Interpreting Sediment Dispersal in Western North America from Detrital Zircon Ages*

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Abstract

U-Pb ages for detrital zircons (DZ) augment paleocurrent, petrofacies, and deposystem analysis for provenance studies but DZ constraints require shrewd orchestration. The exact sources of DZ grains are eroded away, with only analogues or deeper horizons remaining in the provenance. Sediment dispersal systems mix DZ from multiple sources to generate integrated provenance signals that must be deconvolved to understand. Since zircon U-Pb ages are not reset by any sedimentary processes and zircon is resistant to weathering, DZ ages define ultimate bedrock sources but not necessarily proximate sources because recycling of DZ from older sedimentary rocks is common. As there are only a finite number of basement provinces and volcanic belts of discrete ages in North America, DZ populations cannot readily contain grains of other ages. Volumetric yields of DZ from basement rocks are controlled by varying zircon fertility of different source granitoids, and proportions of DZ do not necessarily equate to proportions of total sand. Mafic volcanics yield few DZ grains of sand size, but polymodal volcanic suites contribute abundant DZ to derivative sands. Detecting DZ grains derived from airborne ash clouds is challenging because suspension transport in streams can carry fine sand for long distances without rounding the grains.

Despite inherent caveats, DZ studies provide advantages over other provenance tools. Intrabasinal paleocurrent trends cannot delineate extrabasinal dispersal paths but DZ can. Petrofacies analysis largely founders for quartzose sands but DZ does not, and provenance signals from DZ are geographically more specific than those from petrofacies. Facies analysis of deposystems can mistakenly relate stratal assemblages that DZ shows had different provenances. Salient contributions of DZ studies to Cordilleran sedimentary assemblages include the appreciation that transcontinental paleorivers loom large for sediment dispersal across cratons, and tectonically transverse and longitudinal transport paths can deliver sediment jointly to basinal depocenters.

Selected References

Dumitru, T.A., J. Wakabayashi, and R. Prohoroff, 2012, Sandstone matrix olistostrome deposited on intra-subduction complex serpentinite, Franciscan Complex, Western Marin County, California: Tectonophysics, v. 568-569, p. 296-305.

Moecher, D.P., and S.D. Sampson, 2006, Differential zircon fertility of source terranes and natural bias in the detrital zircon record: implications for sedimentary provenance analysis: Earth and Planetary Science Letters (EPSL), v. 247, p. 252-266.

INTERPRETING SEDIMENT DISPERSAL IN WESTERN NORTH AMERICA FROM DETRITAL ZIRCON AGES

*William R. Dickinson**
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*with massive assists and background from colleague

George E. Gehrels, 2010 GSA Day Medalist and

Majordomo of the Arizona LaserChron Center

WHY DZ PROVIDES A NEW LEASE ON PROVENANCE LIFE

paleocurrent and deposystem analysis can define intrabasinal sand transport *and* **petrofacies can define the general character of extrabasinal sand sources**

whereas

DZ analysis defines specific source rock ages and extrabasinal sand dispersal (*zircon ages are proxy for qtz-felds ages as both derive from felsic igneous rocks*)

thereby

wedding *paleogeomorphology* to *paleosedimentology*
(if sand is the bullets, streams and winds are the gun)

but

DZ cannot detect direct vs tortuous dispersal paths nor sand recycling (*nothing short of granulite metamorphism resets zircon U/Pb ages, which pertain to ultimate bedrock sources rather than proximate recycled sources*)

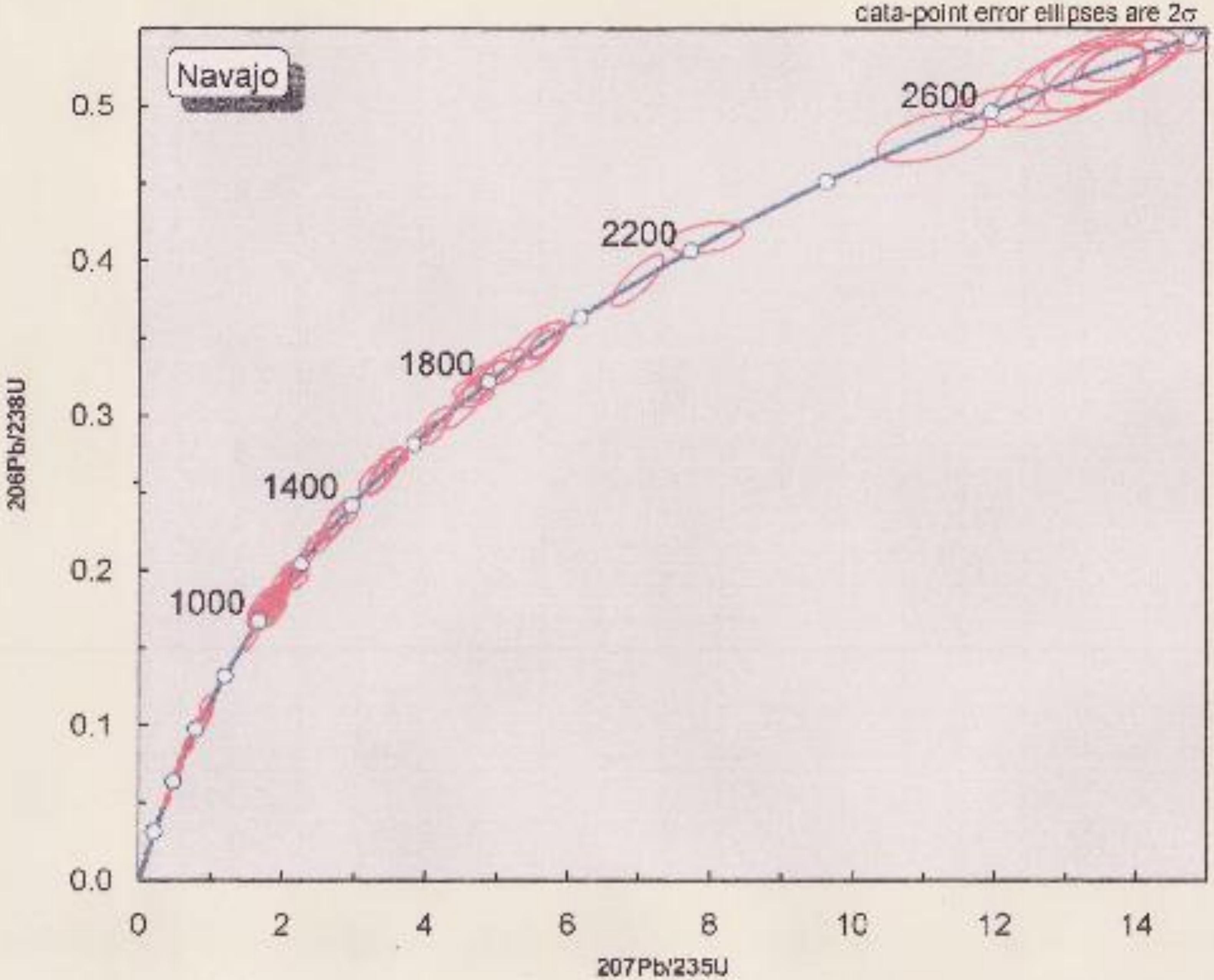
HOW U-PB GEOCHRONOLOGY WORKS FOR DZ GRAINS

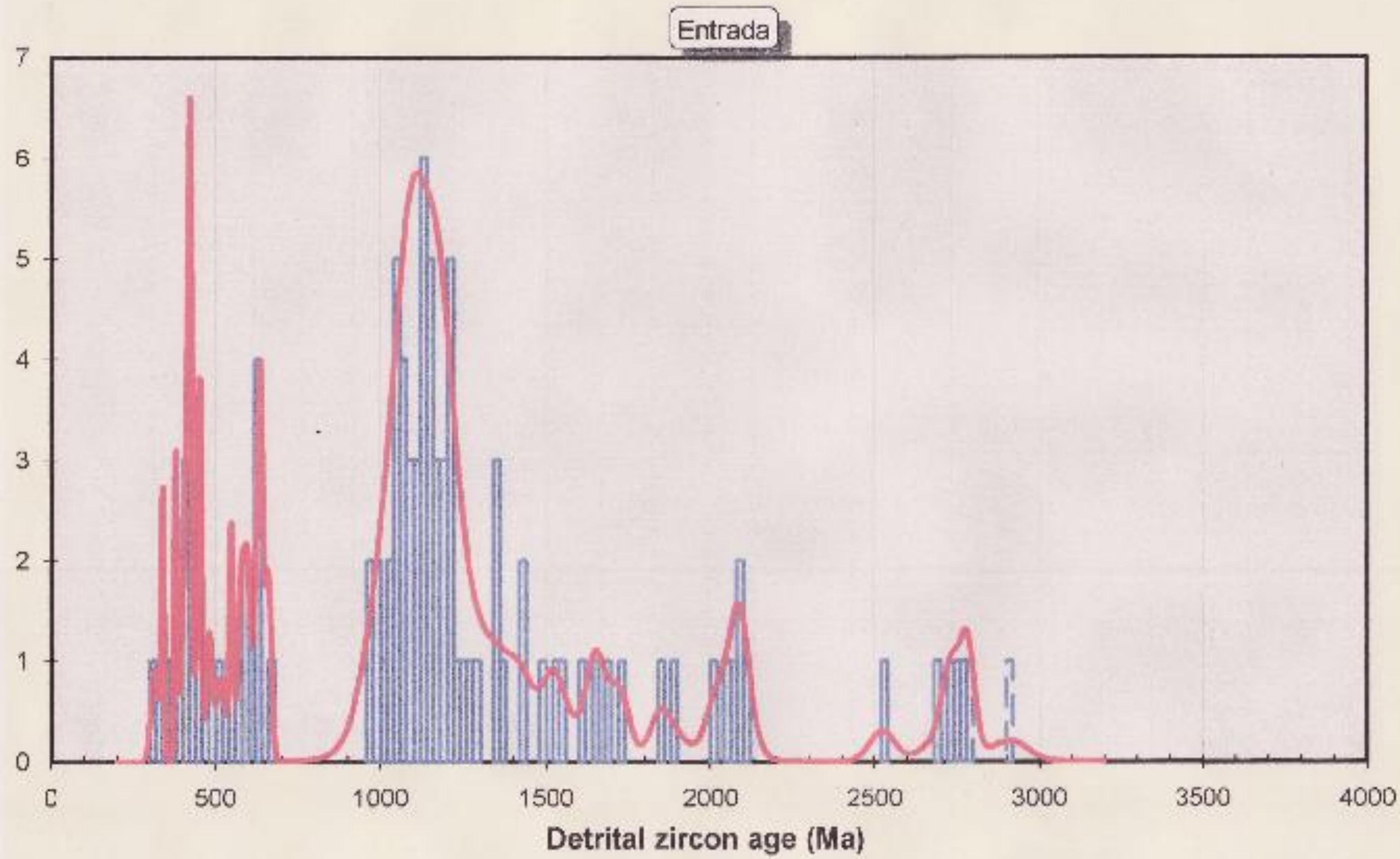
Igneous zircon naturally contains plenty of uranium (*100-1000 ppm*) but little non-radiogenic lead (*ppb-ppt*) – finessed by the *common lead correction* (CLC) made with direct knowledge of the $^{206}Pb/^{204}Pb$ ratio measured in all DZ grains *(without adjusting ^{206}Pb & ^{207}Pb to $^{206}Pb^*$ & $^{207}Pb^*$, DZ ages are slightly too old)*

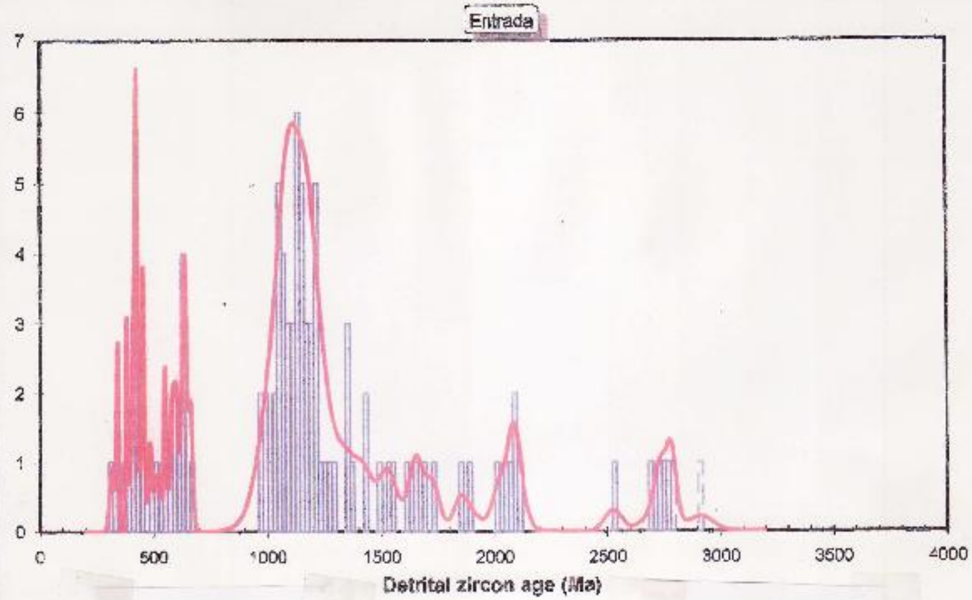
Double U-Pb decay system ($^{238}U \rightarrow {}^{206}Pb^*$ & $^{235}U \rightarrow {}^{207}Pb^*$) provides internal experimental confirmation that the U-Pb system in a DZ grain is undisturbed (grains yielding discordant $^{206}Pb^*/^{238}U$ & $^{207}Pb^*/^{235}U$ ages are rejected)

In practice, directly measure $^{206}Pb^*/^{238}U$ ratios (adjusted with the CLC) but calculate $^{207}Pb^*/^{235}U$ ratios from measured $^{206}Pb^*/^{207}Pb^*$ ratios (adjusted with the CLC) and the sure knowledge that modern $^{238}U/^{235}U = 137.88$ (precisely)

SPECIAL NOTE:
$^{206}Pb^*/^{238}U$ ages are more precise for grain ages <1000 Ma
$^{206}Pb^*/^{207}Pb^*$ ages are more precise for grain ages >1000 Ma
(*the alternate ages are used accordingly for plots of DZ age spectra*)

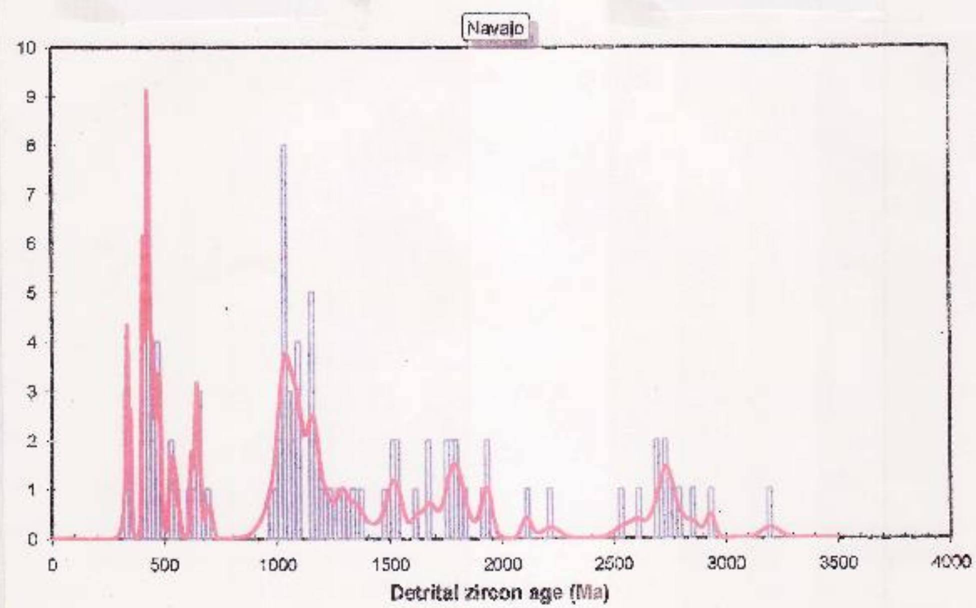

cata-point error ellipses are 2σ
Navajo
2600
2200
1800
1400
1000
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
206Pb/238U
207Pb/235U


Entrada
7
6
5
4
3
2
1
0
C
500
1000
1500
2000
2500
3000
3500
4000
Detrital zircon age (Ma)



North Wash UT

P = 0.49 from K-S



KOLMOGOROV-SMIRNOFF (K-S) ANALYSIS

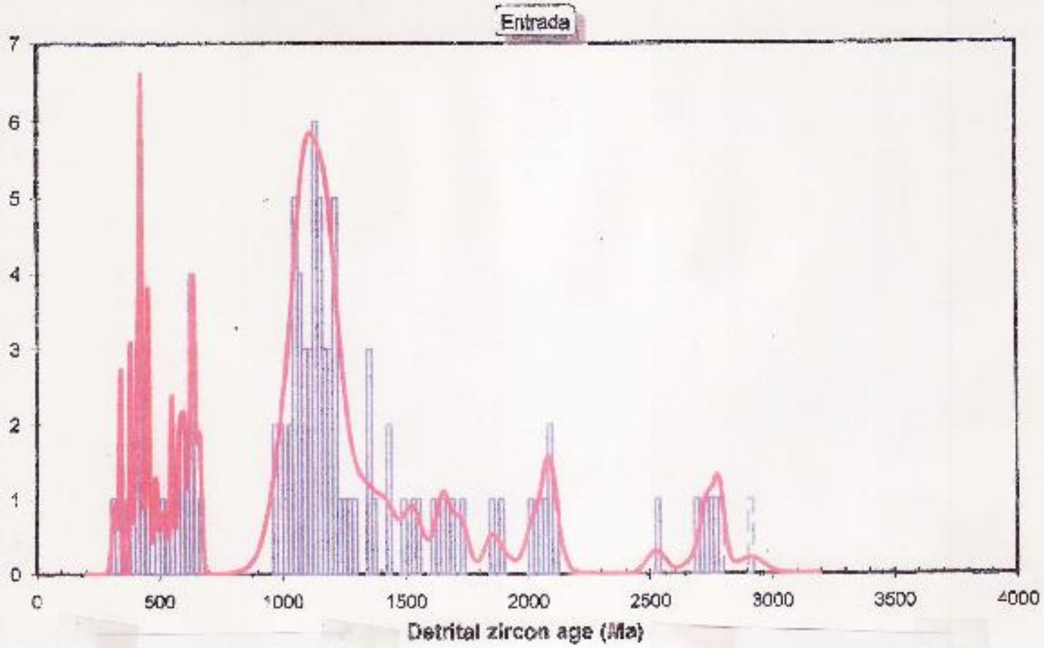
ALC algorithm courtesy of Jerome Guynn

calculates a probability P (taking into account all grain age uncertainties) that two DZ age populations could have been derived by random selection of grains from the SAME parent population
(*implication: common provenance or recycled one from the other*)

where P=1.0, two DZ grain populations are congruent (*age spectra identical*)

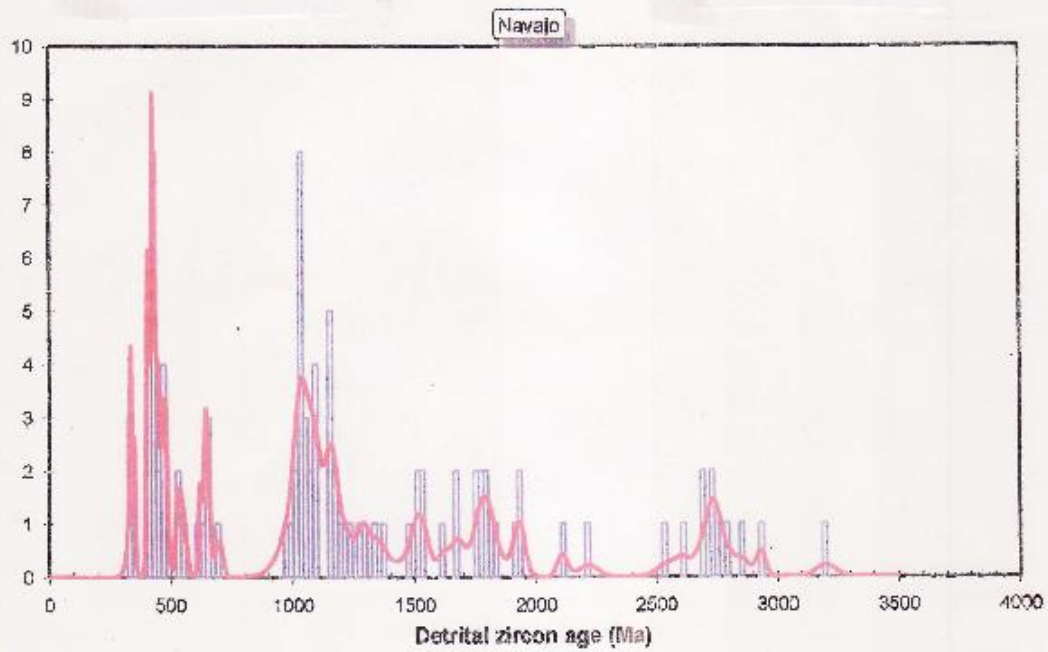
where P>0.05 (*inverse of 0.95*) cannot be 95% confident (a standard statistical criterion) that two grain age populations were NOT derived by random grain selection from the same parent population

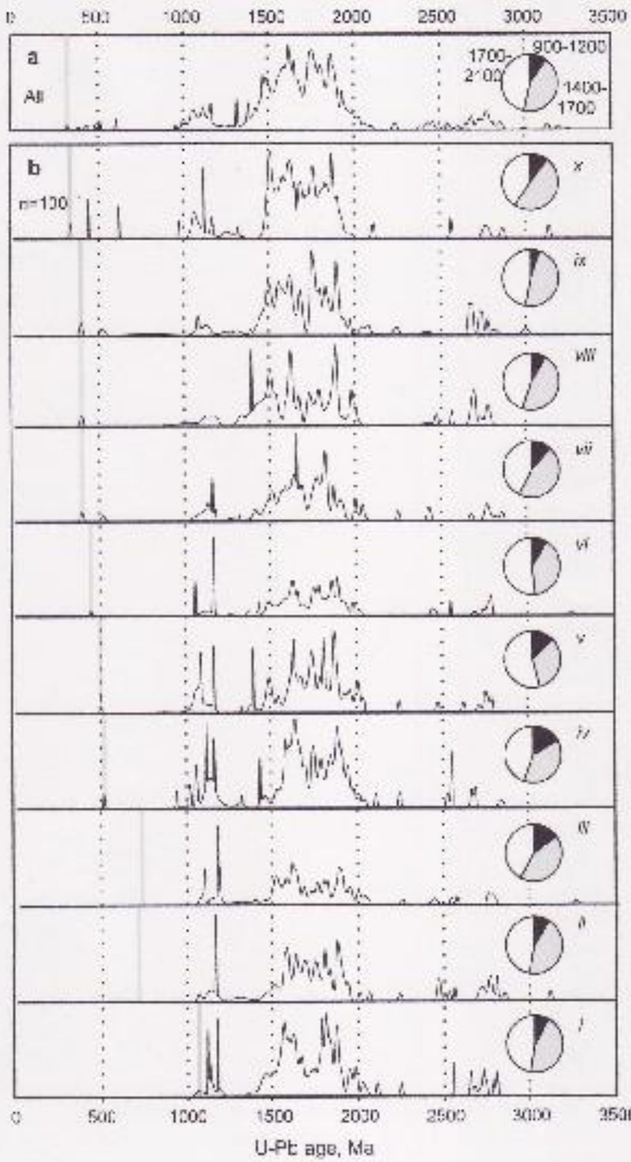
CAVEAT: for full statistical reliability, need to compare two age populations containing comparable numbers of grain ages



North Wash UT

P = 0.49 from K-S





0
500
1000
1500
2000
2500
3000
3500
a
All
1700-
2100
900-1200
1400-
1700
b
n=100
x
ix
viii
vii
vi
v
iv
iii
ii
i
U-Pb age, Ma

SIGNIFICANCE OF ZIRCON FERTILITY FACTOR

Proportions of DZ grains of various ages in do not necessarily equate to overall proportions of detritus from source rocks of those ages because differential *ZIRCON FERTILITYof source rocks affects zircon yield**

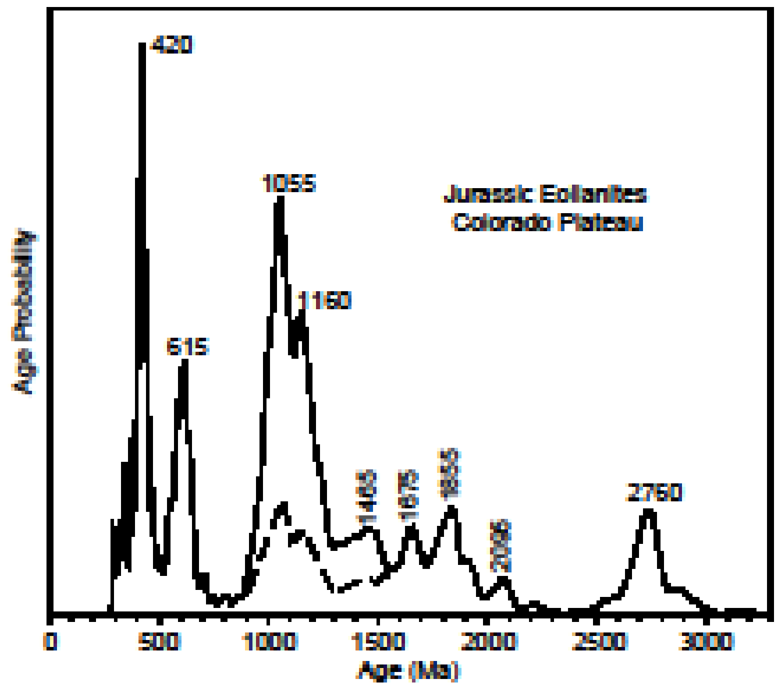
(*Moecher & Sampson 2006 EPSL 247:252-266)

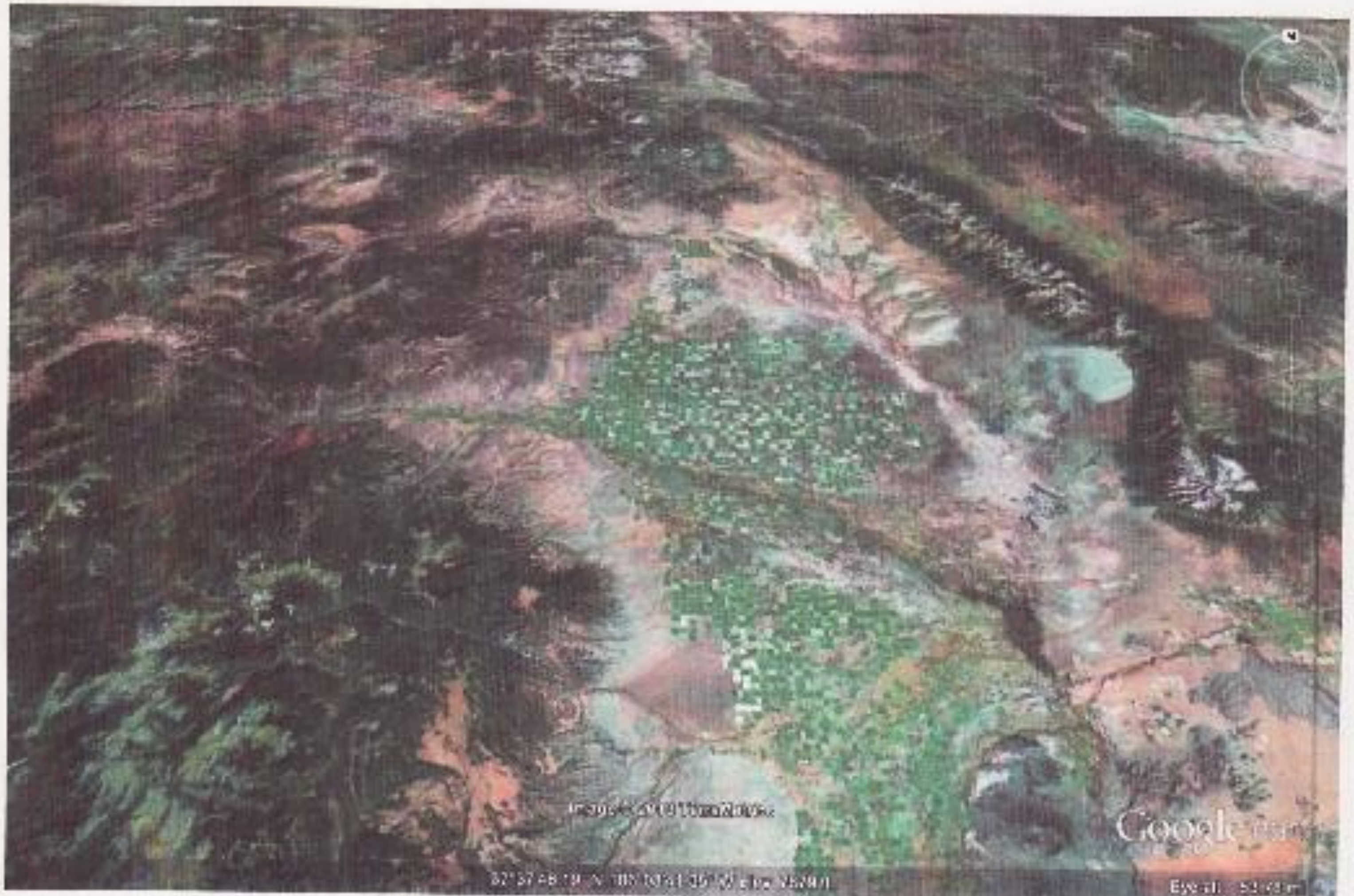
most zirconium in magmas enters zircon rather than other minerals

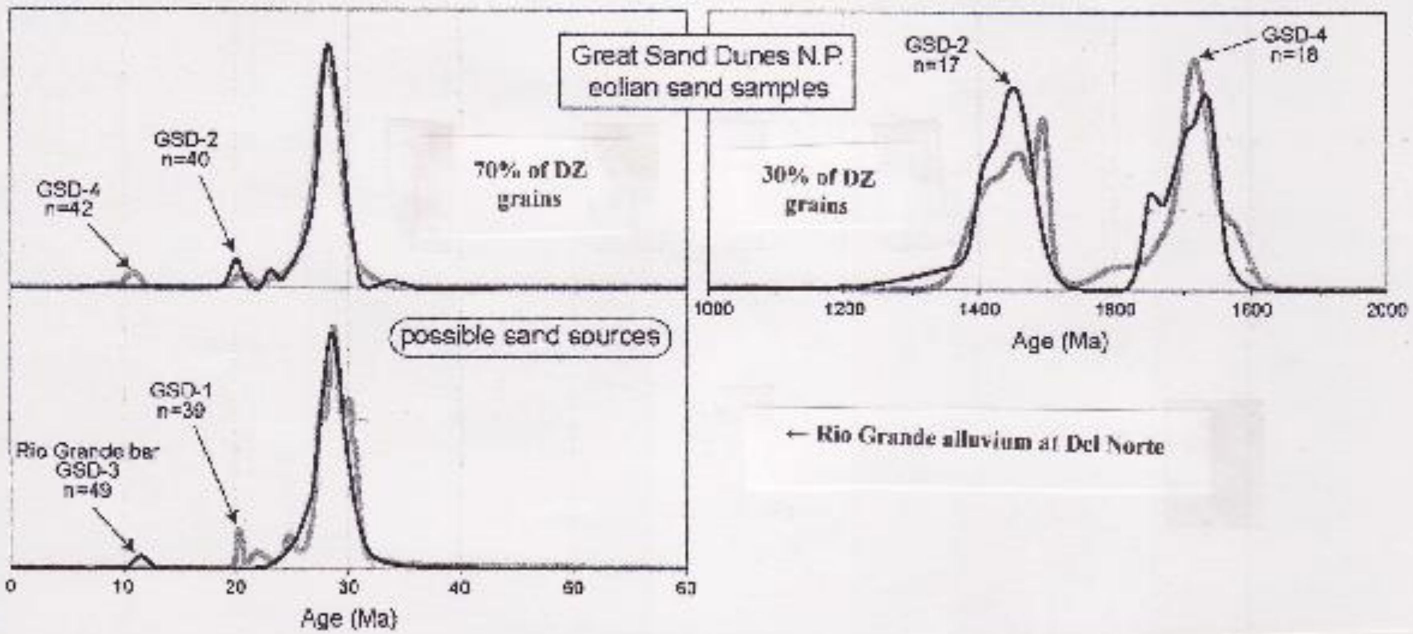
granitic rocks of orogenic (subduction-related) arc igneous suites of all ages (*Cenozoic-Mesozoic-Paleozoic-Proterozoic-Archean*) contain mean Zr ~ 150 ppm and can be assigned a baseline ZIRCON FERTILITY FACTOR (ZFF) = 1.0

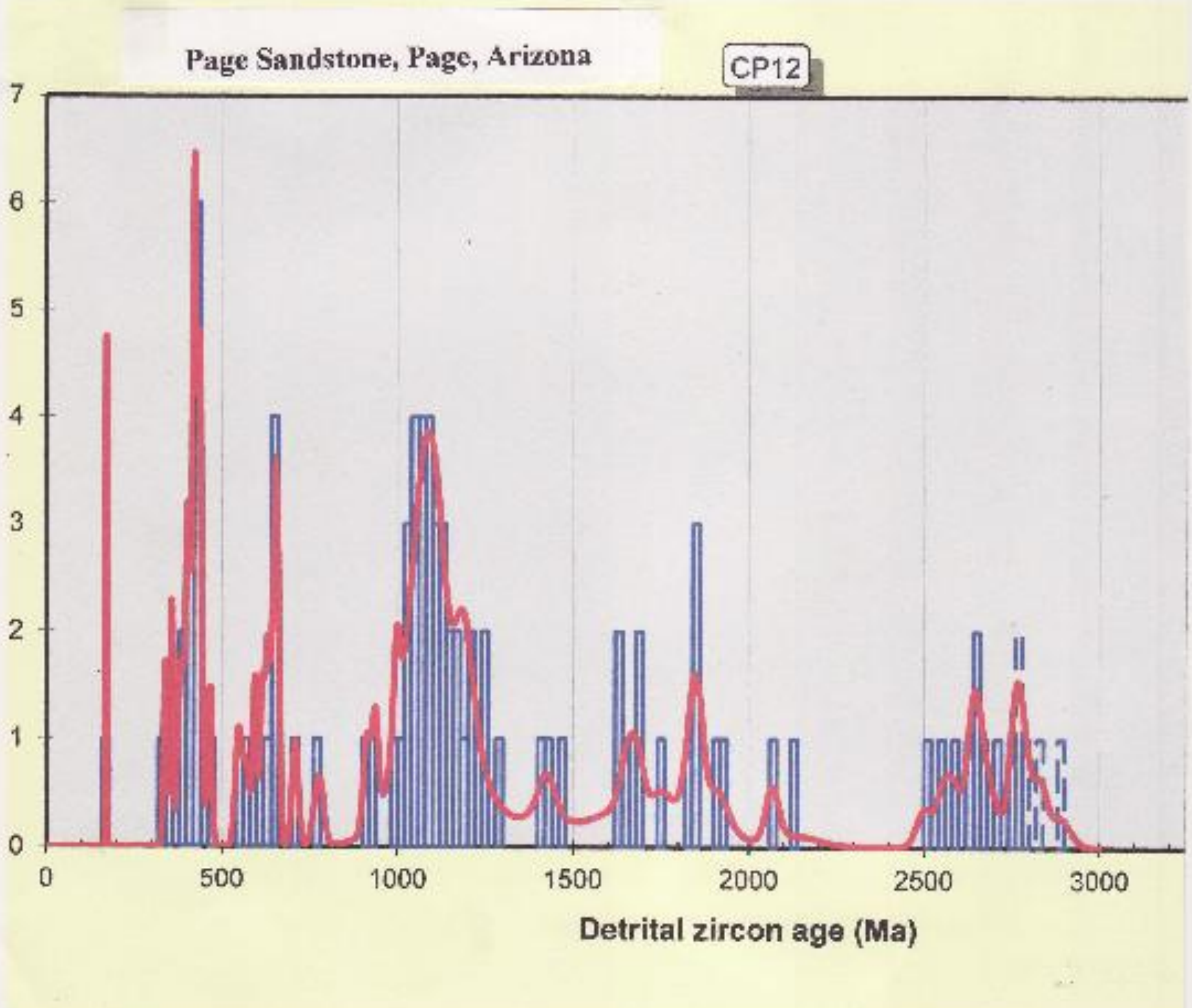
anorogenic Mesoproterozoic (1545-1360 Ma) and rift-related Neoproterozoic (pre-Iapetan 765-550 Ma) and Mesozoic (pre-Atlantic 200-165 Ma) plutons contain mean Zr ~ 375 ppm for ZFF ~ 2.5

collision-related Grenvillean (Mesoproterozoic 1250-1025 Ma) assemblages (granitoid-gneissoid) contain mean Zr ~ 525 ppm for ZFF ~ 3.5

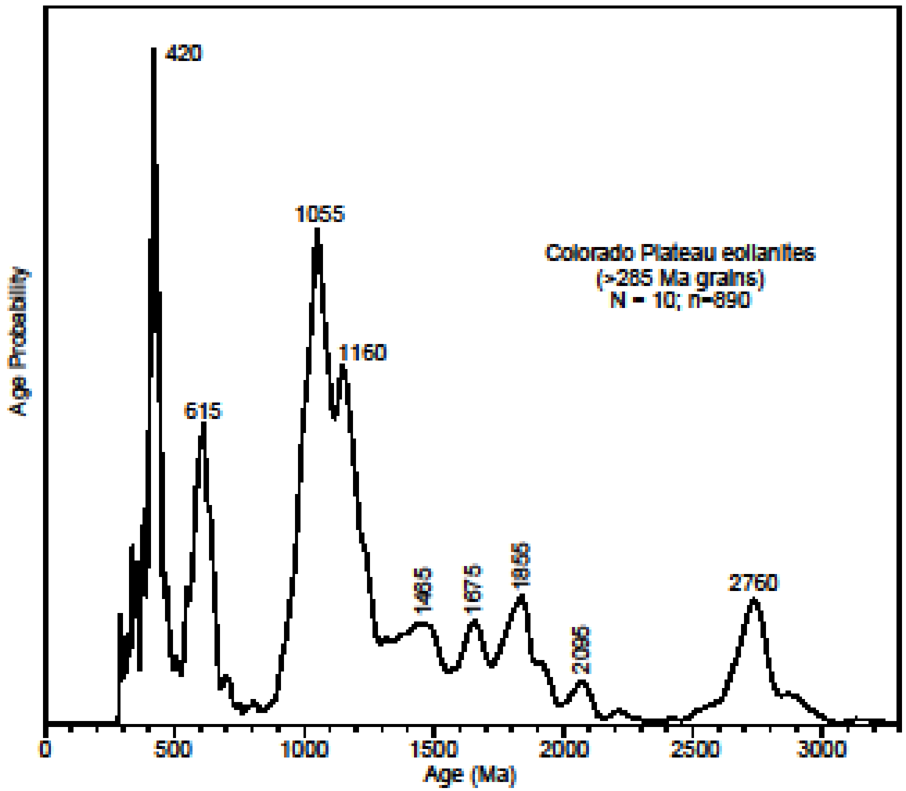

420
615
1055
1160
1465
1675
1855
2085
2760
Jurassic Eolianites
Colorado Plateau
Age Probability
0
500
1000
1500
2000
2500
3000
Age (Ma)

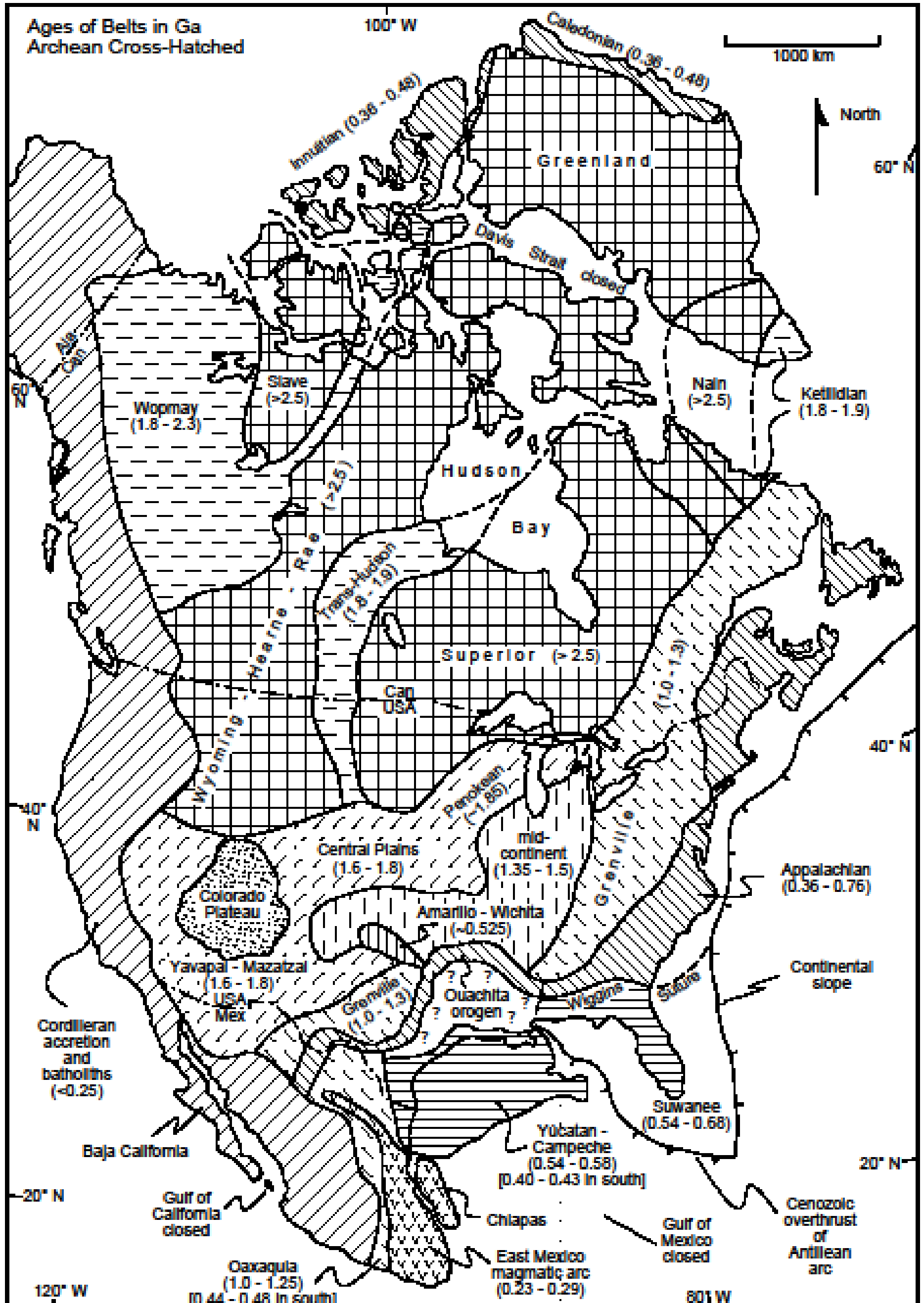

Google

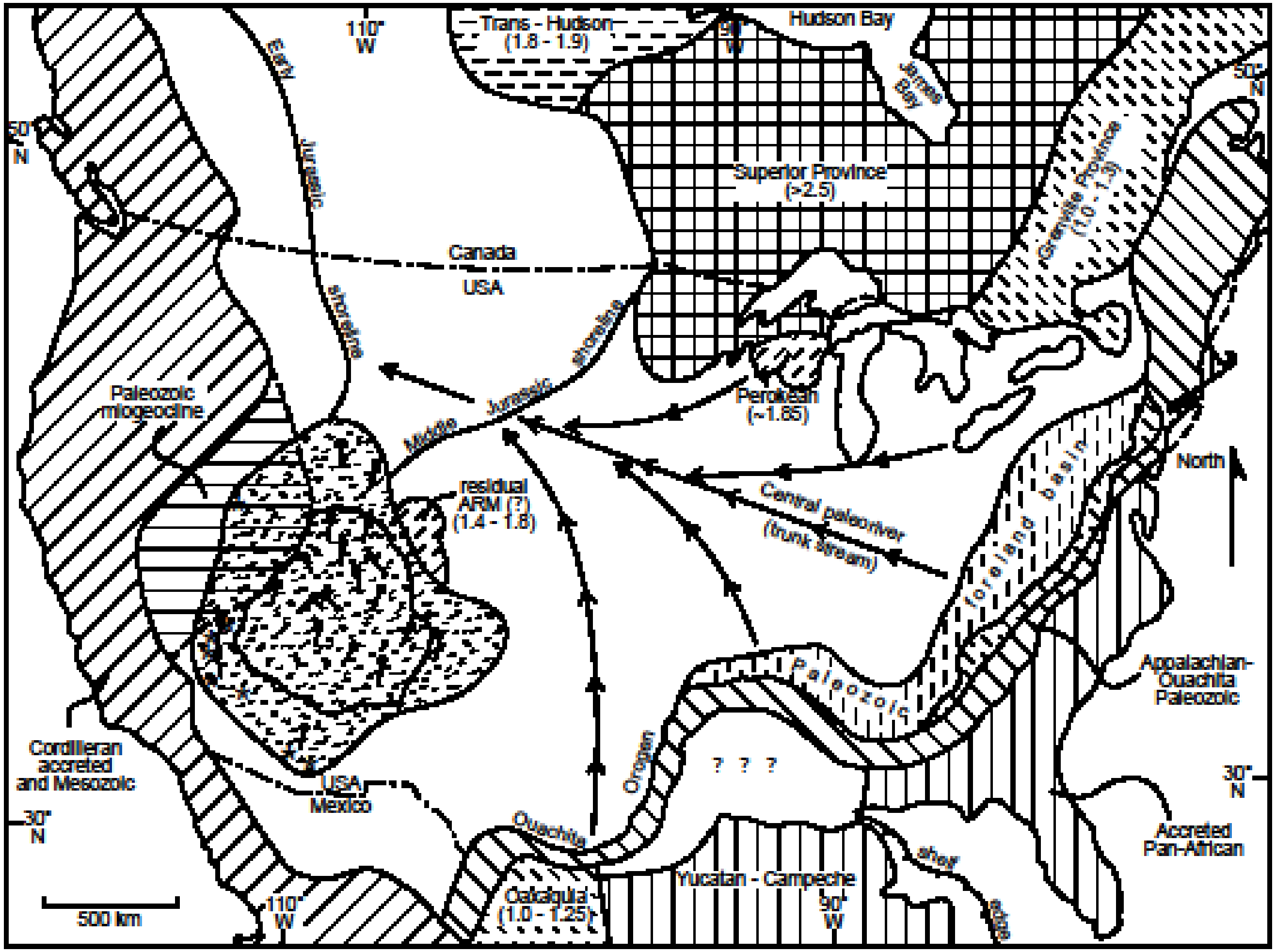

Great Sand Dunes N.P.
eolian sand samples
GSD-2
n=40
GSD-4
n=42
70% of DZ
grains
possible sand sources
GSD-1
n=39
Rio Grande bar
GSD-3
n=49
0
10
20
30
40
50
60
Age (Ma)
GSD-2
n=17
GSD-4
n=18
30% of DZ
grains
1000
1200
1400
1600
1800
2000
Age (Ma)
← Rio Grande alluvium at Del Norte



Page Sandstone, Page, Arizona
CP12
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
Detrital zircon age (Ma)

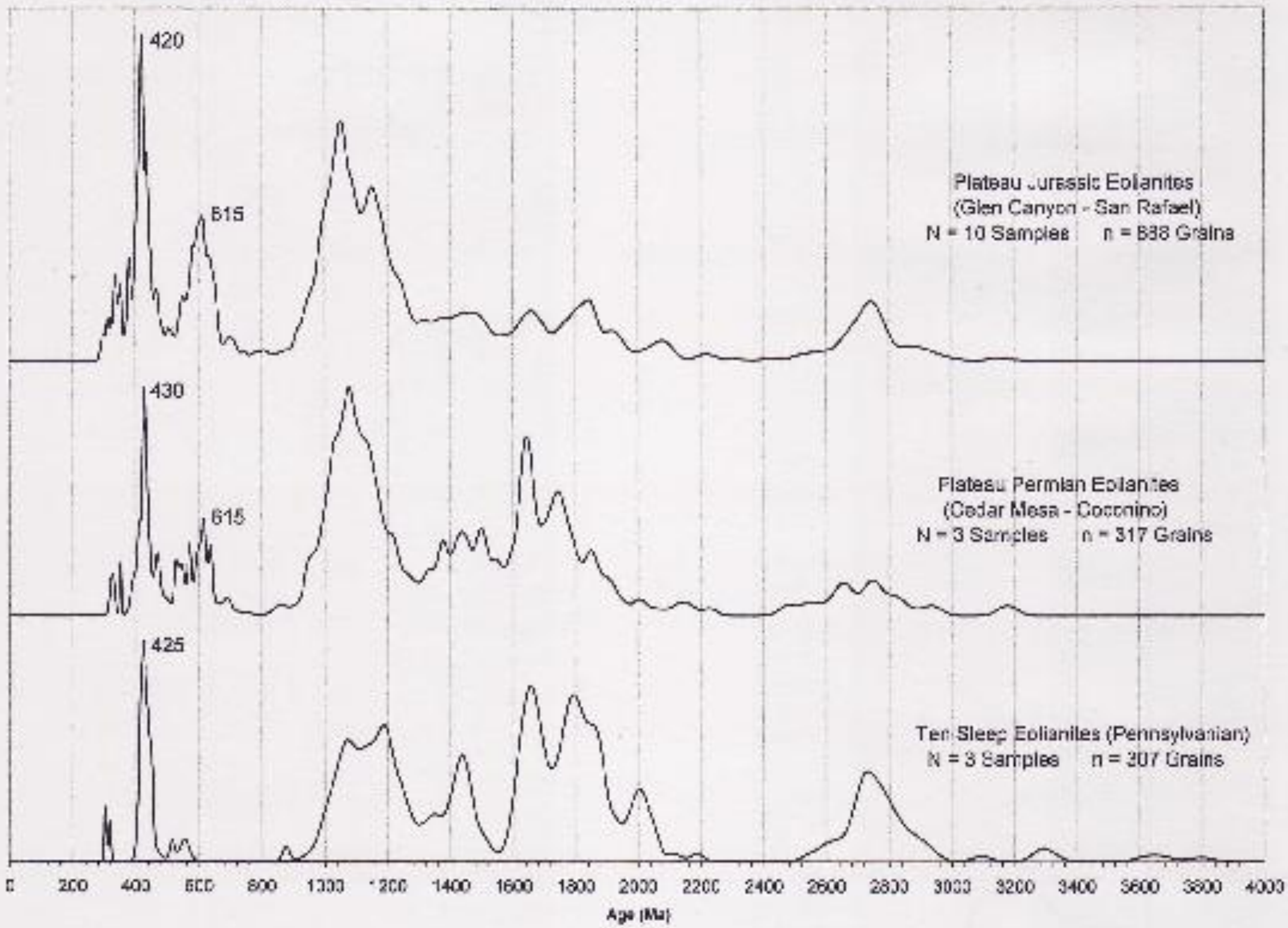

420
1055
1160
615
1465
1675
1855
2095
2760
Colorado Plateau eolianites
(>285 Ma grains)
N = 10; n=890
Age Probability
0
500
1000
1500
2000
2500
3000
Age (Ma)


Ages of Belts in Ga
Archean Cross-Hatched
100° W
Caledonian (0.36 - 0.48)
1000 km
North
60° N
Innuitian (0.36 - 0.48)
Greenland
Davis Strait closed
Alas
Can
60° N
Wopmay
(1.8 - 2.3)
Slave
(>2.5)
Nain
(>2.5)
Ketilidian
(1.8 - 1.9)
Hudson
Bay
Wyoming - Hearne - Rae (>2.5)
Trans-Hudson
(1.8 - 1.9)
Superior (> 2.5)
Can
USA
(1.0 - 1.3)
40° N
40° N
Penokean
(~1.85)
mid-
continent
(1.35 - 1.5)
Central Plains
(1.6 - 1.8)
Grenville
Appalachian
(0.36 - 0.76)
Colorado
Plateau
Amarillo - Wichita
(~0.525)
Yavapai - Mazatzal
(1.6 - 1.8)
USA
Mex
Grenville
(1.0 - 1.3)
Ouachita
orogen
Wiggins
Suture
Continental
slope
Cordilleran
accretion
and
batholiths
(<0.25)
Suwanee
(0.54 - 0.68)
Baja California
Yucatan -
Campeche
(0.54 - 0.58)
[0.40 - 0.43 in south]
20° N
20° N
Gulf of
California
closed
Chiapas
Gulf of
Mexico
closed
Cenozoic
overthrust
of
Antillean
arc
Oaxaquia
(1.0 - 1.25)
[0.44 - 0.48 in south]
East Mexico
magmatic arc
(0.23 - 0.29)
120° W
80° W

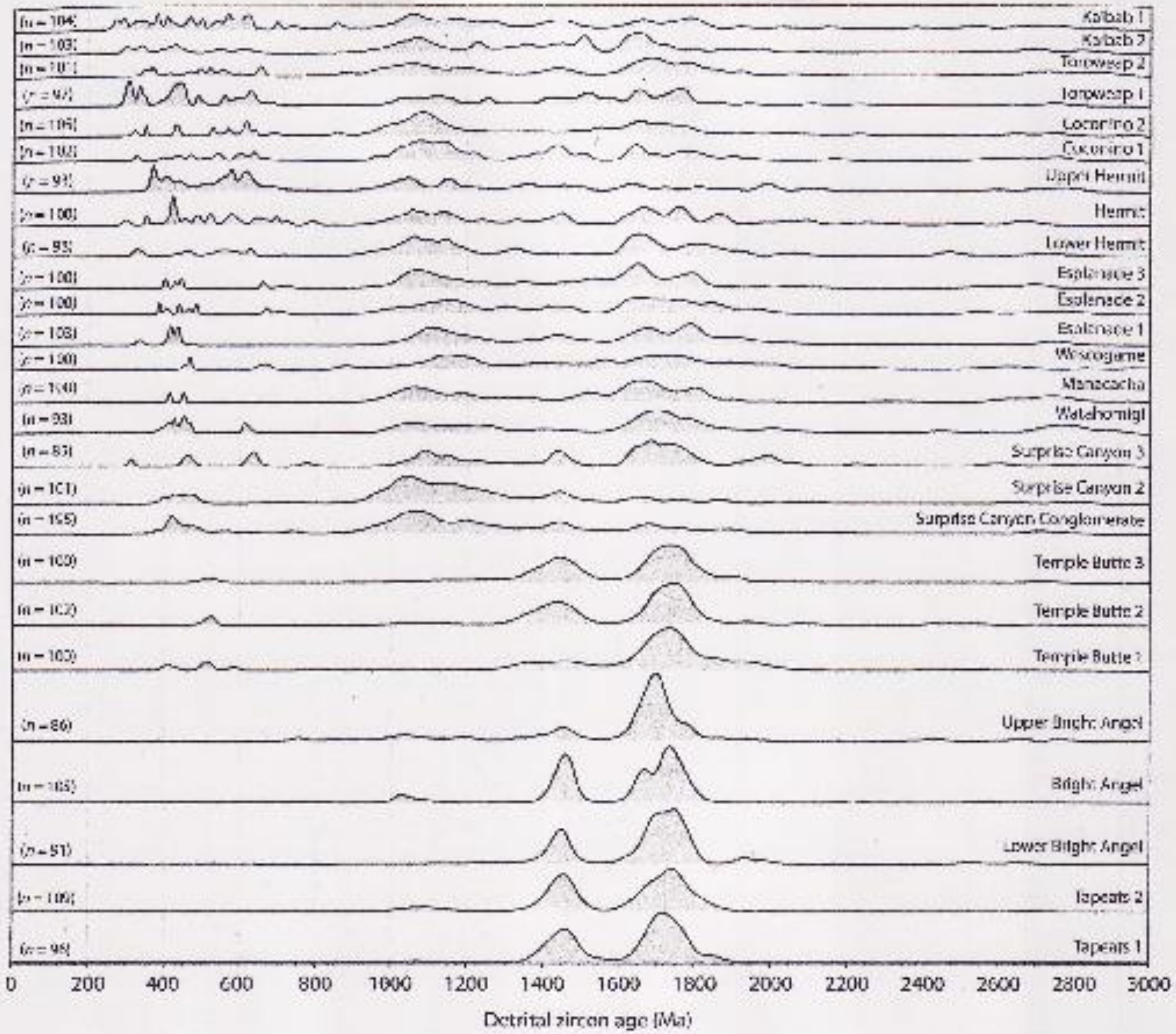

Trans - Hudson
(1.8 - 1.9)
Hudson Bay
110°
W
90°
W
James Bay
50°
N
50°
N
Early Jurassic shoreline
Superior Province
(>2.5)
Grenville Province
(1.0 - 1.3)
Canada
USA
Middle Jurassic shoreline
Paleozoic miogeocline
Penokean
(~1.85)
residual
ARM (?)
(1.4 - 1.8)
Central paleoriver
(trunk stream)
foreland basin
North
Appalachian-
Ouachita
Paleozoic
Paleozoic
Orogen
Ouachita
? ? ?
Cordilleran
accreted
and Mesozoic
USA
Mexico
30°
N
30°
N
Accreted
Pan-African
Oaxaquia
(1.0 - 1.25)
Yucatan - Campeche
shelf edge
500 km
110°
W
90°
W

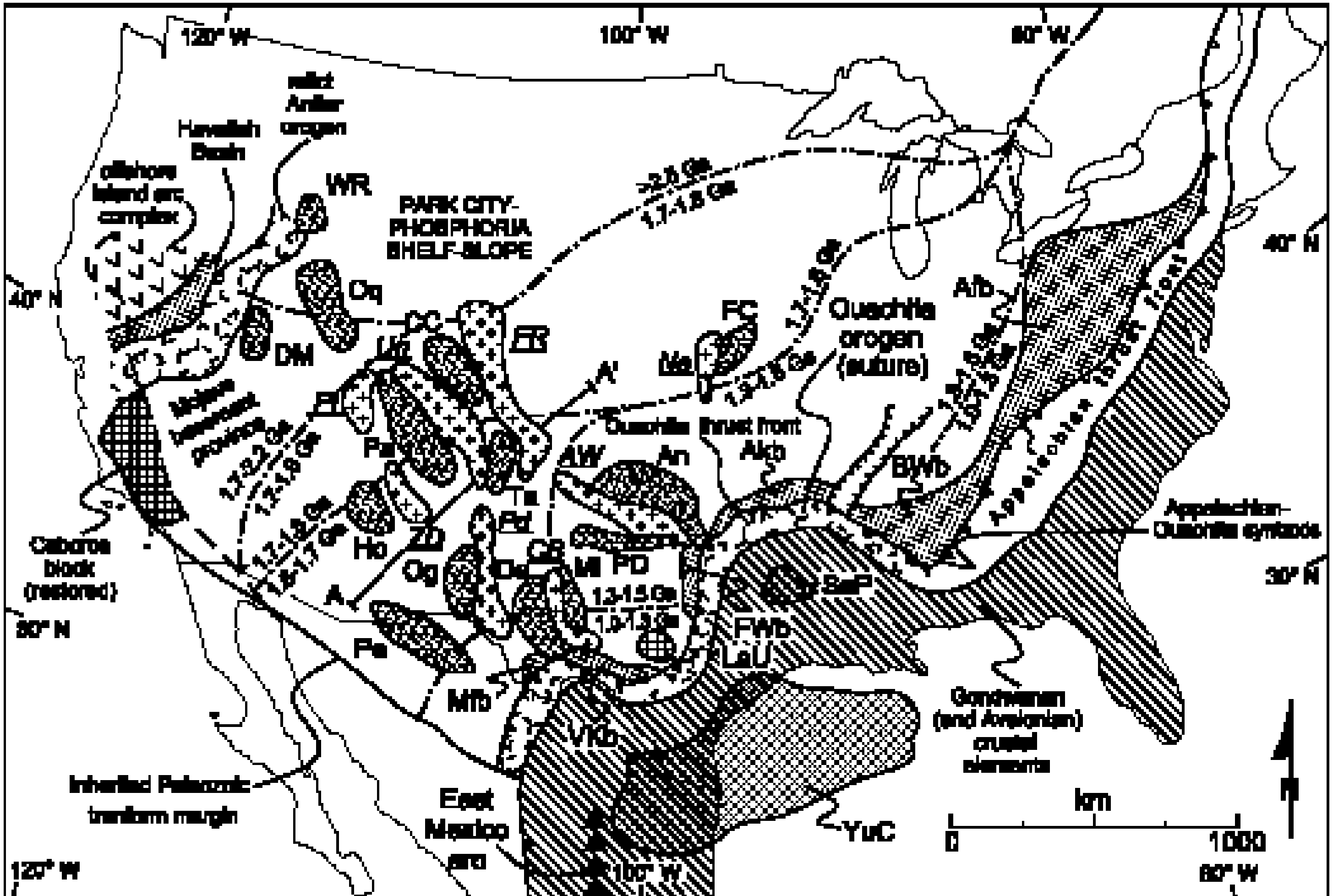
Detrital Zircon Ages

Paleozoic and Mesozoic Eolianites - Bighorn Basin (Ten Sleep) and Colorado Plateau (Pre-Arc Grains >285 Ma)



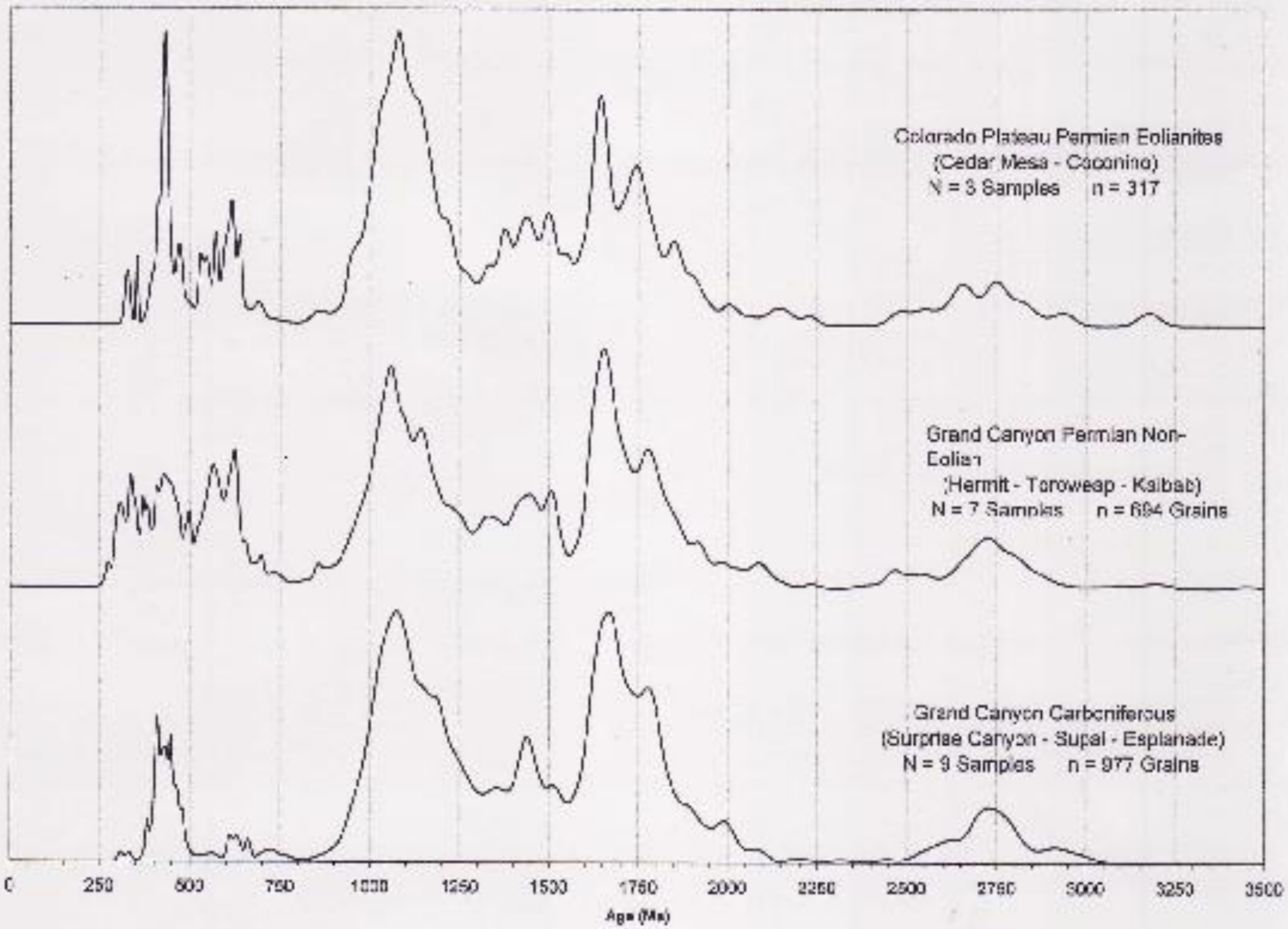
Gehrels et al 2011 Lithosphere

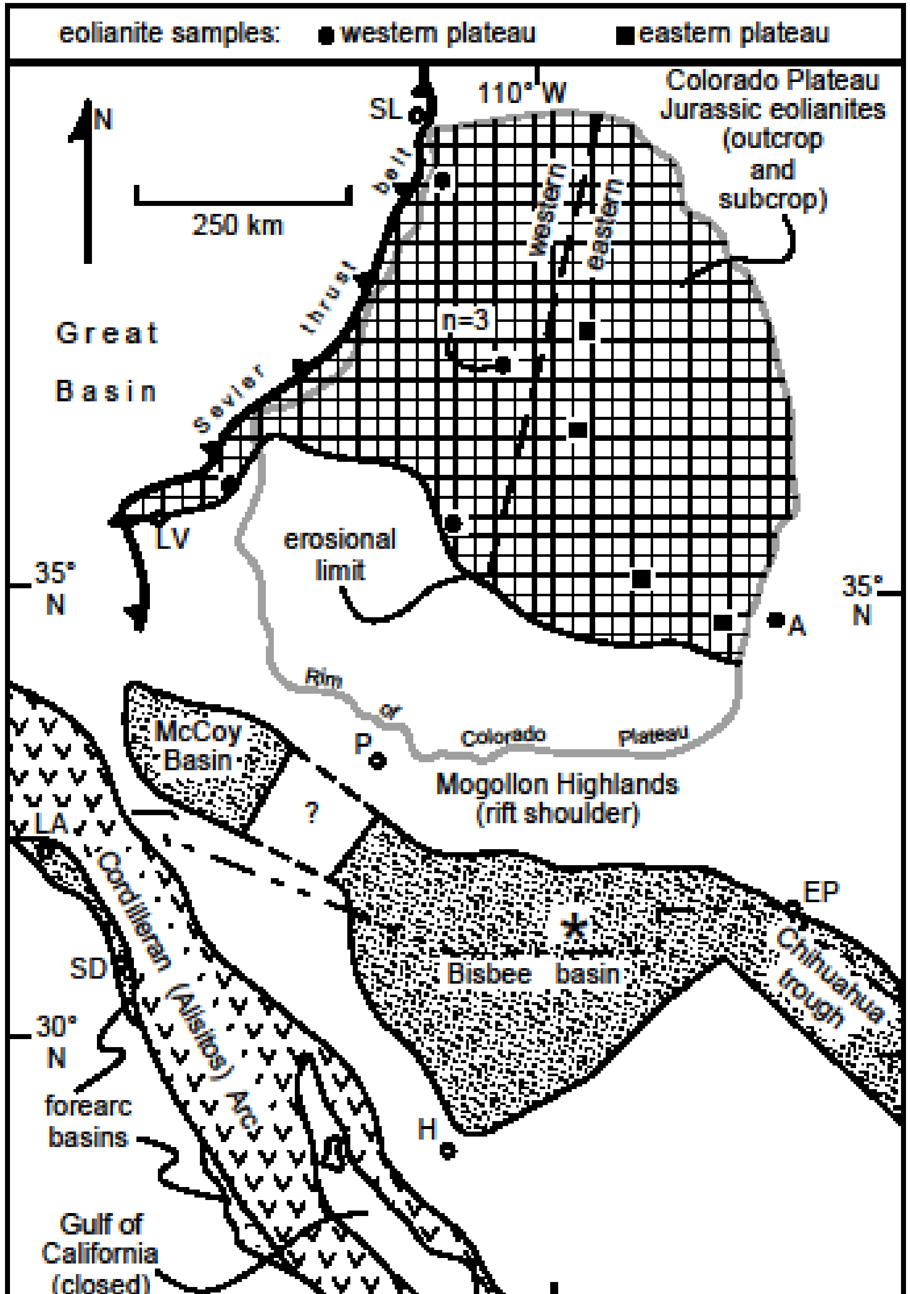



120° W
100° W
80° W
relict Antler orogen
Havallah Basin
offshore island arc complex
WR
PARK CITY-PHOSPHORIA SHELF-SLOPE
>2.5 Ga
1.7-1.8 Ga
40° N
Oq
DC
DM
ER
FC
Ne
Ouachita orogen (suture)
Afb
A'
Mojave basement province
Pa
Ouachita thrust front
An
Akb
AW
BWb
Appalachian thrust front
Appalachian-Ouachita syntaxis
Ho
Og
PD
Caborca block (restored)
30° N
A
Pe
Mfb
SaP
FWb
LaU
Gondwanan (and Avalonian) crustal elements
Inherited Paleozoic transform margin
East Mexico arc
YuC
km
0
1000
N

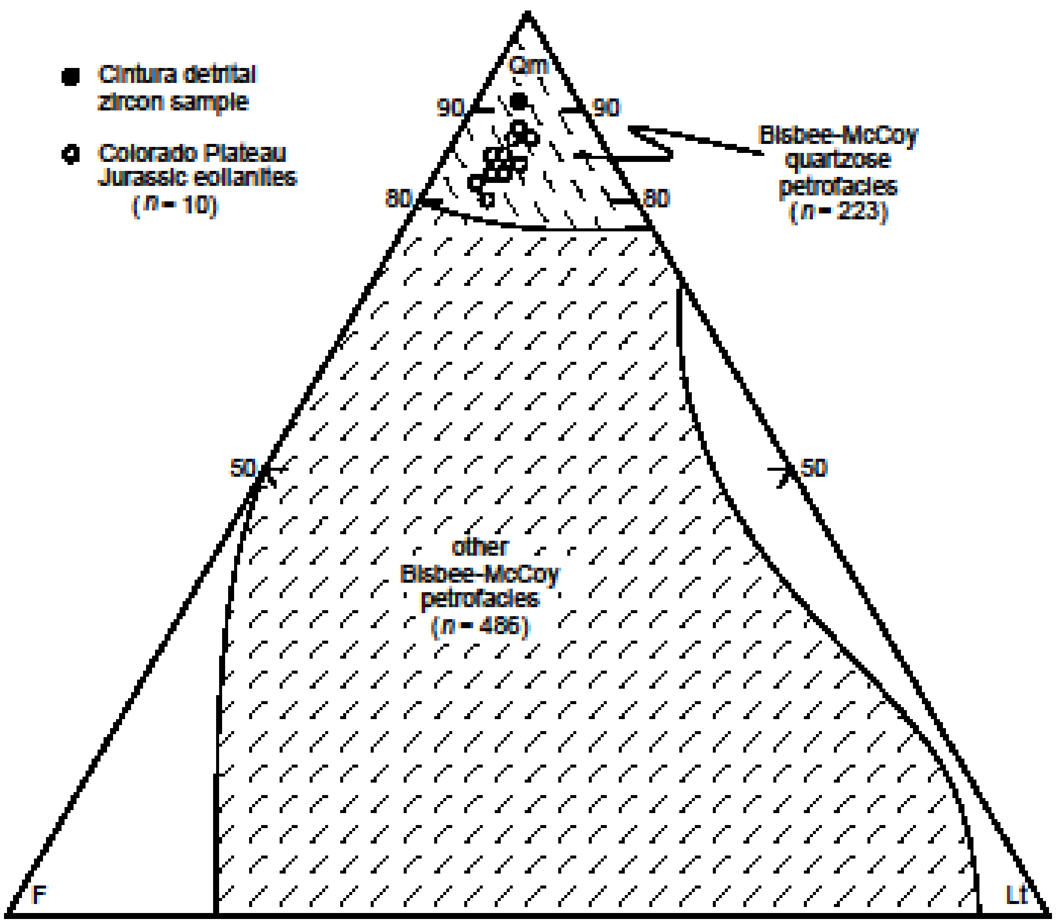
Detrital Zircon Ages

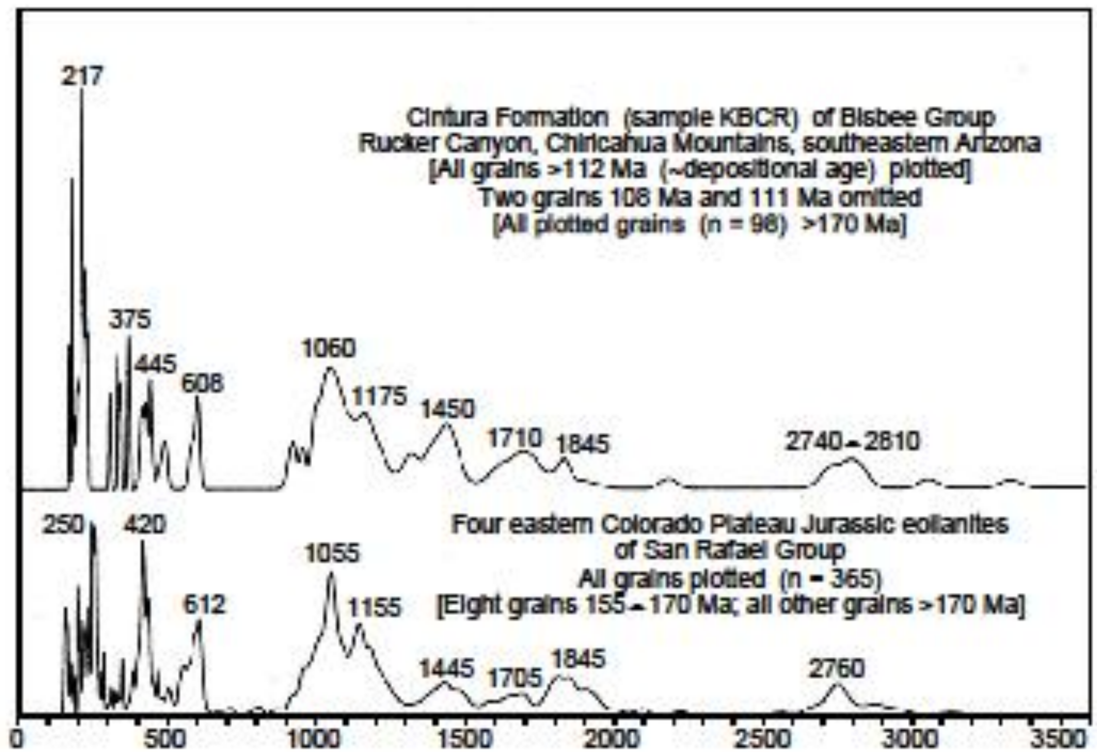
All Detrital Zircon Grains in Upper Paleozoic Eolian and Non-Eolian Strata of the Colorado Plateau

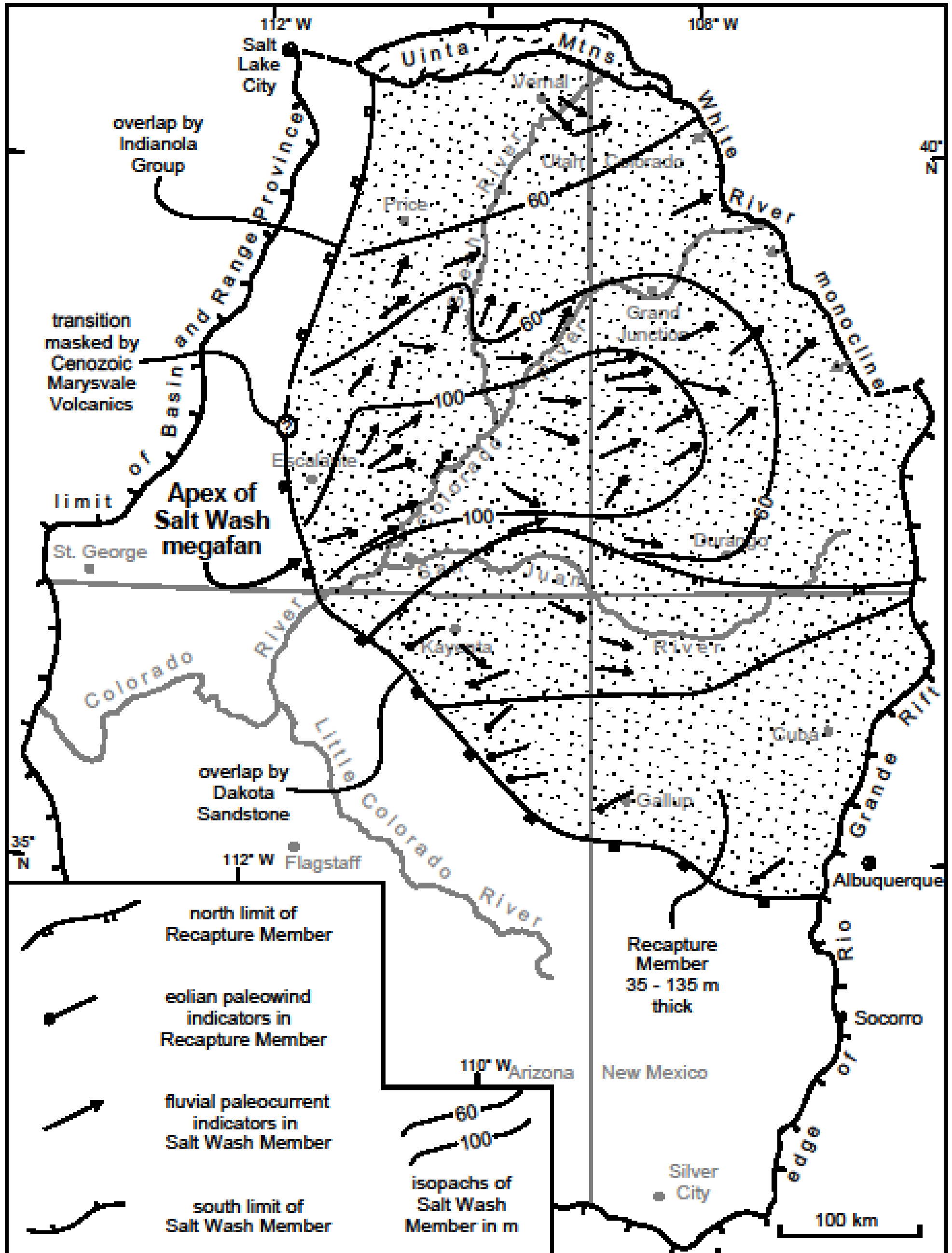




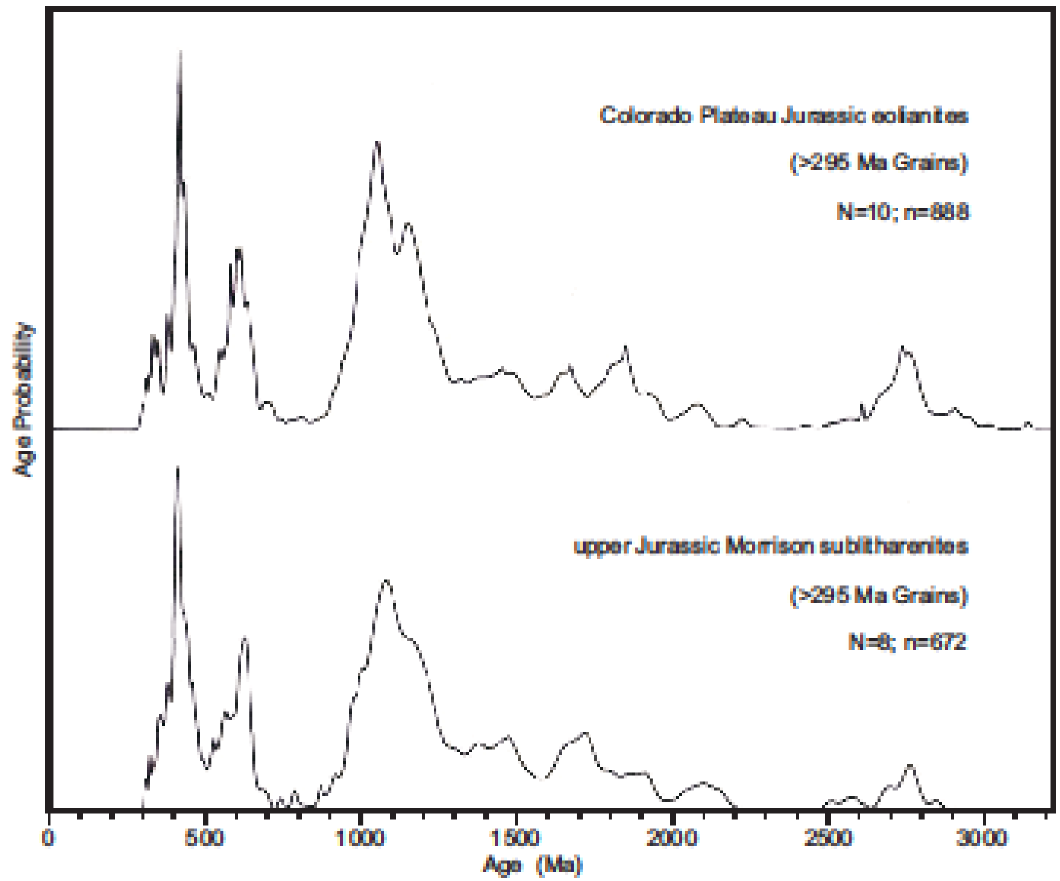
eolianite samples: ● western plateau ■ eastern plateau
N
250 km
SL
110° W
Colorado Plateau
Jurassic eolianites
(outcrop
and
subcrop)
belt
thrust
Sevier
western
eastern
n=3
Great
Basin
LV
erosional
limit
35° N
35° N
A
Rim
of
Colorado
Plateau
McCoy
Basin
P
?
Mogollon Highlands
(rift shoulder)
LA
Cordilleran
(Alisitos)
Arc
SD
30° N
forearc
basins
EP
Bisbee basin
Chihuahua
trough
H
Gulf of
California
(closed)


Cintura detrital zircon sample
Colorado Plateau Jurassic eolianites (n = 10)
Qm
90
90
80
80
Bisbee-McCoy quartzose petrofacies (n = 223)
50
50
other Bisbee-McCoy petrofacies (n = 486)
F
Lt


217
Cintura Formation (sample KBCR) of Bisbee Group
Rucker Canyon, Chiricahua Mountains, southeastern Arizona
[All grains >112 Ma (~depositional age) plotted]
Two grains 108 Ma and 111 Ma omitted
[All plotted grains (n = 98) >170 Ma]
375
445
608
1060
1175
1450
1710
1845
2740–2810
250
420
612
1055
1155
1445
1705
1845
2760
Four eastern Colorado Plateau Jurassic eolianites
of San Rafael Group
All grains plotted (n = 365)
[Eight grains 155–170 Ma; all other grains >170 Ma]
0
500
1000
1500
2000
2500
3000
3500



112° W
108° W
40° N
35° N
112° W
110° W
Salt Lake City
Uinta Mtns.
Vernal
White River
Utah
Colorado
Price
Green River
overlap by Indianola Group
limit of Basin and Range Province
transition masked by Cenozoic Marysvale Volcanics
Grand Junction
monocline
Escalante
Colorado River
Apex of Salt Wash megafan
St. George
San Juan River
Durango
Kayenta
Colorado River
Little Colorado River
overlap by Dakota Sandstone
Flagstaff
Cuba
Gallup
Rio Grande Rift
Albuquerque
Socorro
edge of Rio Grande Rift
Recapture Member 35 - 135 m thick
Arizona
New Mexico
Silver City
100 km
60
100
north limit of Recapture Member
eolian paleowind indicators in Recapture Member
fluvial paleocurrent indicators in Salt Wash Member
south limit of Salt Wash Member
isopachs of Salt Wash Member in m


Colorado Plateau Jurassic eolianites
(>295 Ma Grains)
N=10; n=888
upper Jurassic Morrison sublitharenites
(>295 Ma Grains)
N=8; n=672
Age Probability
0
500
1000
1500
2000
2500
3000
Age (Ma)

Dickinson et al 1986 JSP

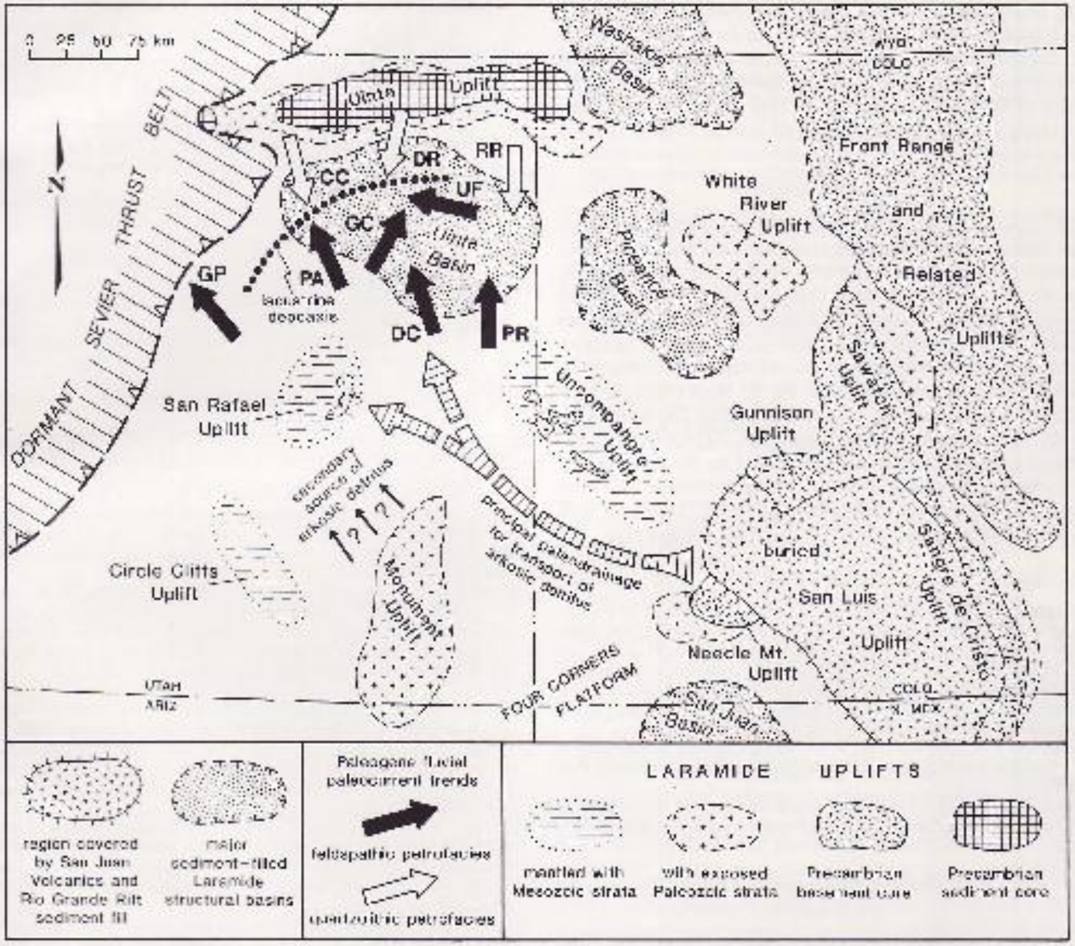
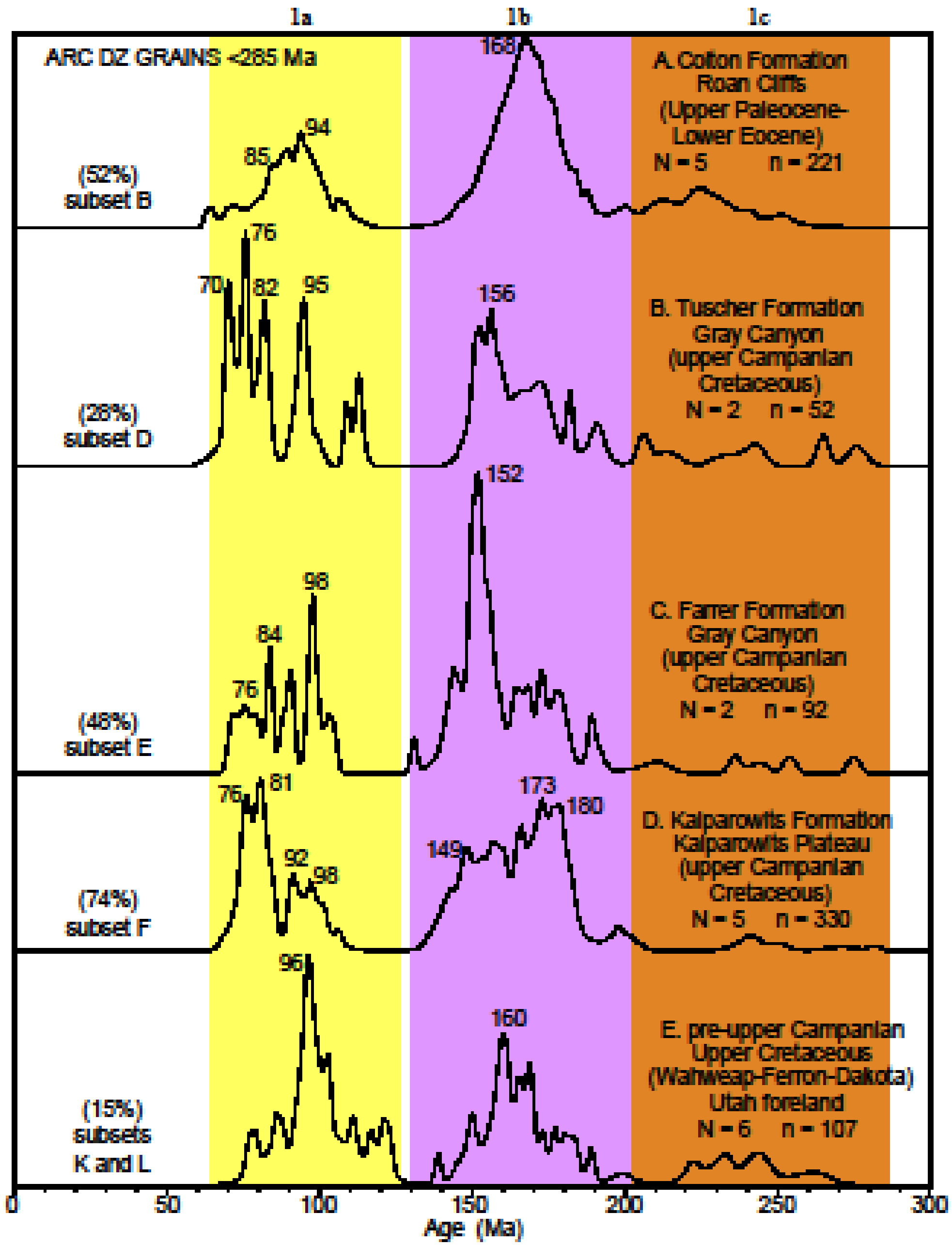
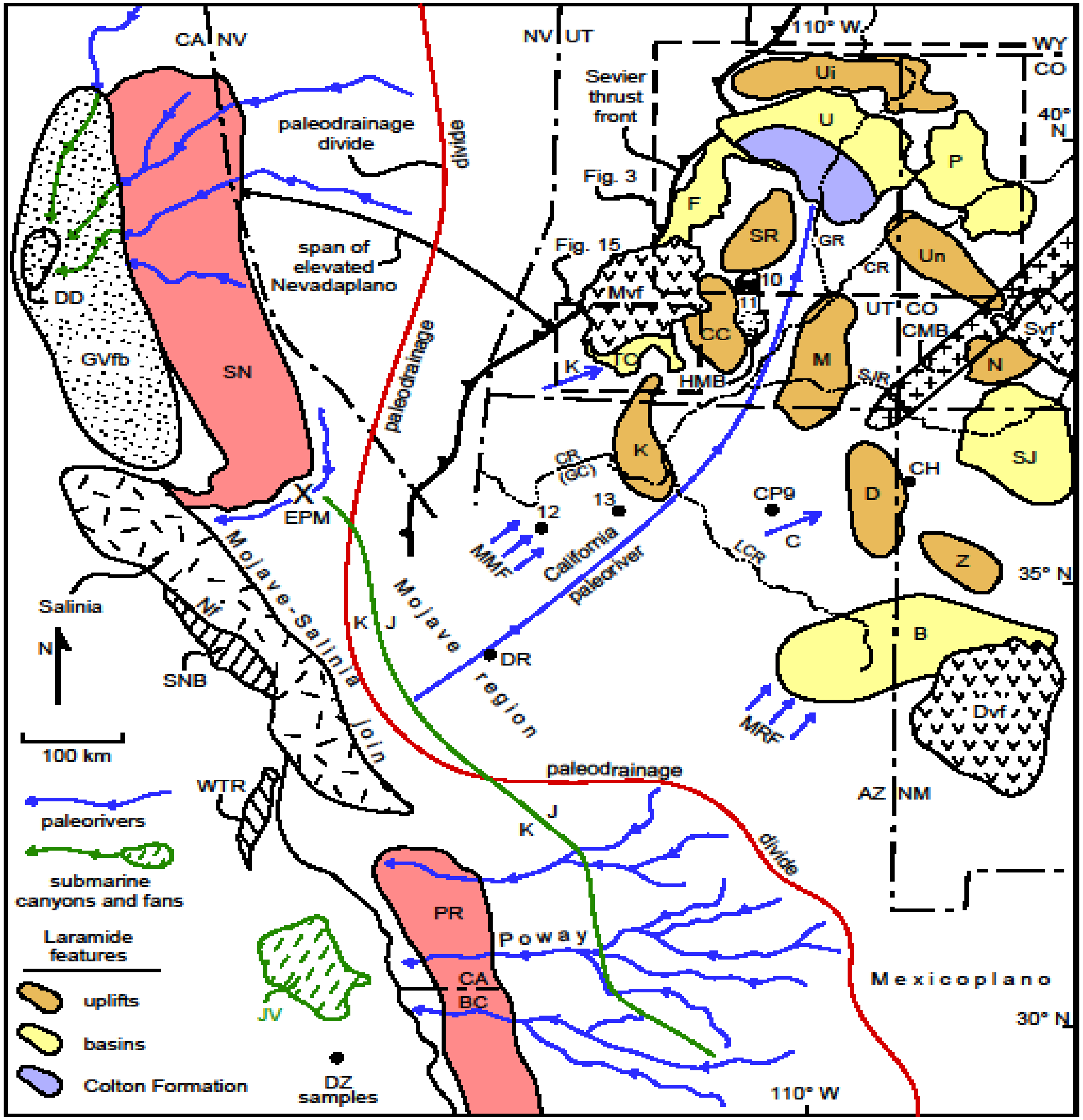
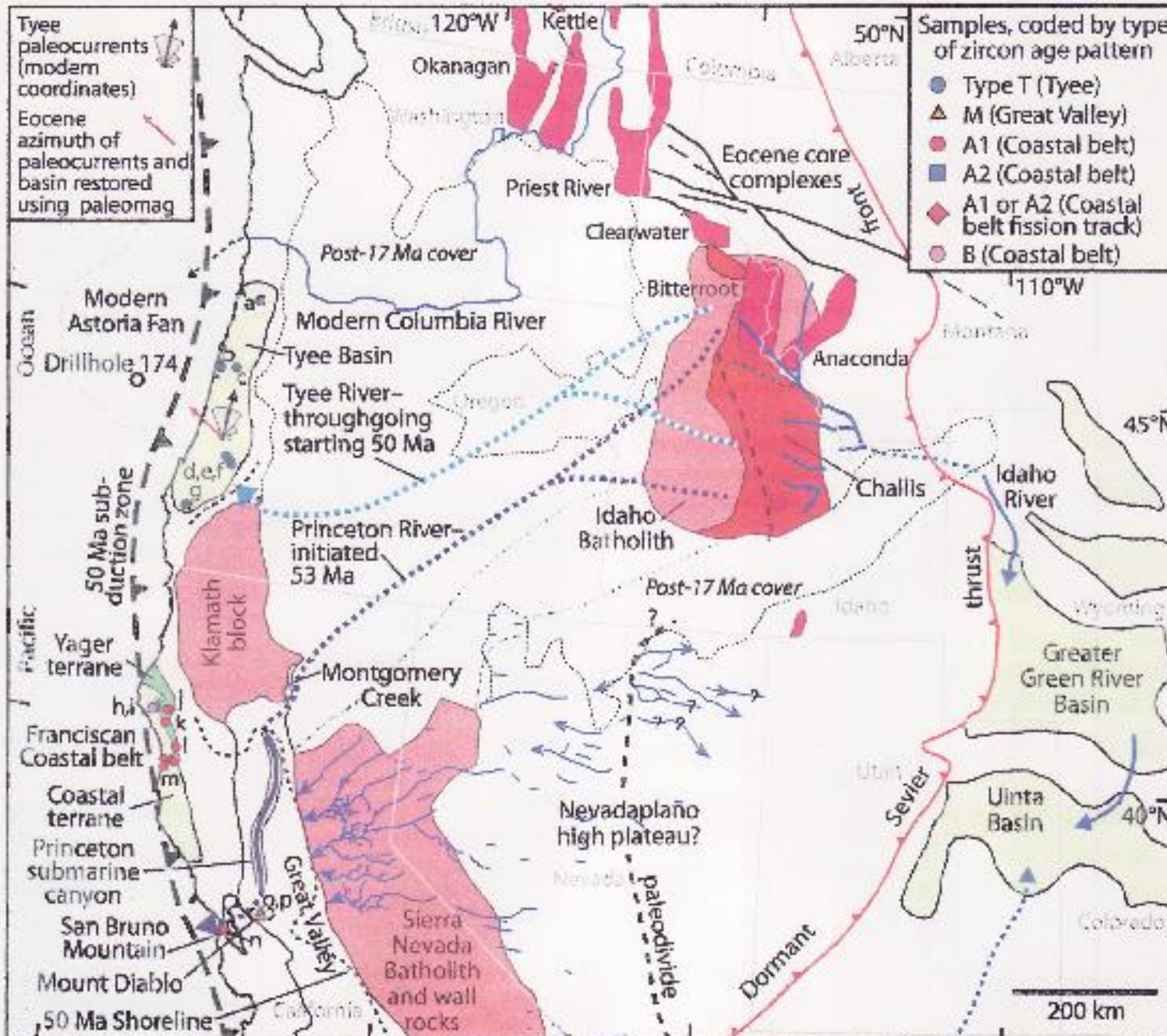


FIG. 10.—Inferred mid-Paleocene to mid-Eocene dispersal path of arkosic detritus from Laramide foreland uplifts of southern Rocky Mountains (Tweto 1975, 1980) and Colorado Plateau (Kelley 1955a, 1955b) into region of Uinta Basin. Paleogeography modified after Picard (1971), Stanley and Collinson (1979), Pitman et al. (1982), Zawiskie et al. (1982), Chapman (1982), and Bruhn et al. (1983). Lacustrine depoaxis refers to lacustrine environments of Lake Flagstaff (NE-SW trend on SW) and Lake Uinta (E-W trend on NE) after Ryder et al. (1976), Stanley and Collinson (1979), and Bruhn et al. (1983). Indicated paleocurrent localities within and near Uinta Basin (in mid-Paleocene to mid-Eocene strata except as noted): CC, Currant Creek Formation (Cretaceous to Paleocene) after Isby and Picard (1983); DC, Desolation Canyon of the Green River (Figs. 3, 9); DR, Duchesne River Formation (Upper Eocene) after Andersen and Picard (1972, 1974 and Fig. 3); GC, Gate Canyon (Figs. 3, 9) and Sunnyside area (Fig. 3 after Chapman 1982); GP, Gunnison Plateau after Stanley and Collinson (1979); PA, Price area (Fig. 3 after Peterson 1976 and Chapman 1982); PR, P. R. Spring area (Picard and High 1972); RR, Raven Ridge area (Picard and High 1972); UF, Uinta Formation (Middle to Upper Eocene) of central Uinta Basin (Bruhn et al. 1983).



1a
1b
1c
ARC DZ GRAINS <285 Ma
A. Colton Formation
Roan Cliffs
(Upper Paleocene-
Lower Eocene)
N = 5 n = 221
(52%)
subset B
94
85
168
B. Tuscher Formation
Gray Canyon
(upper Campanian
Cretaceous)
N = 2 n = 52
(28%)
subset D
76
70
82
95
156
C. Farrer Formation
Gray Canyon
(upper Campanian
Cretaceous)
N = 2 n = 92
(48%)
subset E
152
98
84
76
D. Kaiparowits Formation
Kaiparowits Plateau
(upper Campanian
Cretaceous)
N = 5 n = 330
(74%)
subset F
76
81
92
98
173
180
149
E. pre-upper Campanian
Upper Cretaceous
(Wahweap-Ferron-Dakota)
Utah foreland
N = 6 n = 107
(15%)
subsets
K and L
96
160
0
50
100
150
200
250
300
Age (Ma)


CA NV
NV UT
110° W
WY
CO
40° N
Sevier thrust front
paleodrainage divide
divide
Fig. 3
Fig. 15
span of elevated Nevadaplano
paleodrainage
Ui
U
P
F
SR
GR
CR
Un
10
11
Mvf
CC
UT CO
CMB
Svf
N
M
TC
K
HMB
S/R
SJ
CH
D
CP9
C
CR (GC)
12
13
MMF
California paleoriver
LCR
Z
35° N
B
Dvf
MRF
DR
Mojave region
Mojave-Salinia join
DD
GVfb
SN
EPM
Salinia
Nf
SNB
N
100 km
WTR
paleorivers
submarine canyons and fans
Laramide features
uplifts
basins
Colton Formation
JV
DZ samples
K
J
paleodrainage
divide
AZ NM
PR
Poway
CA
BC
Mexicoplano
30° N
110° W



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