Chronology, sources and transportation mechanism of medial Jurassic - early late Cretaceous tephra delivered to an evolving retroarc foreland basin, north central Wyoming

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Summary

The development of the Western Interior foreland basin from medial-Jurassic to late early Cretaceous results in complex depositional environments and diachronic stratal distribution throughout the basin. The chronostratigraphy of much of the middle Jurassic – lower upper Cretaceous strata is based upon biochronology, where there is a lack of a precise absolute age constraints, especially in the more distal portions of the foreland basin (eg. The modern Bighorn Basin of Wyoming). Isochrons, defined by tephra has the potential to temporally constrain both tectonic and sedimentary process in an evolving basin setting. To this end, tephra sequences in the Sundance, Morrison, Cloverly, Thermopolis, Muddy, Shell Creek, and Mowry formations have been investigated in this study (Fig. 1). A characterization of zircon morphology, as well as U-Pb chronology were carried out to establish a distinctive mineralogical and geochemical signature for representative tephra occurrences (Fig 3, 4, 5.).

In this study, the overall composition of the original tephra varies from dacitic to rhyolitic. Most tephra samples are dominated by type S17 – S25 zircon from calc-alkaline granitoid sources that are hybrid crustal and mantle origin. The Cloverly tuff is dominated by type S8 zircon from intrusive aluminous monzogranites and granodiorites which is influence by a significant crustal component. Zircons from units at basal Morrison that were previously considered to be bentonite bed or accretionary lapilli deposits are dominated by a significant component of detrital zircons, thus making their utility more suspect.

The tephra of north central Wyoming correlate well with known magmatic activity of the Cordillera arc at that time (Fig. 6), with their occurrences also correlated with similar occurrences in Utah, Idaho and Colorado. Most appear to represent plinian eruptive products sourced from localities within the present Sierra Nevada of California, as well as portions of the Idaho Batholith. These tephra were erupted into the upper troposphere /lower stratosphere, and carried by a southwesterly jet stream before being deposited over the Sundance/Western Interior Seaway. This results in a northeast-trending taper to the airfall distribution throughout the basin (Fig. 7). The white siliceous tuff in the Cloverly Formation appears to be a more local deposit, suggesting volcanic activity from unknown sources in relatively close proximity.

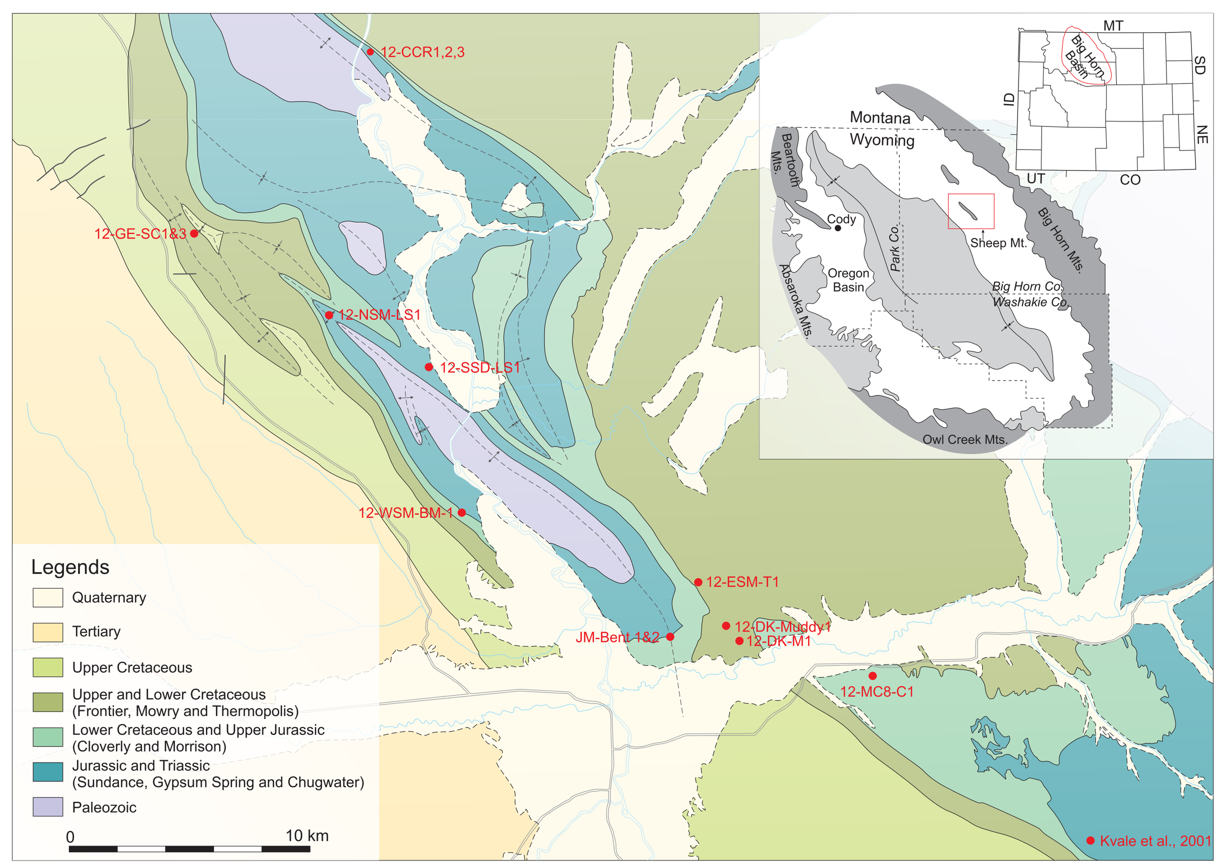


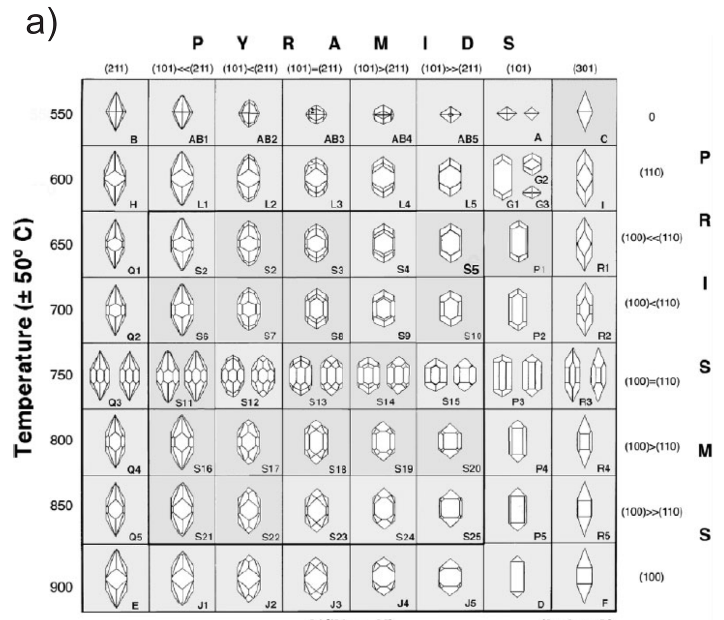
Fig. 1. Simplified geological map and sample locations in the Sheep Mountain area, Bighorn Basin, WY.

Methods

120-150 grains of zircons from each sample were separated. Their external morphology was imaged under SEM before epoxy mounting for a subsequent morphological analysis which is based on a zircon typological scheme proposed by Pupin, 1980 (Fig. 3).

The zircons were then mounted and analyzed using a laser ablation ICP-MS.

Zircon cystals younger than 1000 Ma are presented by the 206Pb/238U ages, and older grains by their 206Pb/207U ages. Errors are in two standard deviation (2σ).



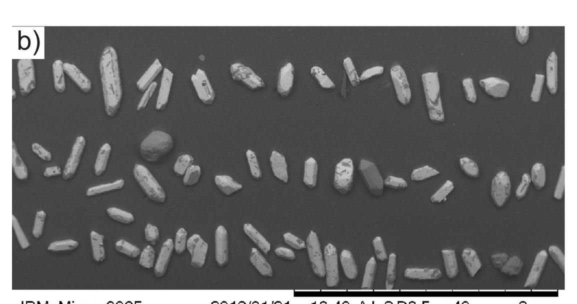
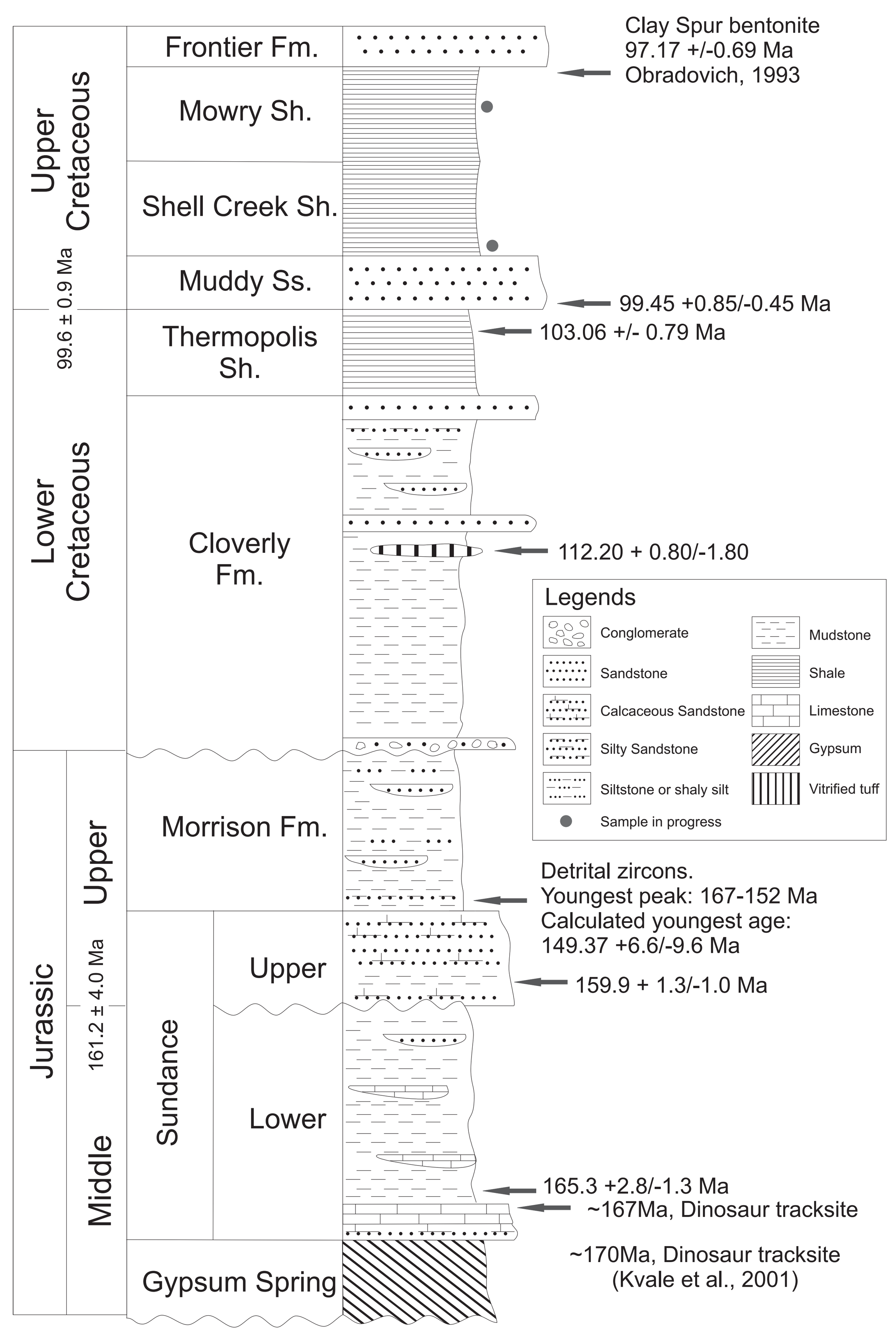
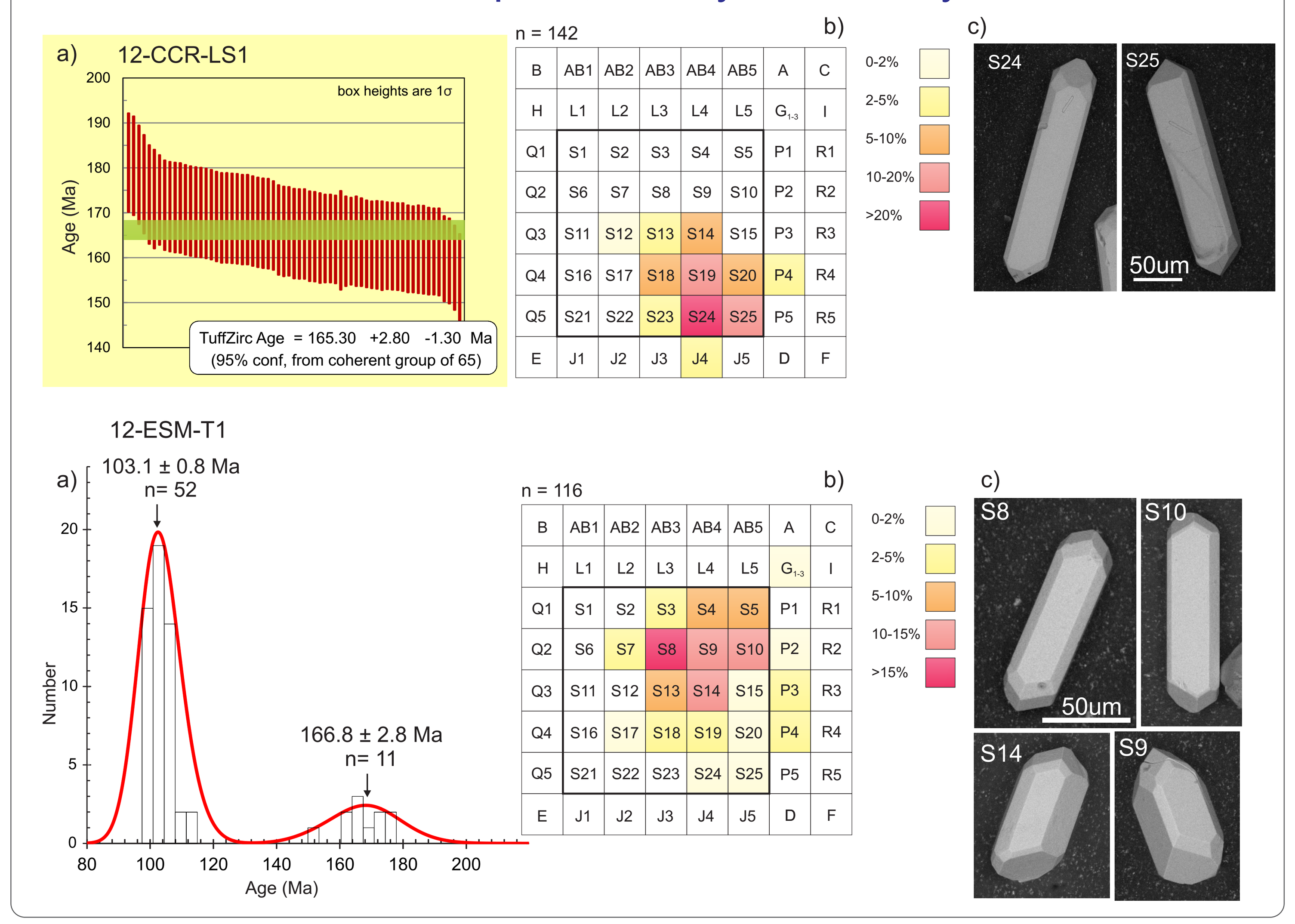


Fig. 2 a) Zircon typological classification and corresponding geothermometric scale proposed by Pupin (1980). Index A reflects the Al/alkali ratio, which controls the development of zircon pyramids, whereas temperature affects the development of different zircon prisms. b) SEM image for specific zircon morphology.

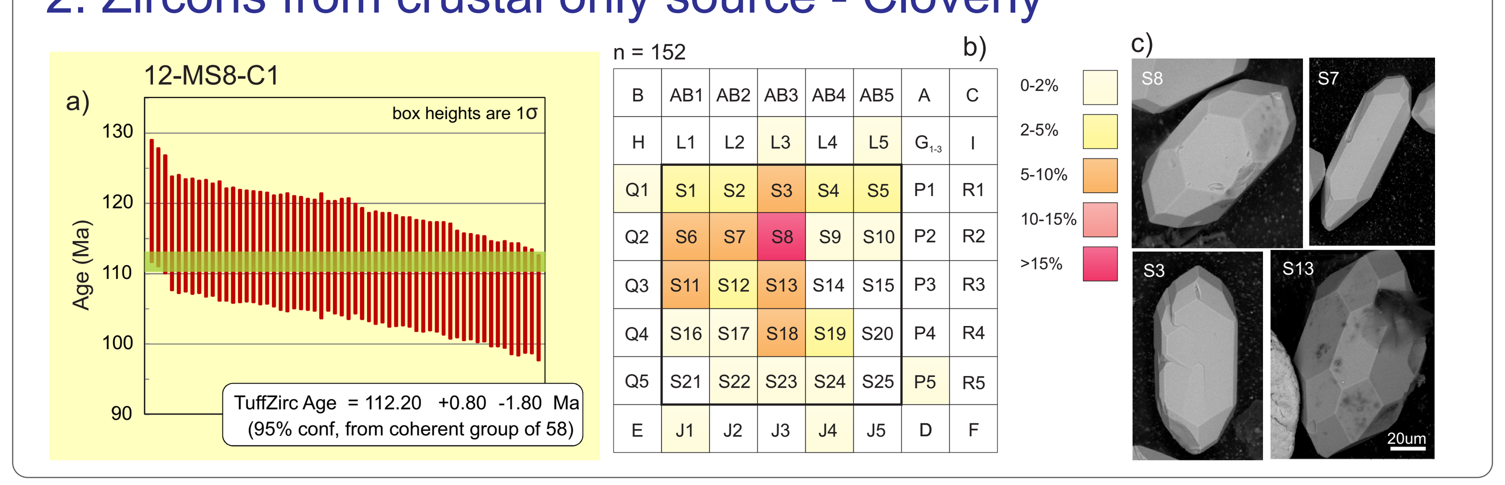
Zircon Morphology and Ages

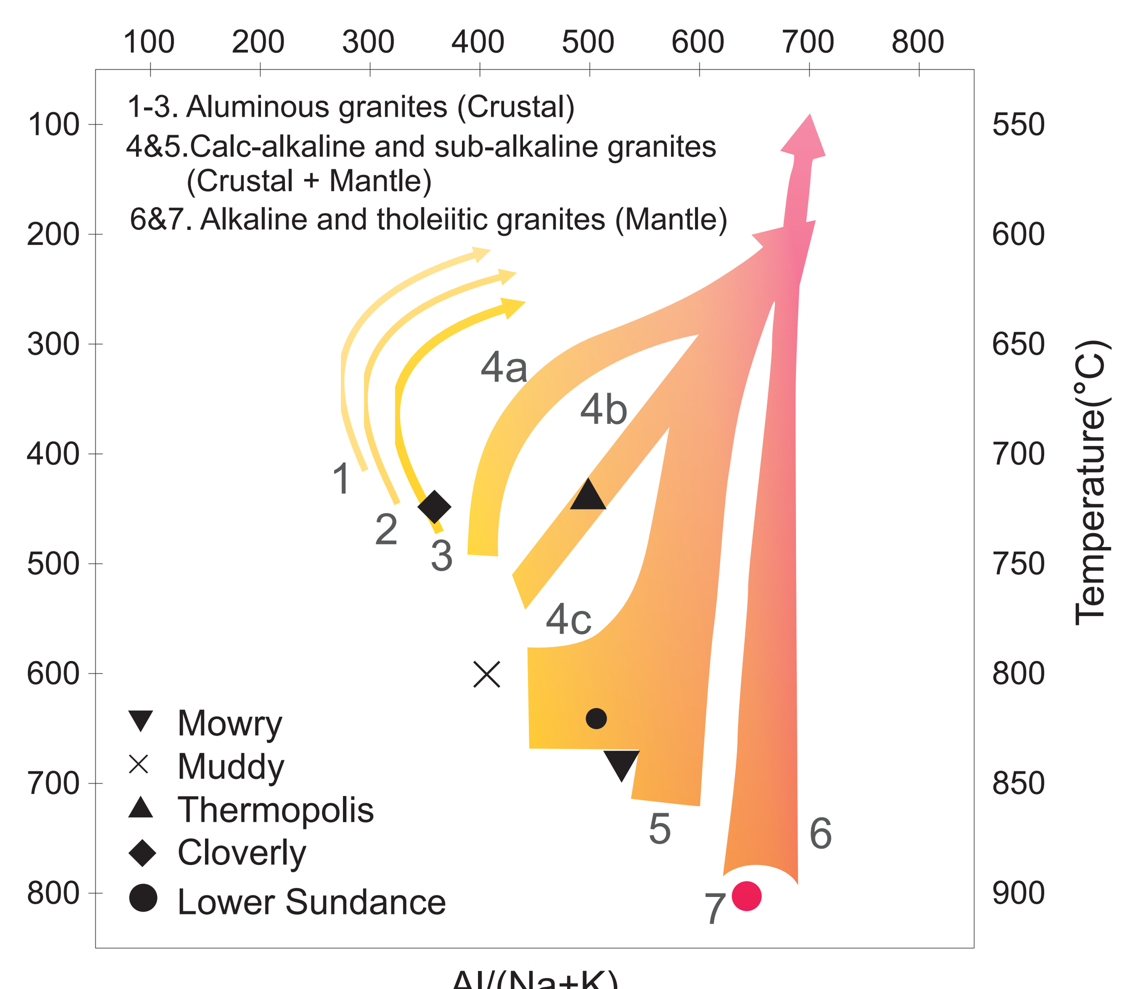


1. Zircons from Hybrid Source – Sundance, Thermopolis, Muddy and Mowry



2. Zircons from crustal only source - Cloverly





3. Detrital zircons - Morrison

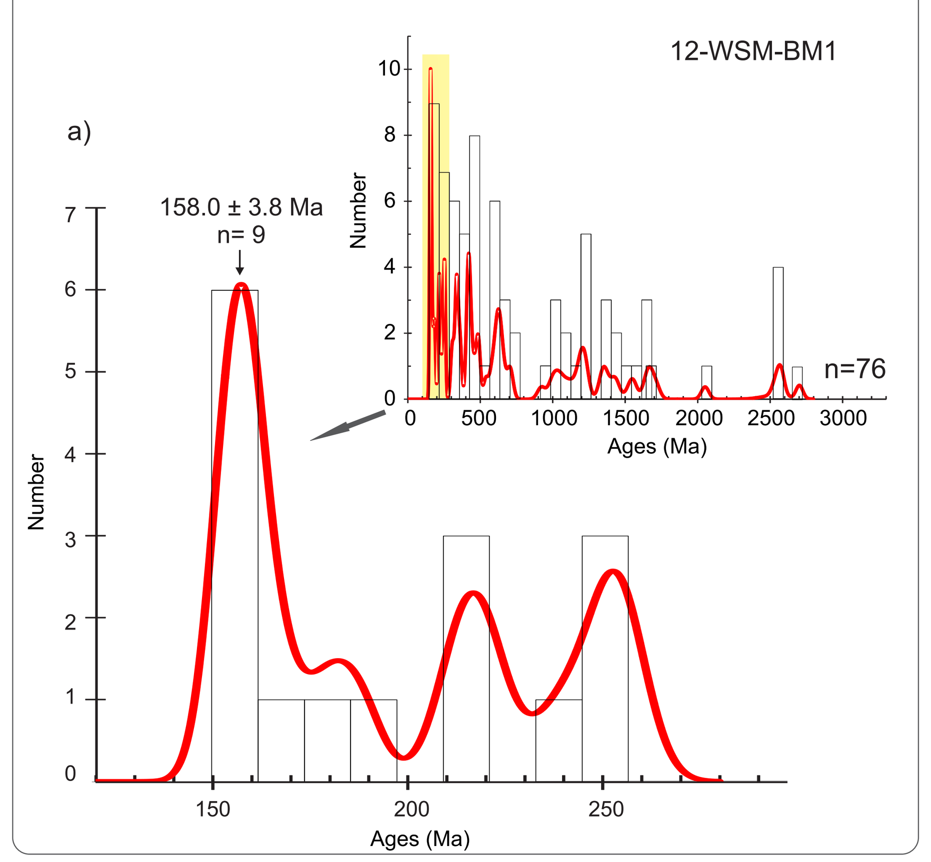


Fig 3. Stratigraphic locations and zircon ages of the samples.

Fig 4. Mean point distribution in the main domains of the typologic diagram for studied volcanic zircons. Zircons from the Sundance, Thermopolis, Muddy and Mowry fall in hybrid calc-alkaline sources, while zircons from the Cloverly fall in crustal origin source.

Fig 5. Classification of the samples according to their zircon ages and typological types. ***a)*** *Age distributions for selected samples. The volcanic zircons from the Thermopolis show bimodal age distribution. The mean age for the older zircons is statistically identical to the older bentonite bed in the Sundance (12-CCR-LS1), indicating of the same volcanic source. The samples from the basal Morrison were collected from a unit that was previous considered as an accretionary lapilli yields only detrital zircons. The mean age for the youngest peak in this unit is 167-152Ma, which is statistically identical to the younger bentonite bed in the Sundance, indicating of recycling from the Sundance, or from its volcanic source.* ***b)*** *Distribution of zircon crystals on the typologic diagram.* ***c)*** *SEM imaging for dominant zircon types from selected samples.*

Sources and Transportation Mechanism

The age distribution of the zircons in this study is well correlated to the magmatic activity of the Cordillera Arc (Fig. 6). According to the zircon typological analysis, tephra beds from the Sundance, Thermopolis, Muddy and Mowry are mainly arc derived. Coeval tephra beds are widely spread in the Western Interior Basin by the SW – NE upper level jet stream (Fig. 7). The temporal distribution of the tephra beds also correlate to the magmatic intensity of the arc: the purity, thickness, and number of the bentonite beds from the Middle – Upper Jurassic are relatively small (Fig. 8b), while they increase dramatically during the major Cordilleran magmatic period from the late early Cretaceous (Fig. 8a).

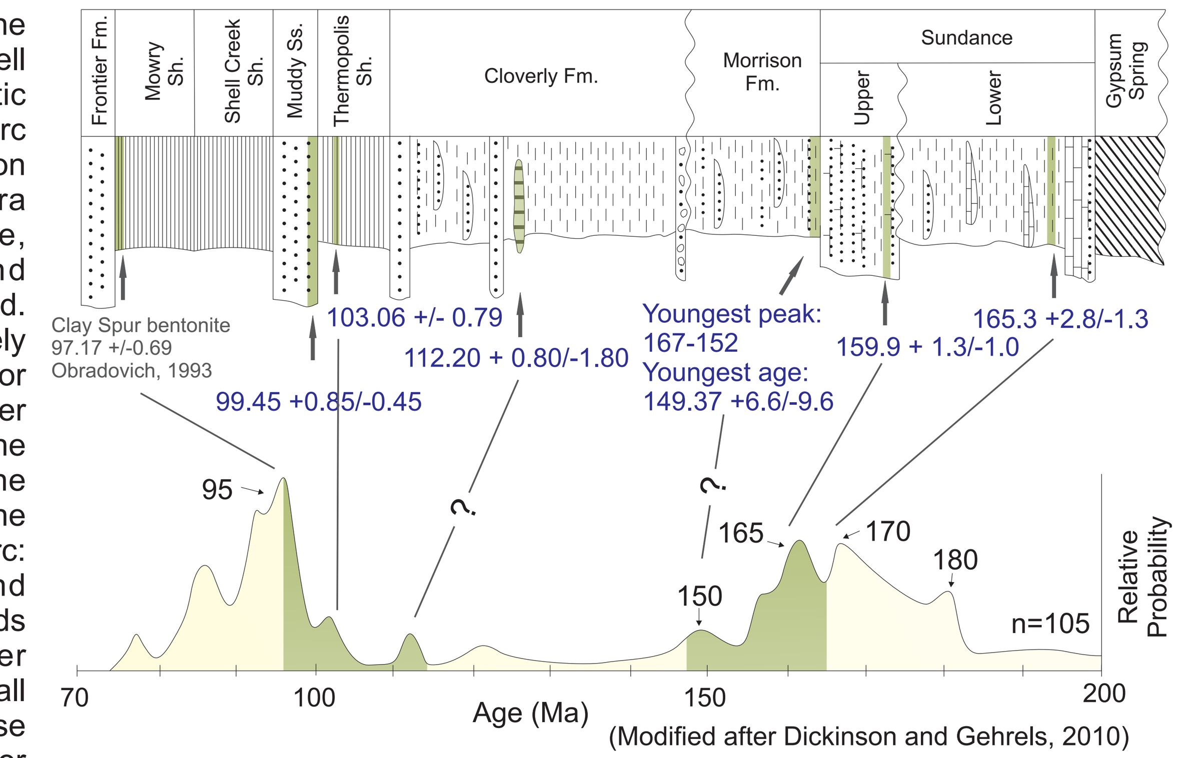


Fig. 6. Correlation between the zircon ages from this study and ages of Cordillera arc-derived detrital zircons from the Colorado Plateau. The latter shows the magmatic intensity of the arc.

Although the age of the siliceous tuff from the Cloverly can be correlated to a small flux in arc activity, the zircon typology indicates an increase in continental crustal influence. In addition, this unit has a limited distribution within the Bighorn basin, and has a very different appearance than the other tephra beds(8c). It is highly possible that this particular tephra unity has an unknown plutonic source in relatively close proximity.

The unit that previously has been identified as a "green tuff" – perhaps lapilli-rich - from the basal Morrison (Kvale et al., 1983) turn out less possibly volcanically-derived. The age of the youngest peak in the detrital zircon population, however, has a strongly implies that there was arc-related sedimentary input to this area during late Jurassic.

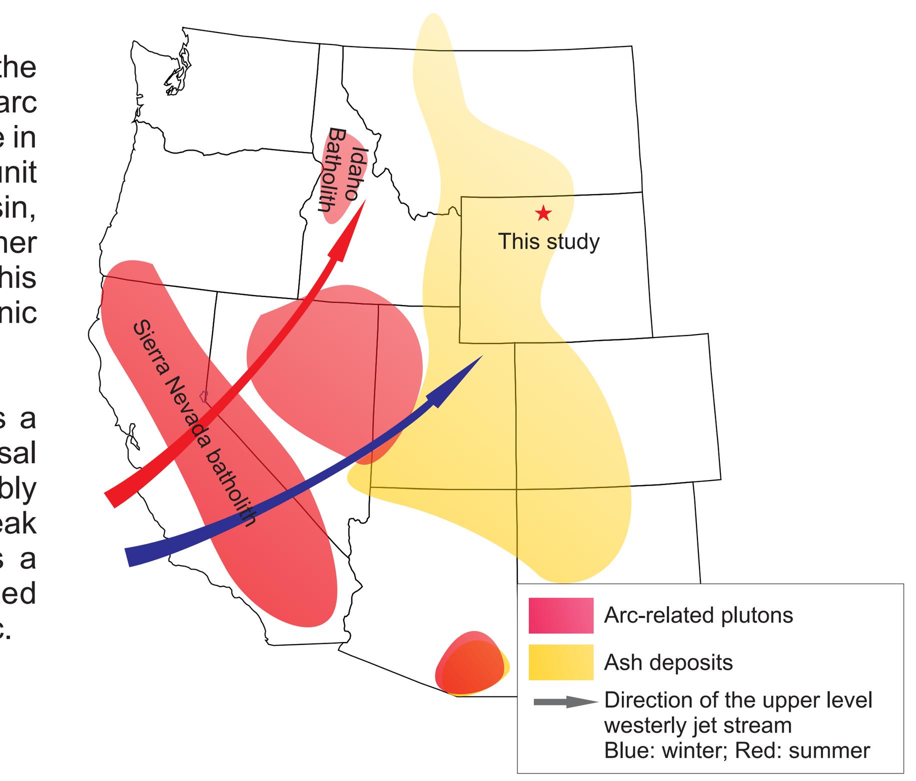
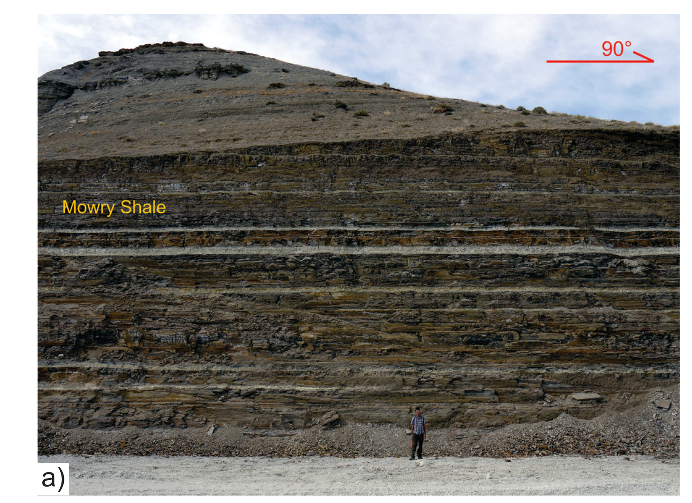
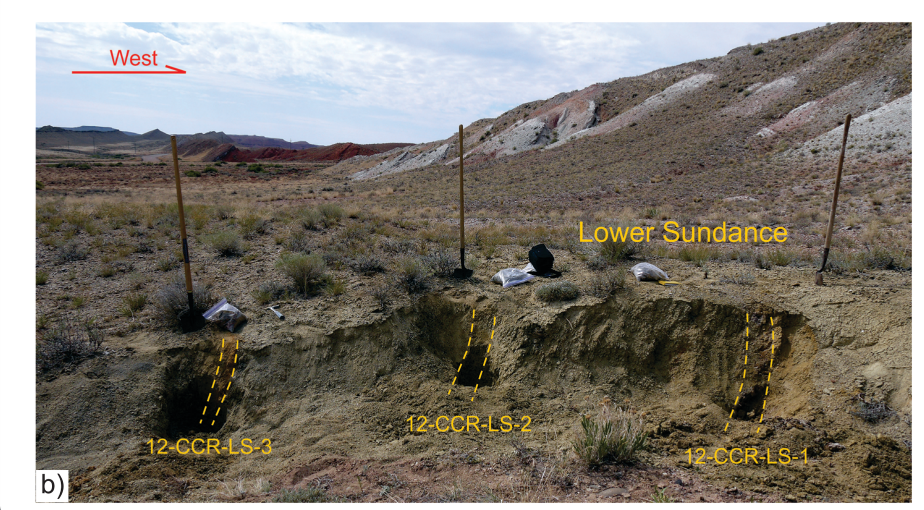


Fig. 7. Simplified map showing the Cordillera arc - related pluton locations (data from the NAVDAT database), tephra distribution (Nielson, 1990, Kowallis et al., 2001, Kvale et al., 2001 etc.), and the wind directions of the upper level westerly jet stream (from Chandler et al., 1992) in the Medial Jurassic - Early Cretaceous.





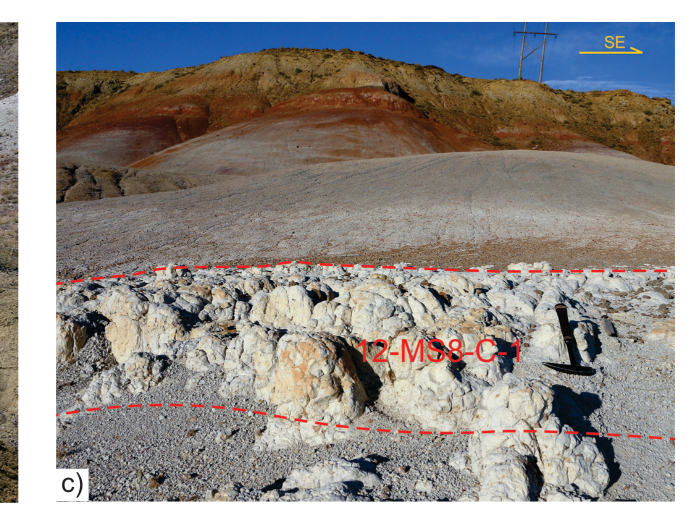


Fig. 8. Field locations for selected tephra beds. a) Three (impure) bentonite beds in the Lower Sundance Formation; b) Multiple bentonite beds in the Mowry Formation. The base of this outcrop is a bentonite bed that is 1.2m thick. c) Siliceous tuff from the Cloverly Formation.

Selected References

Chandler M. et al., 1992. Pangaean climate during the Early Jurassic: GCM simuations and the sedimentary record of paleoclimate. GSA Bulletin, 104, 543-559.
Dickinson W. and Gehrels G., 2010. Insights into North American paleogeography and paleotectonics from U-Pb ages of detrital zircons in Mesozoic strata of the Colorado Plateau, USA. Int J Earth Sci (Geol Rundsh) 99, 1247-1265.
Kvale E. and Vondra C., 1983. Stratigraphy of Upper Jurassic Morrison and Lower Cretaceous Cloverly Formations of Bighorn Basin, Northern Wyoming. AAPG Bulletin, 67(8) 1346-1346.
Kvale E. et al., 2001. Middle Jurassic (Bajocian and Bathonian) dinosaur megatracksites, Bighorn Basin, Wyoming, U.S.A.. Palaios, 16, 233-254.
Kowallis B. et al., 2001. The record of Middle Jurassic volcanism in the Carmel and Temple Cap Formations of southwestern Utah. GSA Bulletin, 113(3), 373-387.
Pupin J., 1980. Zircon and granite petrology. Contrib. Mineral. Petrol., 73, 207-220.
NAVDAT (The Western North American Volcanic and intrusive Rock Database): http://www.navdat.org/

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