Provenance of the South Texas Paleocene-Eocene Wilcox Group, Western Gulf of Mexico Basin: Insights from Sandstone Modal Compositions and Detrital Zircon Geochronology*

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Abstract

Sandstone modal compositions and detrital zircon U-Pb analyses of the Paleocene-Eocene Wilcox Group of the southern Gulf Coast of Texas indicate long-distance sediment transport from primarily volcanic and basement sources to the west, northwest, and southwest. The Wilcox Group of south Texas represents the earliest series of major post-Cretaceous pulses of sand deposition along the western margin of the Gulf of Mexico (GoM). Laramide basement uplifts have long been held to be the source of Wilcox sediment, implying that initiation of basement uplift was the driving factor for the transition from carbonate sedimentation to clastic deposition. To determine the provenance of the Wilcox Group and test this conventional hypothesis, Upper and Lower Wilcox samples were collected from 18 outcrop localities and 5 core sections along the southwestern Gulf Coast. Forty thin-sections were point-counted using the Gazzi-Dickinson method to determine sandstone composition and 10 detrital zircon samples were analyzed by LA-ICP-MS to determine U-Pb age-spectra.

Modal data for sand grain populations suggest mixed sources, including basement rocks, magmatic arc rocks, and subordinate sedimentary rocks. Zircon age-spectra for these sandstones reveal a complex grain assemblage derived from Laramide uplifted crystalline blocks of the central and southern Rocky Mountains, the Cordilleran arc of western North America, and arc-related extrusive and intrusive igneous rocks of northern Mexico. Zircon ages also suggest possible recycling of older sediment through uplift related to accretion of arc terranes along the westernmost North America, but that recycling of Cordilleran foreland basin sediments was not a major contributor. Comparison of Upper and Lower Wilcox zircon age-spectra indicate that Lower Wilcox sediments are richer in arc and volcanic material, whereas Upper Wilcox sediments are richer in basement material. Regional trends in detrital zircon age-spectra indicate that Upper Wilcox sediments are moderately homogeneous over the region studied, whereas the Lower Wilcox shows significant heterogeneity.

This study indicates that the drainage area for the Gulf of Mexico during the Paleocene-Eocene was larger than previously thought, encompassing not only the Laramide basement uplifts, but the volcanic province of northern Mexico and possibly Cordilleran tectonic regions along the westernmost North America.

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Outline

- Project Objectives
- Introduction to the Wilcox Group
- Results and Interpretation
  - Petrography Data
  - Mass Spectrometry Data
- Discussion
  - Comparison to Cordilleran Foreland Basin Sediment
  - Comparison to Difunta Group
  - Comparison of Upper Wilcox and Lower Wilcox
  - Comparison of Petrography and Detrital Zircon Data
- Conclusion

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Study Objectives

- Provenance of the Wilcox Group
  - Southern Rocky Mountains?
  - Northern Rocky Mountains?
  - Northern Mexico?
  - Appalachian Mountains?

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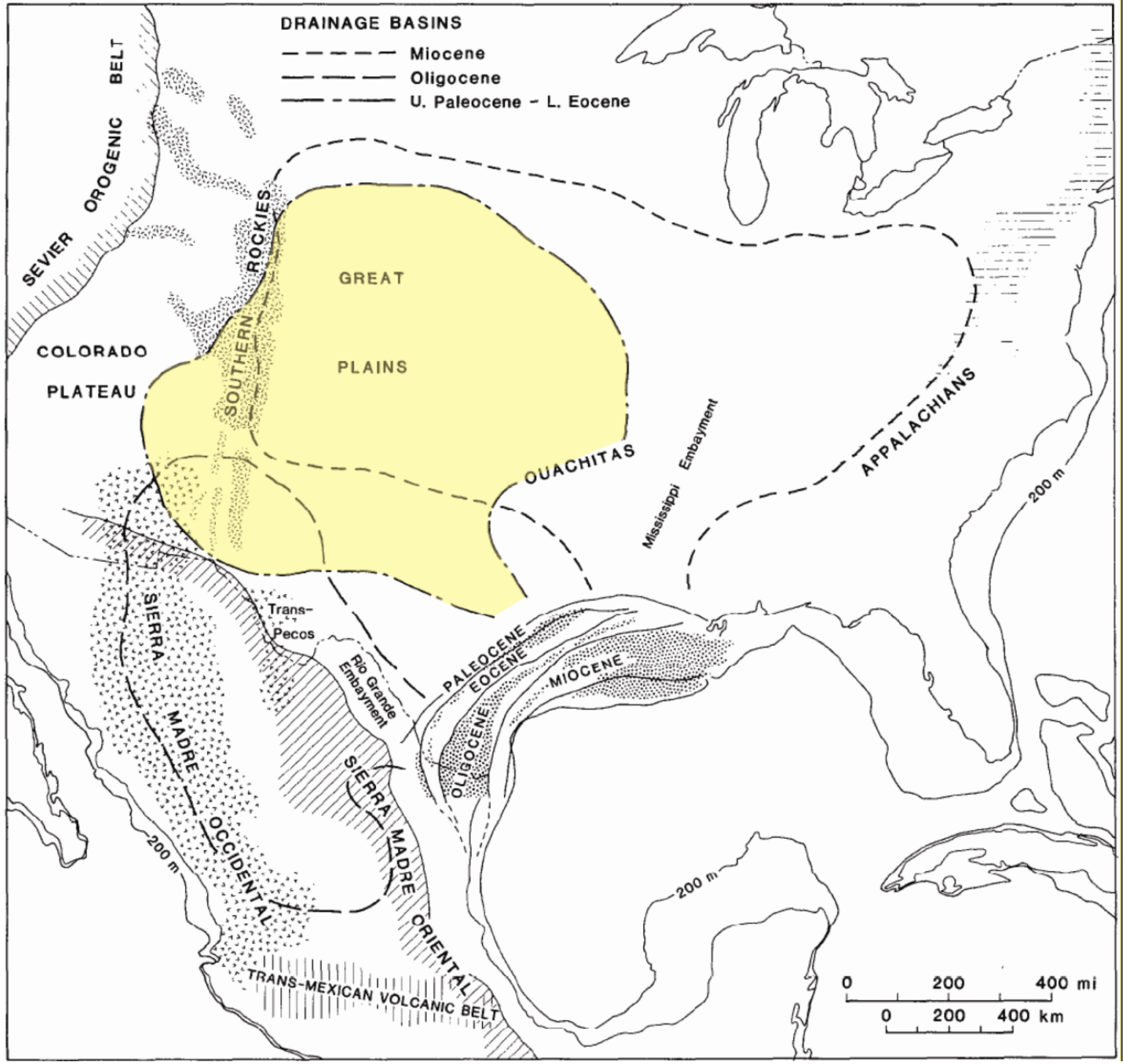

(Modified from Winker, 1982)

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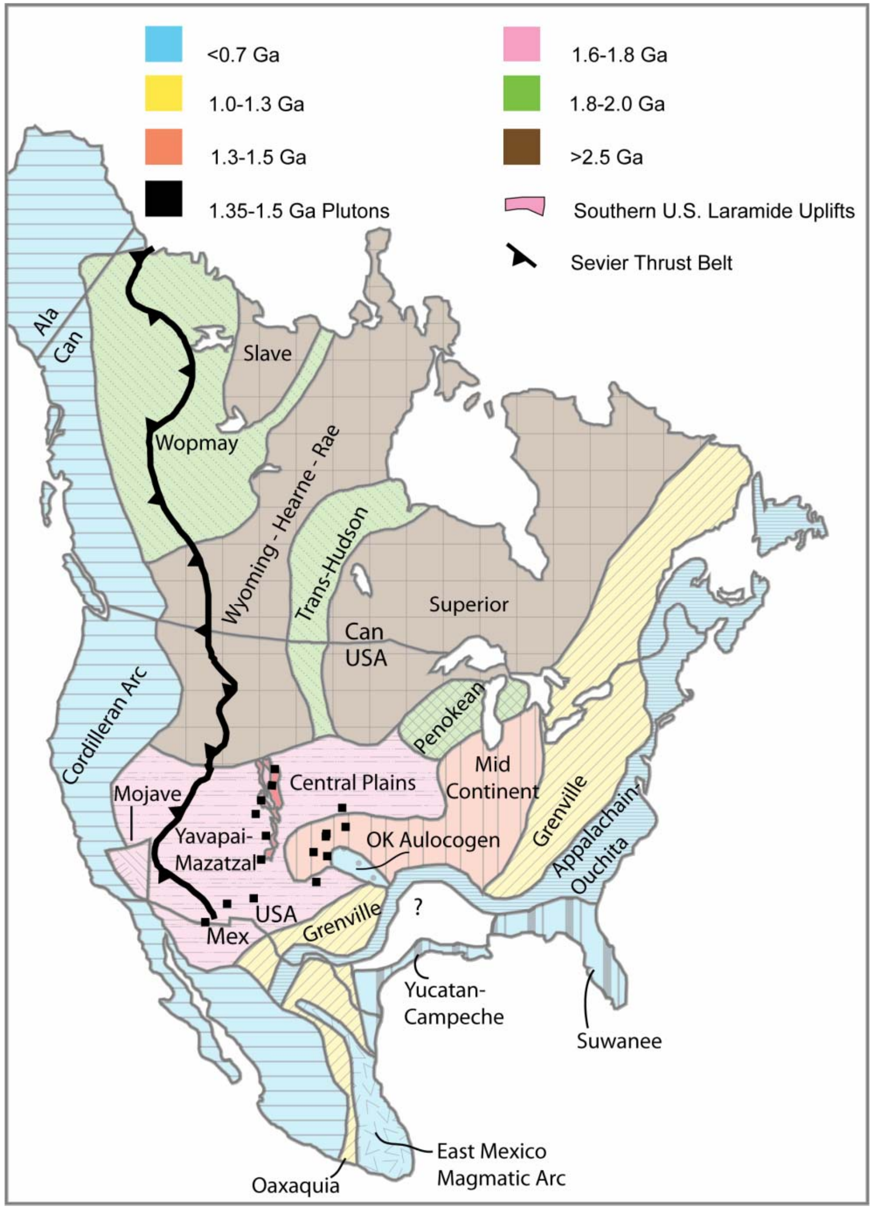

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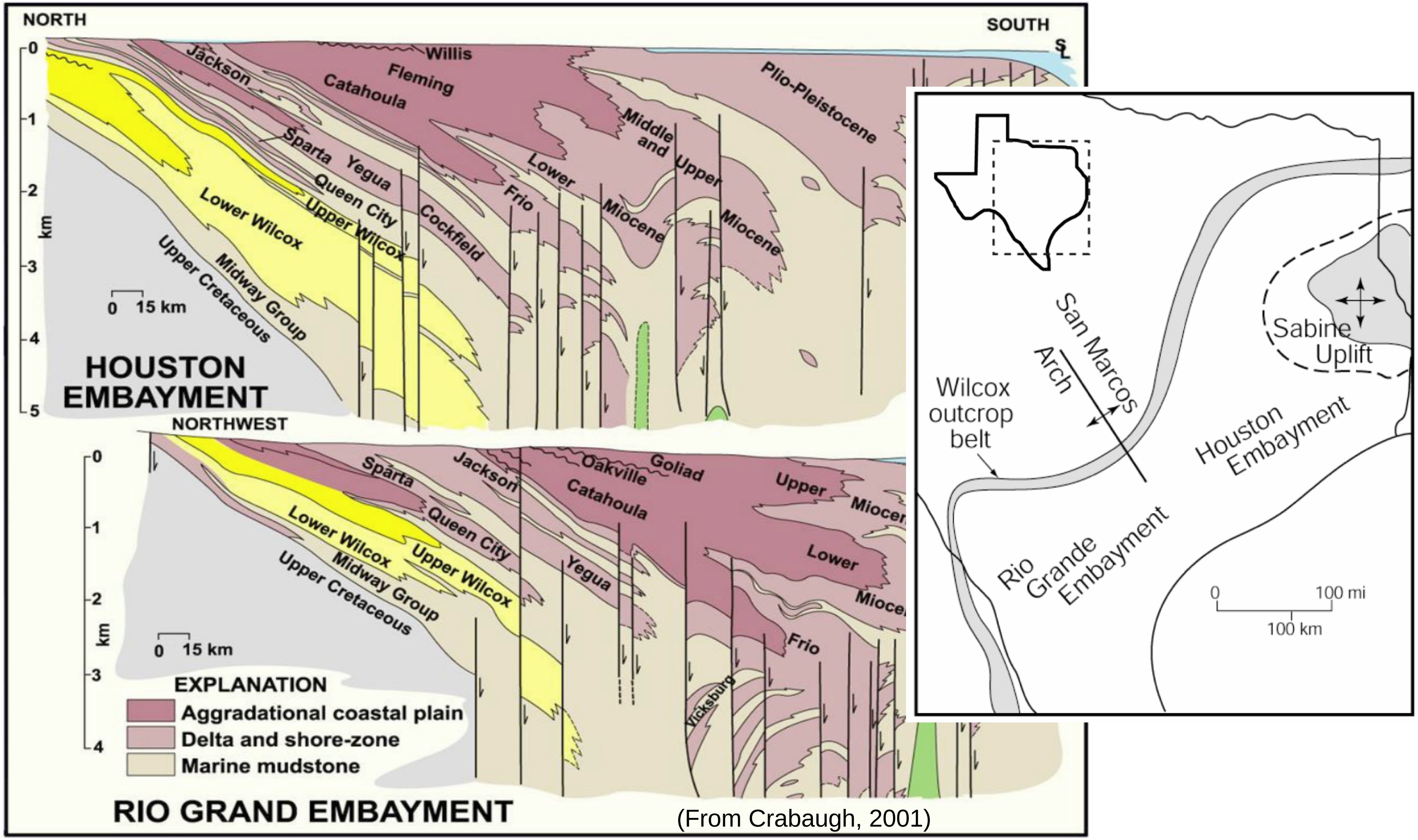
Cross Section of the Cenozoic Texas Gulf Coast



(From Crabaugh, 2001)

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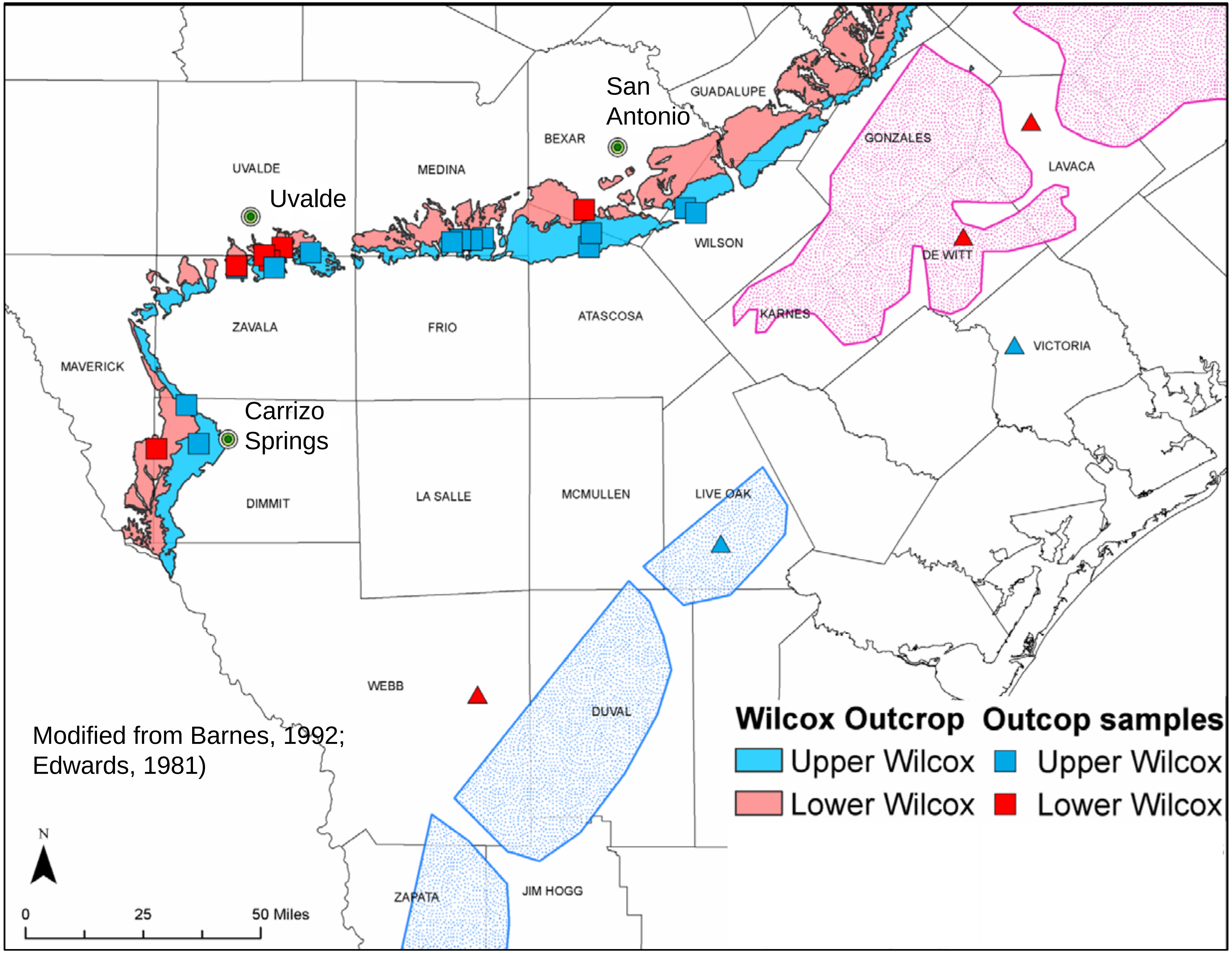
Sample Locations



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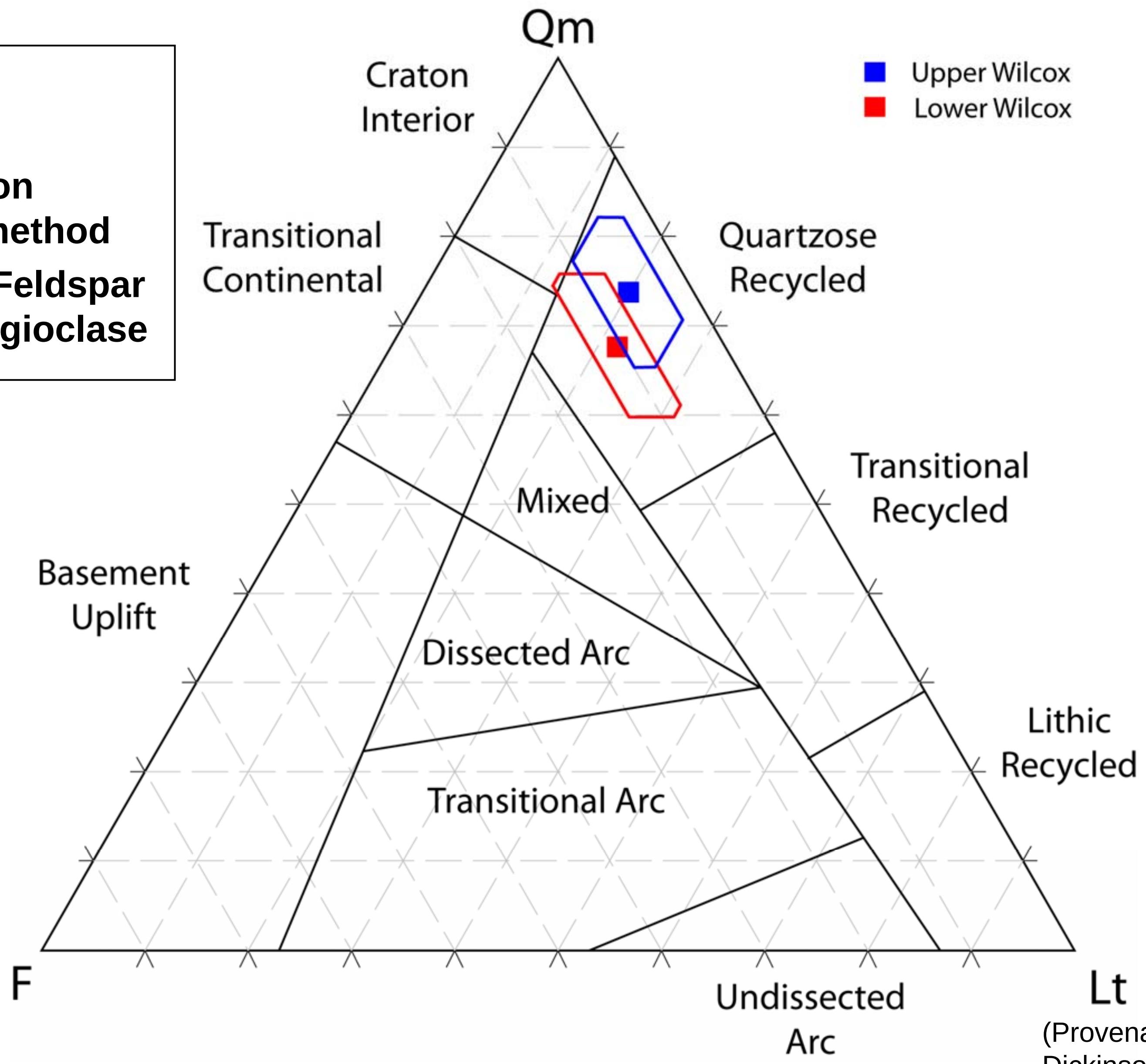
Grain Composition

40 samples

350 points

Gazzi-Dickinson counting method

Stained for K-Feldspar and Ca-plagioclase



(Provenance fields from Dickinson, 1985)

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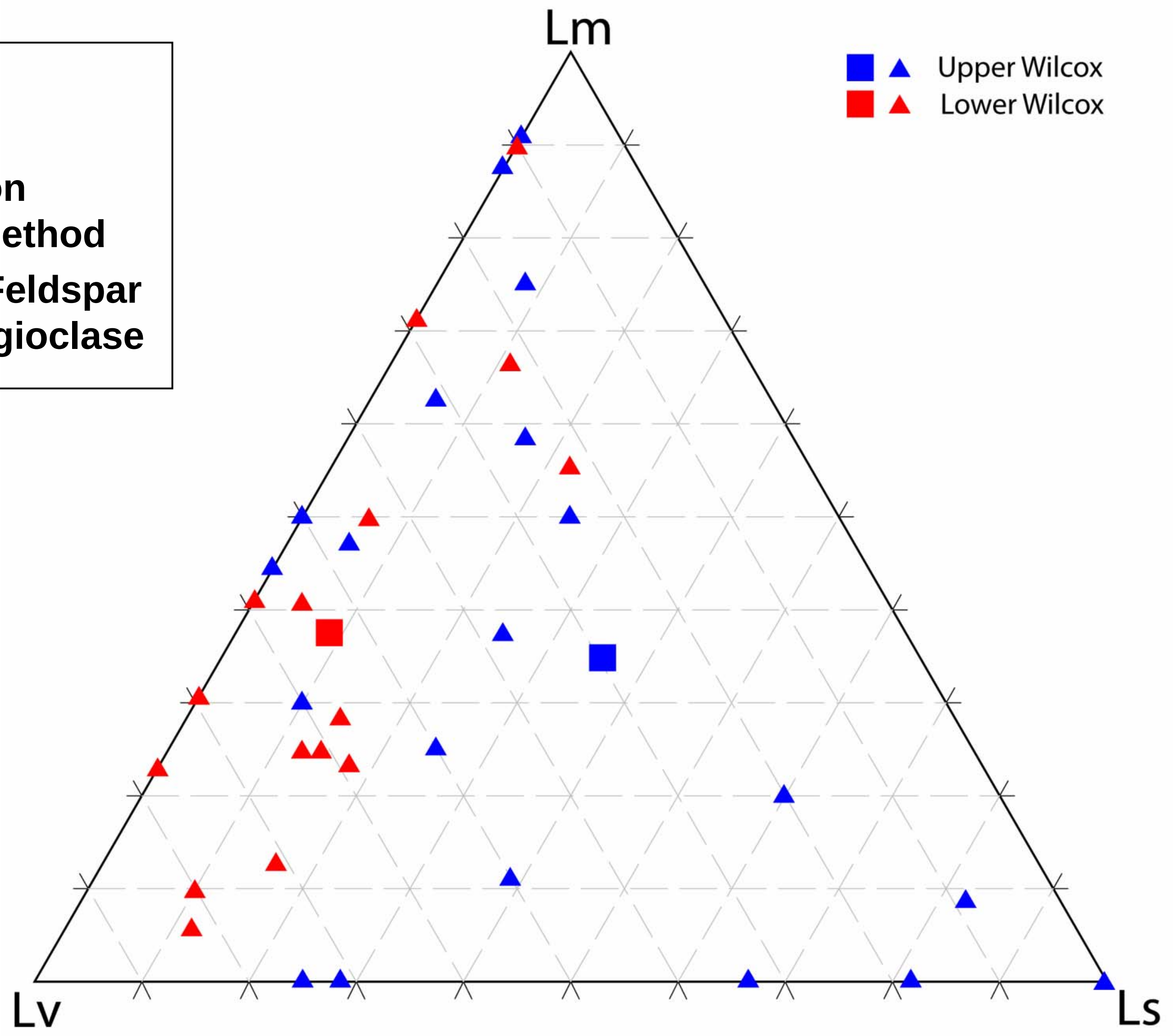
Grain Composition

40 samples

350 points

Gazzi-Dickinson counting method

Stained for K-Feldspar and Ca-plagioclase



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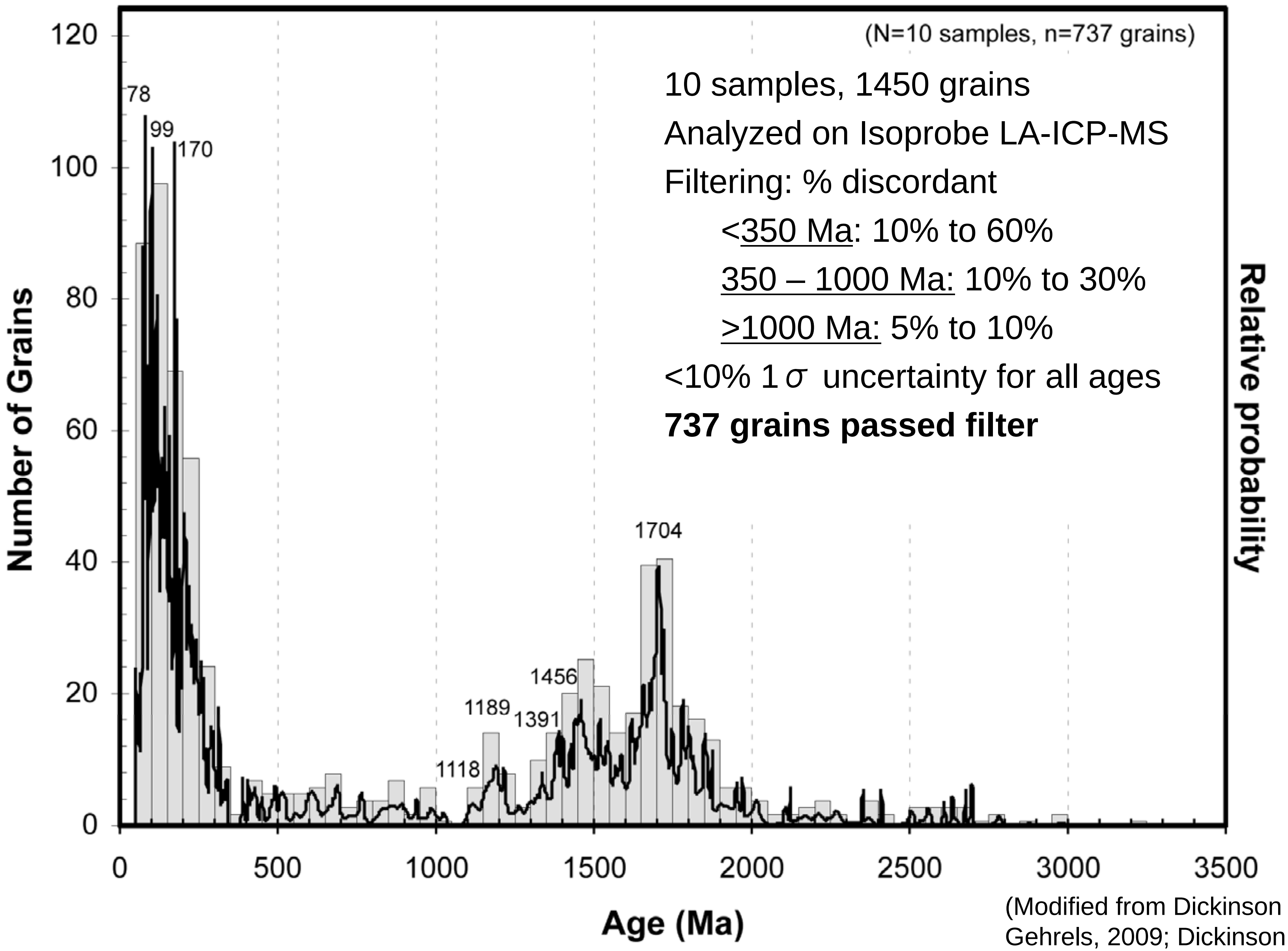
Detrital Zircon Age Spectra



(Modified from Dickinson and Gehrels, 2009; Dickinson and Gehrels, 2008; Hoffman, 1988)

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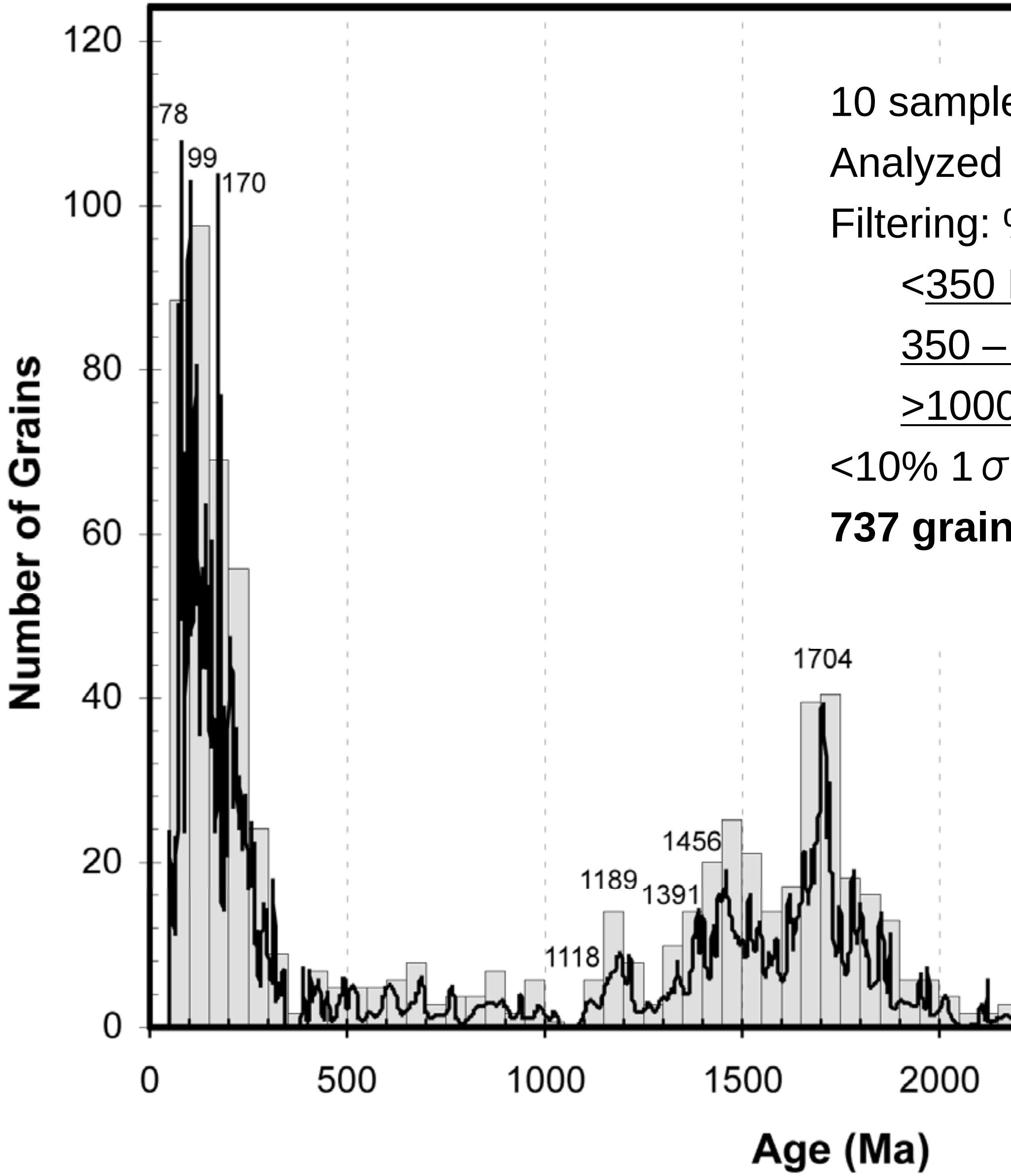
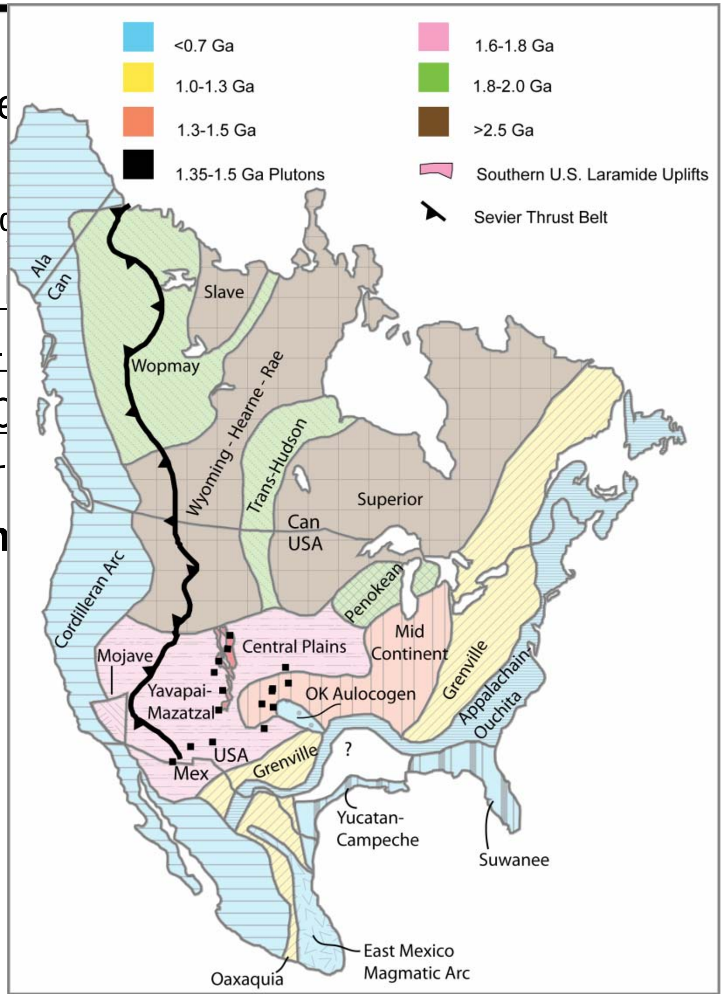
Detrital Zircon Age Spectra



10 sample
Analyzed
Filtering:
<350
350 –
>1000
<10% 1 σ
737 grain



(Modified from Dickinson and Gehrels, 2009; Dickinson and Gehrels, 2008; Hoffman, 1988)

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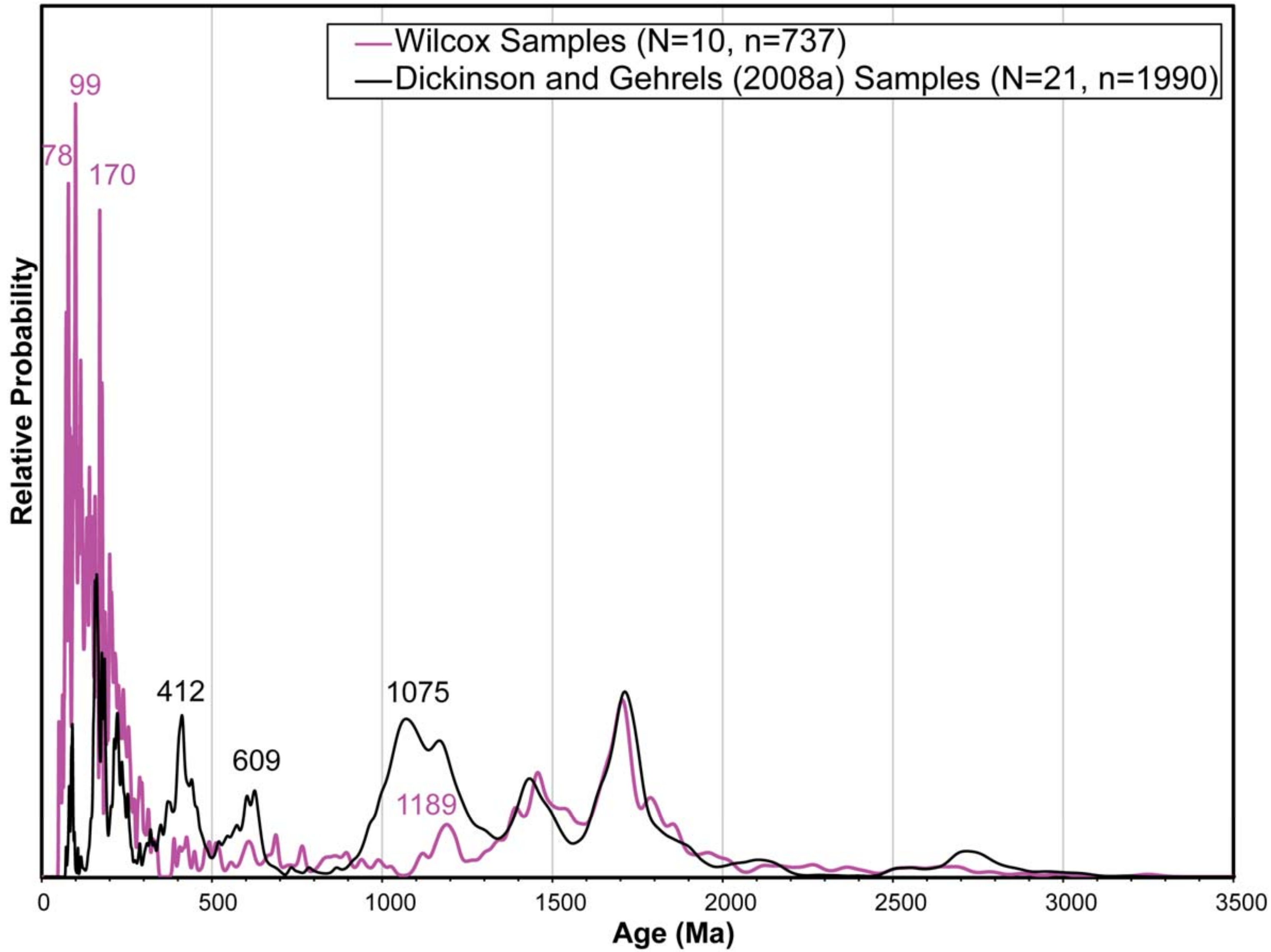
Comparison of Wilcox to Upper Jurassic - Cretaceous Cordilleran Foreland Basin, U.S.



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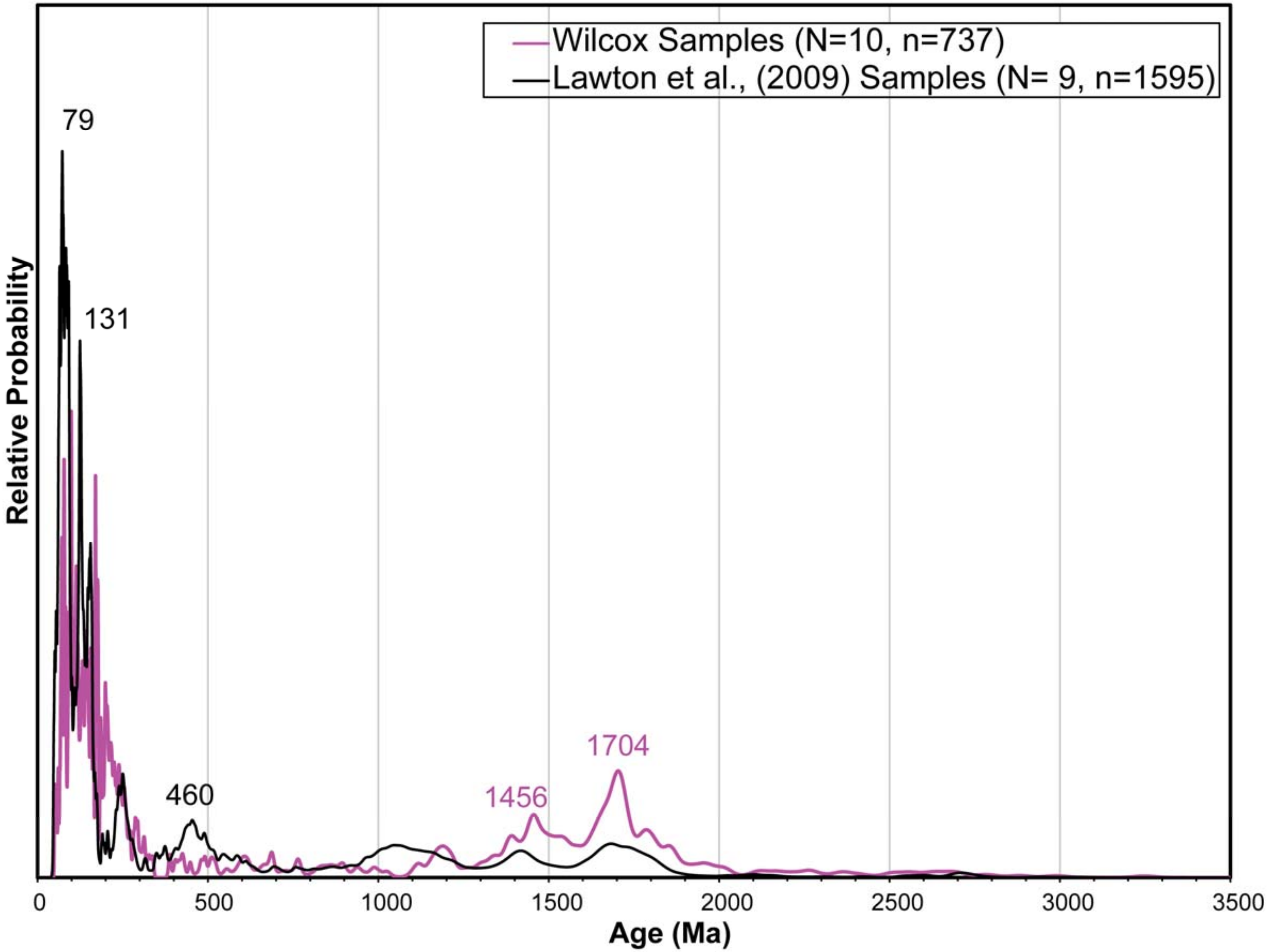
Comparison of Wilcox to Upper Cretaceous - Paleocene Difunta Group, Northern Mexico



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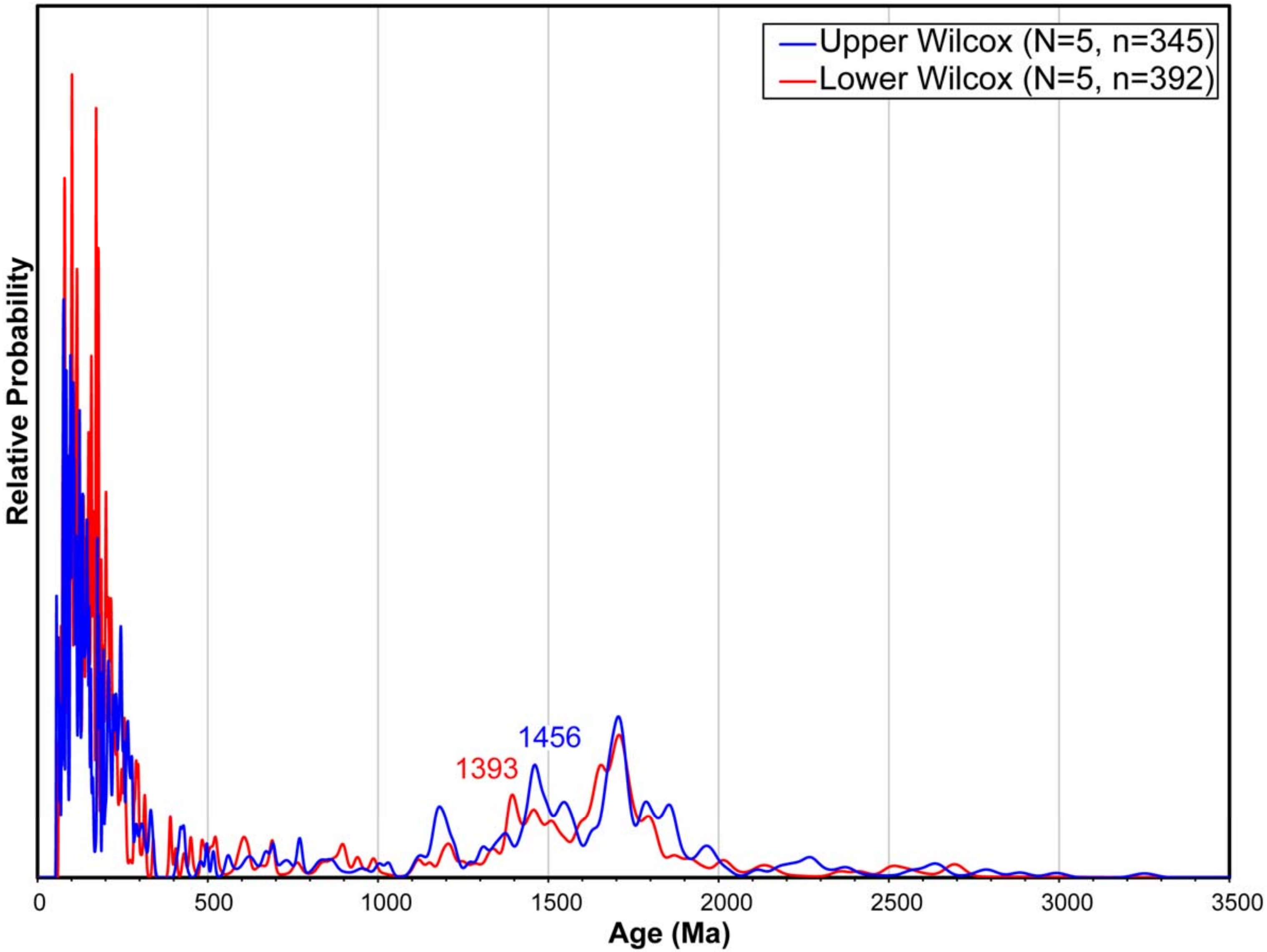
Comparison of Upper and Lower Wilcox



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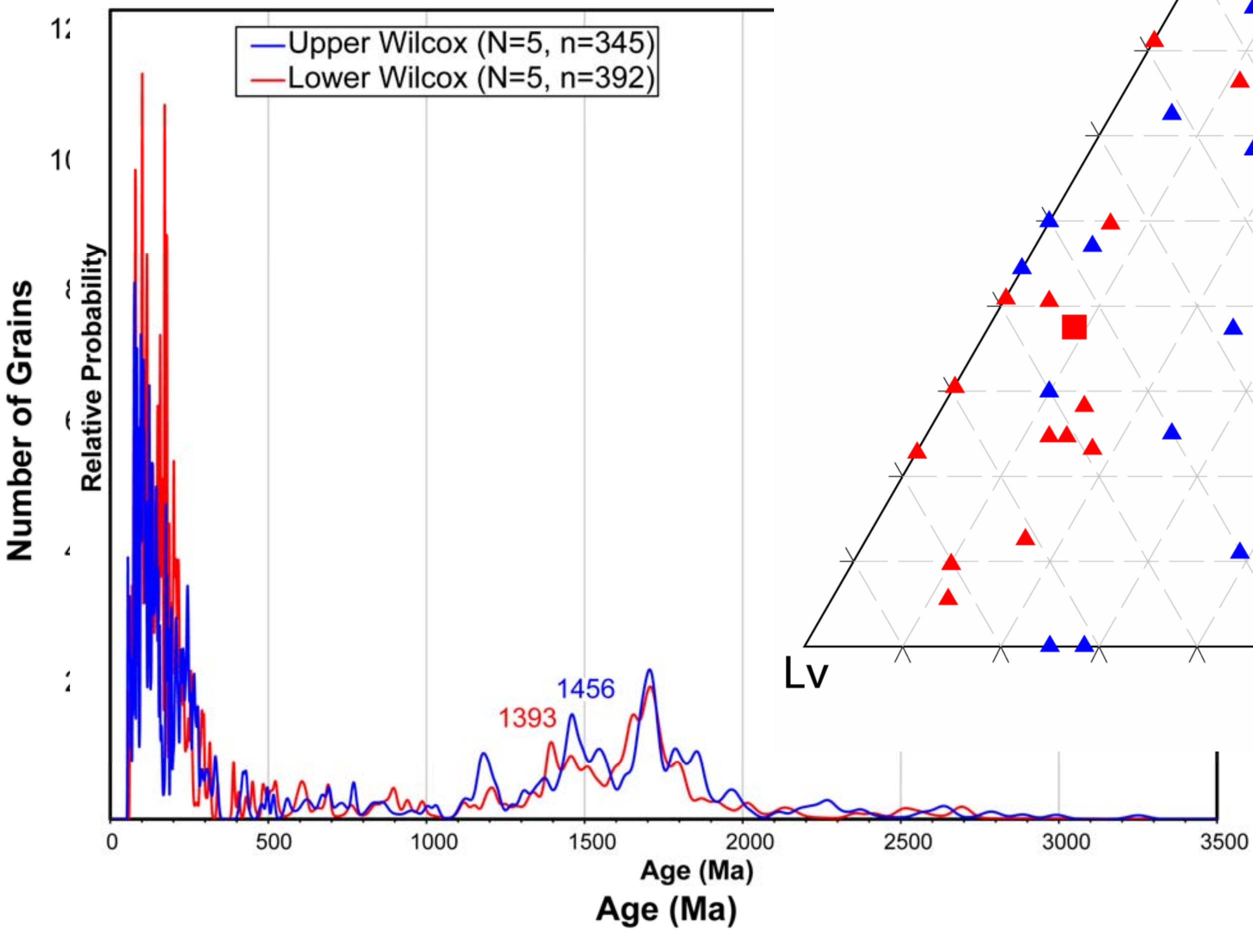
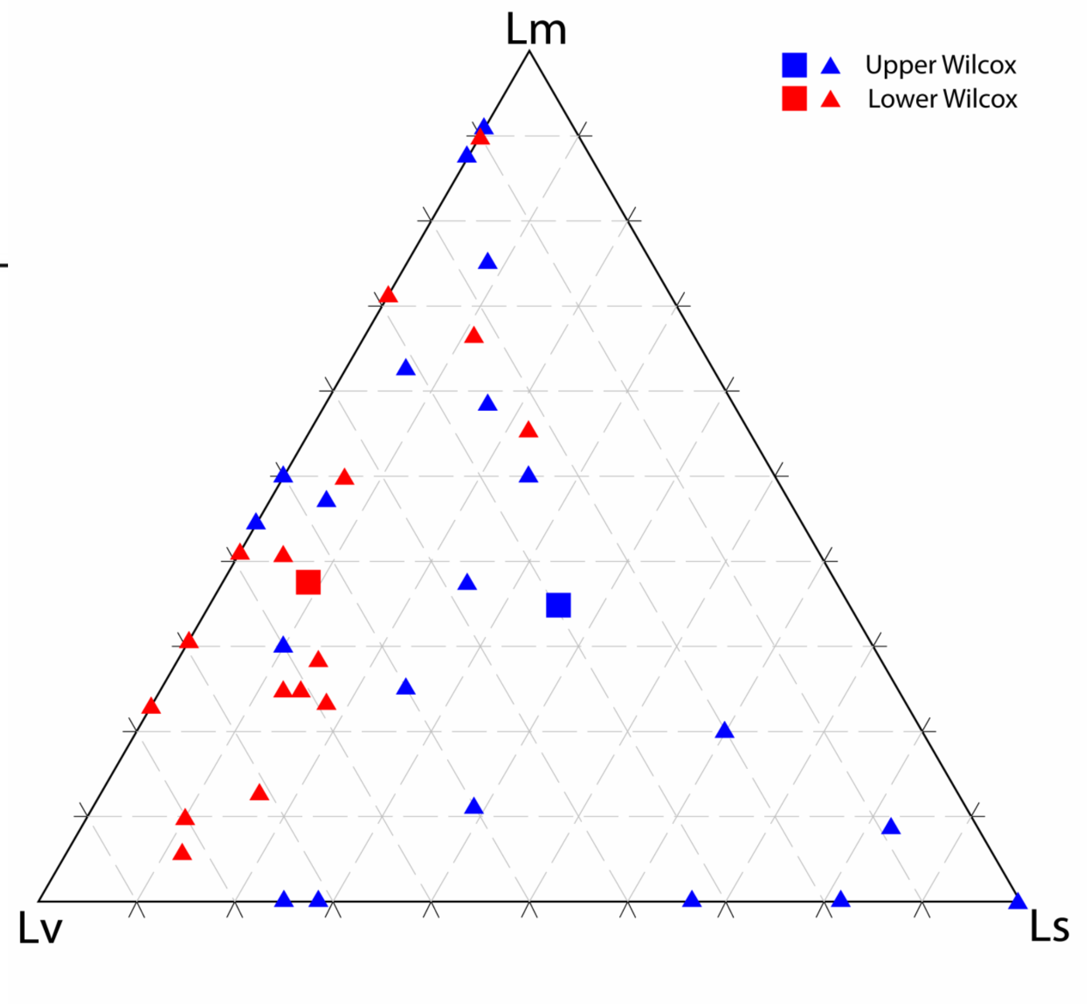
Petrography and Detrital Zircon Data Comparison





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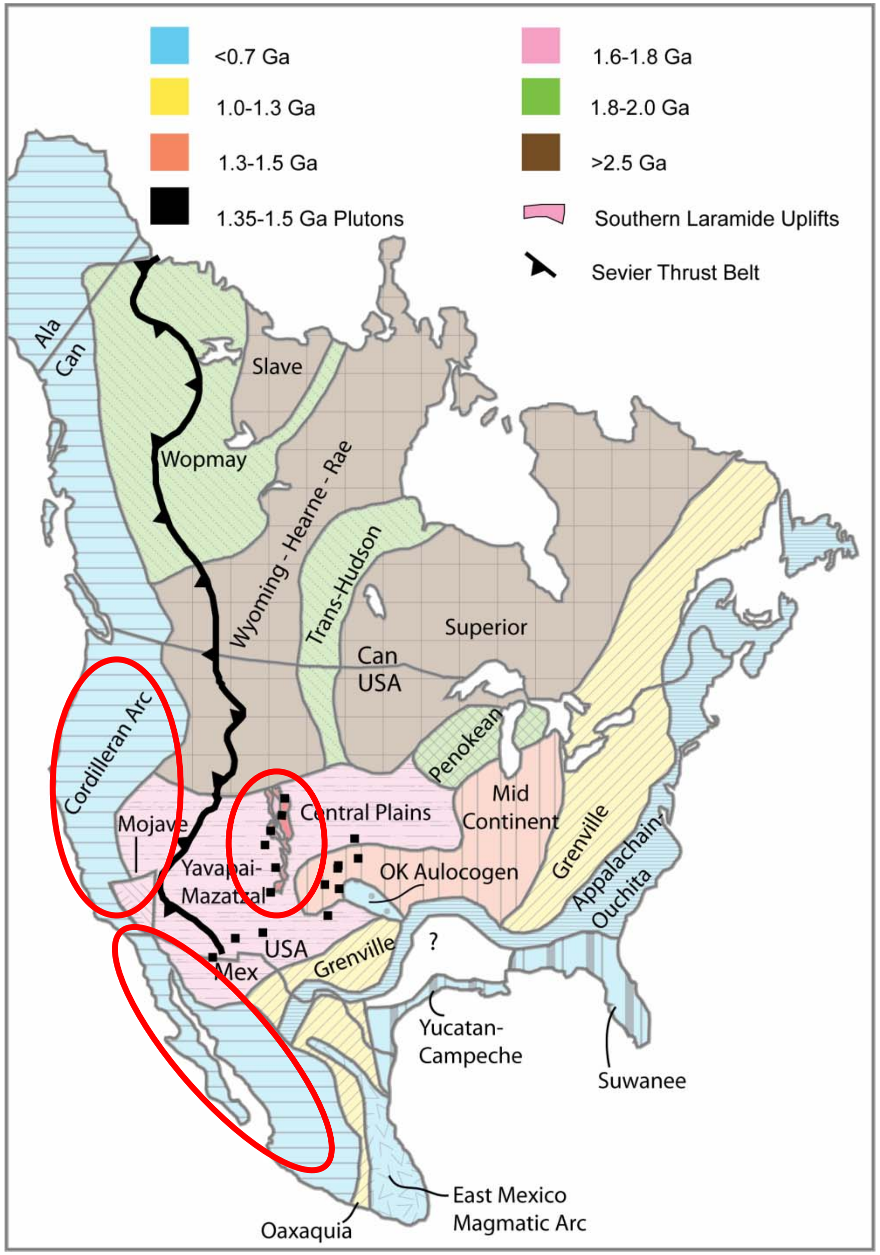
Conclusions

- Two Primary Sources
  - Southern U.S. Laramide Uplifts
  - Cordilleran Arc and inland Mexican volcanoes
- Drew from a wide range of the Cordilleran Arc
- Stratigraphic shift in provenance

(Modified from Dickinson and Gehrels, 2009; Dickinson and Gehrels, 2008; Hoffman, 1988)



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- The Gulf Coast Geological Library
- The Briscoe Ranch

Presenter's Notes Accompanying Slides

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I start with the overall objectives of the project, followed by an introduction to the Wilcox Group and my sampling map. Then I shall present petrography and mass spectrometry results, with discussion comparing the data from the Wilcox Group to several other recent studies conducted in North America that can assist in the interpretation of the Wilcox Group sources. Also discussed is some of the stratigraphic variance in the DZ data and the DZ data in comparison to the petrography data.

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1) Conventional hypothesis is that Wilcox came from Southern Rocky Mountains. Map by Winker (1982) is one of most reproduced maps on Texas Gulf Coast.

2) Goal of my work is to test some of the current provenance hypotheses.

3) Match DZ ages with regional basement ages to get an idea of where sediments came from. We can test Southern Rockies, Northern Rockies, Northern Mexico and Appalachian hypotheses by looking for specific age bands.

4) Provenance of Wilcox (how large a region it drained) can give us an idea of the interplay of tectonics and sedimentation in passive margin of Texas Gulf Coast.

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The primary objective of this study is to determine the provenance of the Wilcox Group. The conventional hypothesis, best characterized by this map from Winker (1982), has been that the Wilcox was derived from the Laramide uplifts of the Southern Rocky mountains. This is a logical conclusion as the timing of the uplift of the Southern Rocky Mountains is coincident with Wilcox deposition, and it fits with the current model of river systems in Texas, which are primarily sourced from highlands in New Mexico and Southern Colorado.

Surprisingly, for the amount of interest in the Wilcox Group, there have been few studies that looked at its provenance. Instead, most of the work on it has been focused on the practical economic matters of its depositional architecture, diagenesis, and reservoir characteristics, given that it is such a large petroleum producing unit.

The goal of this work is to test some of the current hypotheses of the provenance of the Wilcox Group using sandstone petrography and U-Pb DZ geochronology. If the Wilcox came from the Rocky Mountains, did it come from the North, as suggested by Crabaugh (2001), or the South, as suggested by Winker (1982) and the preponderance of the previous work? Alternatively, did it come from the volcanic province of Northern Mexico, or did it come from the Appalachian Mountains, as Dr. Bob Folk has long held?

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Fortunately each of these source areas has a distinctive zircon-age-spectra signature which would allow it to be identified. We would expect peaks at 1.6-1.8 Ga and 1.4 Ga if it were sourced from the Southern Rockies, an Archean influence if it were sourced from the Northern Rockies, grains of 50-100 Ma if the source was Northern Mexico, and grains of .9-1.3 Ga if it came from the Appalachian Mountains.

Understanding the sources of sediment for the Wilcox Group can give us a better understanding of the region drained by the Texas Gulf Coast during the Early Cenozoic. This can help us understand the interrelation of regional tectonics and passive-margin sedimentation. It also may give us an idea of the source composition of the Wilcox, which in turn can give some insight into the amount of compositional alteration that has occurred either during transport or diagenesis.

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Major points: 1) Wilcox Group is 1st major Cenozoic delivery of sand; Age – ~60.5 to 49 Ma; Large Delta systems that prograded 150km into basin. 2) Lower Wilcox's main depocenter in the Houston Embayment; Upper Wilcox's main depocenter in the Rio Grande Embayment.

The Wilcox Group records the first major delivery of sand to the Gulf of Mexico Basin during the Cenozoic, from ~60.5 Ma to ~49 Ma, in the form of large delta systems that are thought to have prograded the shoreline ~150 km into the basin. With such a large amount of sediment delivered to the basin during its deposition, the Wilcox is an excellent unit in which to study tectonic controls on passive-margin sedimentation.

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Samples from 5 wells, ranging in depths from 9000 ft to 14500 ft and 18 outcrop localities on map that shows Lower Wilcox Rockdale delta system (red) and Upper Wilcox Rosita delta system (blue).

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1) Petrographic data in QmFLt space, provenance, with overlay of interpretations of Dickinson (1985); 2) UW is in blue, LW is in red; 3) plot indicates Wilcox primarily sourced form other sedimentary rocks; 4) LW more rich in lithics and feldspar; 5) difference is statistically similar at 95% confidence interval.

This plot indicates that the sediment coming into the Gulf of Mexico basin was probably sourced primarily from other sedimentary rocks, though long transport distances; continued weathering in outcrop and diagenesis in the subsurface could cause the resulting rock to be significantly more quartzose than its source.

The Lower Wilcox tends to be more lithic-rich and feldspathic than the Upper Wilcox, suggesting that there was a change in provenance between the two.

The differences shown in the diagram are supported by the statistics. Using a chi-square test of the QmFLt (and QtFL) data, the two subunits have statistically different compositions at the 95% confidence interval.

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1) Composition of samples in LmLvLs space; 2) Triangles represent individual samples; squares are subunit averages; 3) LW is more volcanic lithic-rich; 4) LW and UW have different provenances; Lv and Ls are statistically different.
Because there is so much scatter in the data, I decided not to show the 1-sigma polygons, but instead to show the samples and averages together on the same plot. In the last plot we could see that the LW is more feldspathic and lithic-rich. This plot shows that in addition to having more lithic grains, the Lower Wilcox also tends to be much more volcanic lithic-rich. Although it is masked by the vast increase in volcanic grains, there is also more chert in the Lower Wilcox in absolute terms. While the proportions of metamorphic grains is statistically similar between the UW and LW, the proportions of volcanic and sedimentary grains are not statistically similar. This supports the previously stated supposition that the two subunits have (slightly) different provenances.
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1) Normalized age-distribution plot of entire Wilcox zircon dataset. Filtering criteria is included on plot.
2) Major peaks at 1700, 1400-1450 and 170, 99 and 78 Ma. Last peak is really one peak from 70-300 Ma. Minor peak at 1120-1200 Ma.
3) Age peak locations – Southern Rockies, Cordilleran Arc, and inland Mexico.
4) Small Proterozoic/Archean peaks are common in sediments in Sevier thrust belt and could indicated recycling.
This is a normalized age-distribution plot of the entire Wilcox zircon dataset. These types of graphs can be a bit misleading because they not only graph the number of grains of each age but take into account the uncertainty on each analysis. The relative proportion of each age peak is determined by the area under the curve, and not solely by the height of the peak. In regard to the distribution of grains, the median age for the sample set is ~625 (630) Ma; the area under the curve younger than 625 Ma equals the area under the curve older than 625 Ma.
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If we compare the DZ age spectra to the basement map we can get an idea of where the major sediment sources were. Major Peaks:
~1700 Ma – Southern Rockies – Yavapai and Mazatzl basement, possibly some from Mojave terrane
1450 – 1400 Ma – Southern Rockies – "anorogenic" granite plutons of desert SW
90-250/300 Ma – Cordilleran Arc, extending from Mexico to Alaska
<90 Ma – Inland Northern Mexico volcanic province which resulted from inland migration of arc volcanism due to flat slab subduction.
While the older age peaks could indicate sediment input from Proterozoic-aged basement rocks of the Southern Rocky Mountains and Archean basement of the Northern Rockies, grains of these ages are common in Neoproterozoic through Jurassic strata of Western North America that were uplifted during the Sevier Orogeny, possibly representing recycling.
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Our Wilcox sample set (purple) vs D&G data set (2008) (black): 1) Brief comparison to some other recently published data sets that relate to interpretation of the Wilcox. 2) This is a comparison of Wilcox to Cordilleran foreland basin, which occupied portions of UT, CO, NM, AZ, OK, TX, and KS, sourced from Sevier thrust belt and Mogollon rim. 3) Comparison may indicate if sediments came from uplifted portions of the basin or if the

Wilcox was sourced from weathering of the Sevier thrust belt. 4) Biggest difference is in Grenville, Rodinia break-up, and Taconic-age peaks being high in Cordilleran foreland basin and Cordilleran Arc grains being rich in the Wilcox. This precludes the Cordilleran Foreland or Sevier thrust belt from being significant contributors to the Wilcox. 5) Gap at 115-150 Ma in Cordilleran foreland may indicate southern source (lines up with active time in the south, but older peaks that line-up may indicate northern sources). 6) Presence of some older Proterozoic/Archean and Grenville/Appalachian-sourced material is consistent with inclusion of some Cordilleran foreland basin sediments in the Wilcox.
The significant differences between the Wilcox populations and the age populations of the Cordilleran foreland basin indicate that 1) any uplifted portions of the Cordilleran foreland basin by Laramide uplifts were not a source of sediments for the Wilcox and 2) the source of most of the Cordilleran foreland sediment, the Sevier thrust, was not a source for the Wilcox. What you can see visually is supported by K-S test statistics. All ages = E-47, >350Ma = E-20, >350Ma & <1360 Ma = 0.001.
One of the more obvious differences is in grains in the 115-150 Ma range; that is a gap in the Cordilleran foreland basin data. These ages correspond to a period of high activity in the Alisitos arc and PRB in Southern CA and Baja. The lack of grains of these ages in the Cordilleran foreland basin and the age match to a well dated and very active portion of the arc points towards material derived from southern arc sources being deposited in the Wilcox. This does not rule out inclusion of northern arc sourced material in the Wilcox. DZ peaks at similar ages in the Wilcox and Cordilleran foreland basin sediment suggest that the Wilcox probably incorporated sediments from northern arc sources that were also available to the Cordilleran foreland basin. The presence of some 2000-2700 Ma grains in the Wilcox is consistent with the inclusion of a minor amount of Sevier thrust belt material, as formations in the Sevier thrust belt and Cordilleran foreland basin are known to contain grains of these various ages in close proximity.
From D&G (2008): 1) Wilcox is most likely not from Cordilleran foreland basin or Sevier thrust. 2) There is significant component of Grenville (1075) and Appalachian (412, 609) in D&G that is not present in Wilcox. 3) Wilcox is much more rich in Cordilleran arc (<250); in particular there is a gap from 115-150 in D&G--but no similar gap in Wilcox. These grains probably came from Alisitos/PRB arc in Southern CA and northern Baja CA; does this indicate a southern arc source? 4) Several overlaps in Cordilleran arc-aged sediment; do they indicate northern arc sources?? (the Mogollon rim is thought by D&G to block the Cordilleran foreland from southern arc sediments during this time); any volcanigenic sediment (and therefore DZ ages) in the Cordilleran basin had to come from north. The question is how far north. 5) Grains around 300 Ma could be indicators of Northen CA arc (Klamath terrane), but this is not definitive.
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Wilcox data set vs Lawton et al., (2009) data set. 1) Lawton data set was from Cretaceous-Paleocene Difunta Group of northern Mexico, sourced from arc(s) in Mexico and basement sources in Mogollon Rim. 2) Wilcox has more basement while Difunta has more arc-sourced. 3) Similarity of age peaks in Wilcox and Difunta are good indicators of a significant southern source of the Wilcox. Although the Wilcox and the Difunta groups have fairly similar DZ signatures, they are some differences. In particular, the Wilcox contains much more basement-derived material, and overall it is much less arc-derived.
It is interesting to note that the Wilcox and Difunta groups share peaks at many of the same ages, indicating, that even though the Wilcox is not as volcanigenic as the Difunta Group, it may have shared many of the same southern arc sources.
There are two very interesting differences between the Wilcox and both the Difunta Group and Cordilleran foreland basin. The first is at around 200 Ma. Both the Difunta Group and the Cordilleran foreland basin have a paucity of grains at 200 Ma while the Wilcox seems to have an abundance of them. This is an early arc-aged source.

Likewise the Difunta Group and Cordilleran foreland basin have peaks at 460 Ma and 412 Ma, respectively, but no corresponding peak exists in the Wilcox. Both of these ages match-up to Taconic mountain building, with the Cordilleran Basin 412 Ma being more representative of Eastern US (or TX and Yucutan) and the Difunta 460 Ma being more representative of the Ouachita orogenic belt in NW Mexico. The lack of peaks at either age in the Wilcox indicate that regionally available Taconic-age grains (and inferentially sediments) were not incorporated into the Wilcox. This is consistent with the overall lack of Grenville grains in the Wilcox, as Grenville basement and Taconic basement are both typically found in the Appalachian-Ouachita orogenic belt.
The 200 Ma grains indicate that an early arc-age source that was not available to the Cordilleran foreland basin or the Difunta Group was available to the Wilcox Group. In the case of the ~450 Ma grains, the Difunta Group and Cordilleran foreland had a significant source that is not seen in the Wilcox.

1) Wilcox is similar in pattern to Difunta Group (also Paleocene-Eocene).
2) More basement and less arc ages.
3) Main arc peaks line up well; Wilcox Cordilleran arc grains probably sourced from southern arc and Mexican volcanoes.

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1) UW and LW do match-up. 2) LW is more arc (50% vs 42%), while UW is more basement and recycled-derived. 3) Difference is statistically significant (k-s test score is 0.008). 4) In arc grains it seems that there is more older arc material in LW than in UW; could this possibly support different contraction of arc provenance through time??
A Kolomogorov-Smirnov test indicates that at the 95% confidence level the two were not derived from the same source area (k-s test 0.008). The difference between the two formations in particular is in how much arc-derived sediment is present. On average the LW has more arc-derived grains (50%) than the UW (42%), though this difference is not considered great. The shortfall of arc grains in the UW is made up by slightly more Grenville grains and slightly more 2000+ Ma grains, indicating a slightly higher inclusion of Sevier thrust belt and/or Cordilleran foreland basin sediments. Main arc peaks line-up well; Wilcox Cordilleran arc grains were probably sourced from southern arc and Mexican volcanoes.

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1) Difference in provenance suggested by the petrography and DZ data. 2) Difference in UW and LW seen in DZ data is seen in petrography. 3) Difference is also seen in the LmLvLs data. 4) Petrography does show difference between UW and LW, but it does not give an accurate representation of the actual UW and LW sources. 5) This suggests that a study based solely on sandstone petrography may not fully reflect the sedimentary sources. This is very important when studying passive margins that derived sediments from great distances. Alteration of sediments may occur during autogenic storage cycles, affecting the character of the sediment.
An important observation from the Wilcox data is the discrepancy between the sources suggested by the DZ data and the source suggested by the petrography. The petrography indicates a quartzose-recycled source, suggesting weathering of a mature source area, while the detrital zircon data suggests a source of nearly equal parts Proterozoic basement (metamorphic and plutonic) and juvenile arc and inland volcanism.
It should be noted that the difference in the UW and LW is seen by the petrography, showing an increase in feldspar and lithic grains in the LW, which is consistent with a higher relative proportion of arc grains in the DZ data.
This is also seen in the metamorphic, volcanic and sedimentary lithic data where the LW is much richer in volcanic grains than the UW. Therefore, the petrography does show the difference between the formations that is seen in the DZ data.

The petrography does not reflect the overall source areas implied by the DZ ages. This suggests that a study based solely on sandstone petrography may not fully reflect the sedimentary sources in the drainage. This is especially true of large passive margin systems where grains experience very long transport distances with significant mechanical abrasion of labile grains, as well as grains that may undergo significant chemical weathering during transport-storage cycles.
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Two major sources for Wilcox sediments: Laramide basement uplifts of Southern Rocky Mountains and Cordilleran arc and volcanoes of inland Mexico. Cordilleran foreland and Sevier thrust were not major factors. Lack of grains means no Appalachian or Northern Rocky source. This is a significant departure from conventional hypothesis: means much larger drainage area for Wilcox, including much of Cordilleran arc. Age peaks indicate extensive southern source of sediment. Although with certain level of uncertainty, older ages, in particular 388-450 Ma, may indicate northern sources; this may give an idea of how large the sediment source area could have been. Both the petrographic and DZ data suggest a statistically significant shift in provenance between the LW and UW. LW has more volcanigenic sediments, while UW has more basement and recycled sedimentary sediments. This work supports the conventional hypothesis for the provenance of the Wilcox Group, though the presence of a significant Cordilleran Arc source is a new finding that suggests that the Wilcox Group drained a much broader area than previously thought.
The zircon age distribution from the Wilcox samples indicates that there were two primary sources of sediments for the Wilcox Group: the Laramide basement uplifts of the Southern Rocky Mountains and the Cordilleran Arc, including the volcanics of the interior of Mexico. The Cordilleran foreland basin and the Sevier thrust belt were not major sources of sediment. The lack of significant Grenville or Archean age peaks preclude the Appalachian Mountains and Northern Rocky Mountains as significant sources of sediment.
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