a1,an]	s[bn]^2	s[bn,l4]	s[bn,l8]	s[bn,l5]	s[bn,c1]	s[bn,d1]	s[bn,c2]	s[bn,d2]	…	s[bn,cn]	s[bn,dn]
Lambda[40]	l4	s[l4,a1]	s[l4,b1]	s[l4,a2]	s[l4,b2]	…	s[l4,an]	s[l4,bn]	s[l4]^2	s[l4,l8]	s[l4,l5]	s[l4,c1]	s[l4,d1]	s[l4,c2]	s[l4,d2]	…	s[l4,cn]	s[l4,dn]
Lambda[238]	l8	s[l8,a1]	s[l8,b1]	s[l8,a2]	s[l8,b2]	…	s[l8,an]	s[l8,bn]	s[l8,l4]	s[l8]^2	s[l8,l5]	s[l8,c1]	s[l8,d1]	s[l8,c2]	s[l8,d2]	…	s[l8,cn]	s[l8,dn]
Lambda[235]	l5	s[l5,a1]	s[l5,b1]	s[l5,a2]	s[l5,b2]	…	s[l5,an]	s[l5,bn]	s[l5,l4]	s[l5,l8]	s[l5]^2	s[l5,c1]	s[l5,d1]	s[l5,c2]	s[l5,d2]	…	s[l5,cn]	s[l5,dn]
Pb206/U238[1]	c1	s[c1,a1]	s[c1,b1]	s[c1,a2]	s[c1,b2]	…	s[c1,an]	s[c1,bn]	s[c1,l4]	s[c1,l8]	s[c1,l5]	s[c1]^2	s[c1,d1]	s[c1,c2]	s[c1,d2]	…	s[c1,cn]	s[c1,dn]
Pb207/U235[1]	d1	s[d1,a1]	s[d1,b1]	s[d1,a2]	s[d1,b2]	…	s[d1,an]	s[d1,bn]	s[d1,l4]	s[d1,l8]	s[d1,l5]	s[d1,c1]	s[d1]^2	s[d1,c2]	s[d1,d2]	…	s[d1,cn]	s[d1,dn]
Pb206/U238[2]	c2	s[c2,a1]	s[c2,b1]	s[c2,a2]	s[c2,b2]	…	s[c2,an]	s[c2,bn]	s[c2,l4]	s[c2,l8]	s[c2,l5]	s[c2,c1]	s[c2,d1]	s[c2]^2	s[c2,d2]	…	s[c2,cn]	s[c2,dn]
Pb207/U235[2]	d2	s[d2,a1]	s[d2,b1]	s[d2,a2]	s[d2,b2]	…	s[d2,an]	s[d2,bn]	s[d2,l4]	s[d2,l8]	s[d2,l5]	s[d2,c1]	s[d2,d1]	s[d2,c2]	s[d2]^2	…	s[d2,cn]	s[d2,dn]
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
Pb206/U238[m]	cm	s[cm,a1]	s[cm,b1]	s[cm,a2]	s[cm,b2]	…	s[cm,an]	s[cm,bn]	s[cm,l4]	s[cm,l8]	s[cm,l5]	s[cn,c1]	s[cn,d1]	s[cn,c2]	s[cn,d2]	…	s[cn]^2	s[cn,dn]
Pb207/U235[m]	dm	s[dm,a1]	s[dm,b1]	s[dm,a2]	s[dm,b2]	…	s[dm,an]	s[dm,bn]	s[dm,l4]	s[dm,l8]	s[dm,l5]	s[dn,c1]	s[dn,d1]	s[dn,c2]	s[dn,d2]	…	s[c1,cn]	s[dn]^2

U-Pb



$$\begin{bmatrix}
X_1 & s[X_1]^2 & cov[X_1,X_2] & \dots & cov[X_1,X_n] & cov[X_1,Y_1] & \dots & cov[X_1 Y_n] & cov[X_1 Z_1] & \dots & cov[X_1,Z_n] \\
X_2 & cov[X_2,X_1] & s[X_2]^2 & \dots & cov[X_2,X_n] & cov[X_2,Y_1] & \dots & cov[X_2,Y_n] & cov[X_2,Z_1] & \dots & cov[X_2,Z_n] \\
\vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
X_n & cov[X_n,X_1] & cov[X_n,X_2] & \dots & s[X_n]^2 & cov[X_n,Y_1] & \dots & cov[X_n,Y_n] & cov[X_n,Z_1] & \dots & cov[X_n,Z_n] \\
Y_1 & cov[Y_1,X_1] & cov[Y_1,X_2] & \dots & cov[Y_1,X_n] & s[Y_1]^2 & \dots & cov[Y_1,Y_n] & cov[Y_1,Z_1] & \dots & cov[Y_1,Z_n] \\
\vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
Z_n & cov[Z_n,X_1] & cov[Z_n,X_2] & \dots & cov[Z_n,X_n] & cov[Z_n,Y_1] & \dots & cov[Z_n,Y_n] & cov[Z_n,Z_1] & \dots & s[Z_n]^2
\end{bmatrix}$$