Detrital zircon record of thrust belt unroofi ng in Lower Cretaceous synorogenic conglomerates, central Utah

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# ABSTRACT

**U-Pb detrital zircon (DZ) ages (n = 807) from Lower Cretaceous and lowermost Upper Cretaceous synorogenic conglomerate and interbedded sandstone deposited in and near the foredeep of the Cordilleran foreland basin in central Utah indicate stratigraphic compositional variation among the deposits. Eight DZ age populations, ranging from Archean through Mesozoic, are present in the synorogenic foredeep deposits in varying proportions and permit defi nition of three compositional suites, termed here chronofacies. Chronofacies A, present in uppermost Neocomian–lowermost Aptian foredeep deposits, contains Archean through early Paleozoic DZ grains derived from Jurassic–Pennsylvanian strata of the thrust belt. Chronofacies B, in Aptian–Albian foredeep deposits, contains Archean and Paleoproterozoic grains with an age peak near 1850 Ma, a population distribution similar to that of lower Paleozoic quartzites of the thrust belt. Chronofacies C, in Albian–lower Cenomanian foredeep deposits, contains a trimodal population distribution of Paleoproterozoic and Mesoproterozoic grains similar to that of Cambrian–Neoproterozoic quartzite strata of the thrust belt. The chronofacies of the foredeep deposits thus record systematic erosional unroofi ng of the thrust belt during Early Cretaceous time.**

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| **INTRODUCTION**  Provenance modeling of foreland-basin deposits employs identifi cation of clasts in synorogenic conglomerate to infer what formations, termed “source units,” were exposed in an adjoining thrust belt during conglomerate deposition (e.g., Graham et al., 1986; DeCelles, 1988). The technique is useful in determining the history of thrust sheet emplacement and erosion during deposition of particular formations in the basin. An existing shortcoming of lithology-based provenance modeling is that some types of source units in a thrust orogen may be particularly useful in the analysis because they are readily identifi able, whereas others are diffi cult to distinguish from one another. Quartzite units fall into the latter category. For example, in central Utah, specifi c carbonate formations in the Sevier orogenic belt can usually be recognized as clasts in conglomerates of the Cretaceous foredeep (DeCelles et al., 1995; DeCelles and Coogan, 2006; Lawton et al., 2007), and thus serve as a useful record of thrust sheet exposure. But quartzite clasts are more diffi cult to confi dently attribute to their original sources because individual source units typically vary in color and texture, and because different source units locally have similar characteristics. To some extent, the identity of quartzite clasts can be inferred on the basis of associated clasts; for example, quartzite clasts are commonly identifi ed as Ordovician and Devonian in conglom- | erates having abundant lower Paleozoic carbonate clasts (DeCelles et al., 1995; Lawton et al., 2007). Nevertheless, it is likely that erroneous identifi cation of quartzite clasts in some key foreland-basin conglomerates has led to incorrect interpretation of thrust belt unroofi ng history and structural development.  An improved means of identifying quartzite clast sources in foreland-basin conglomerates is desirable for several reasons: (1) Confi dent quartzite clast identifi cation would improve the defi nition of conglomerate exposure gates, or those source units exposed in the thrust belt during deposition of a particular synorogenic conglomerate; (2) some foreland-basin conglomerates contain no carbonate clasts, due either to distance of transport, source area weathering conditions, or absence of exposed carbonate units; (3) compositional differentiation might provide a useful means of correlating quartzite clast conglomerates, which typically lack useful biostratigraphic information.  To test the hypothesis that quartzite clast conglomerates can be attributed to potential source formations in the thrust belt on the basis of their detrital zircon (DZ) age distributions, and to determine if different quartzite clast conglomerates have different provenance signatures, we compare the DZ populations of eight samples from Neocomian through lowermost Cenomanian conglomeratic units in the foredeep of the Cordilleran foreland basin and seven potential source formations in the |
|  | adjacent Sevier orogen of central Utah. Our |
| \*E-mails: tlawton@nmsu.edu; hunt.gary@gmail .com. | small sample set demonstrates that Mesozoic, Paleozoic, and Proterozoic source units can be |

inferred for different conglomeratic deposits in the foredeep.

# METHODS

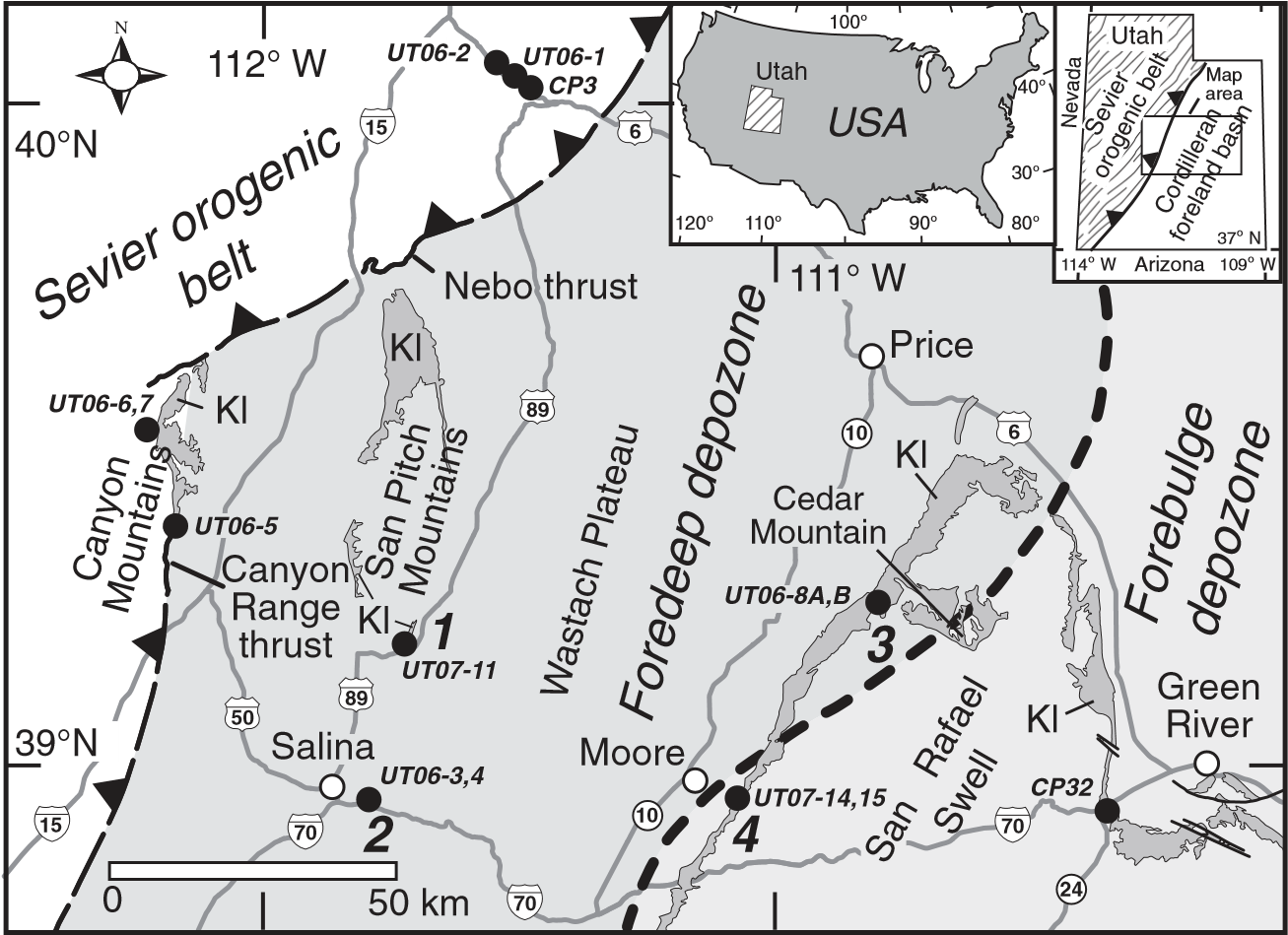
Conglomerate and sandstone samples were collected from several locations and stratigraphic intervals in the foredeep and from several postulated source units in the thrust belt (Fig. 1). Pebbles and cobbles of quartzite and quartzose sandstone were extracted from conglomerate outcrops without regard to color, texture, or inferred source unit and were carefully cleaned of sandstone matrix. The clasts from each site, which likely represent fragments of different source formations, were crushed together to create a single sample. A sandstone bed in the type Buckhorn Conglomerate (UT6-8B) was collected for comparison with clast data (UT06-8A) from the same locality and with a published Buckhorn sandstone analysis (CP32; Dickinson and Gehrels, 2008). We include in our source unit data published analyses from the Ordovician Eureka and Valmy Formations of central Nevada (Gehrels and Dickinson, 1995) and the Jurassic Nugget Sandstone in the Nebo thrust sheet (CP3; Dickinson and Gehrels, 2009).

Zircon grain separation employed standard magnetic and dense-liquid techniques. Detrital zircon ages of sandstone samples (84–139 grain analyses per sample; Table DR1 in the GSA Data Repository1) were obtained using a laser-ablation multicollector–inductively coupled plasma–mass spectrometer (LA-MC-ICPMS) at the University of Arizona LaserChron facility. Procedures and errors associated with the laser facility are detailed elsewhere (Gehrels et al., 2008). Histograms and relative probability curves of zircon U-Pb ages were calculated using Isoplot 3.0 (Ludwig, 2005). We employ the geologic time scale of Walker and Geissman (2009).

# RESULTS

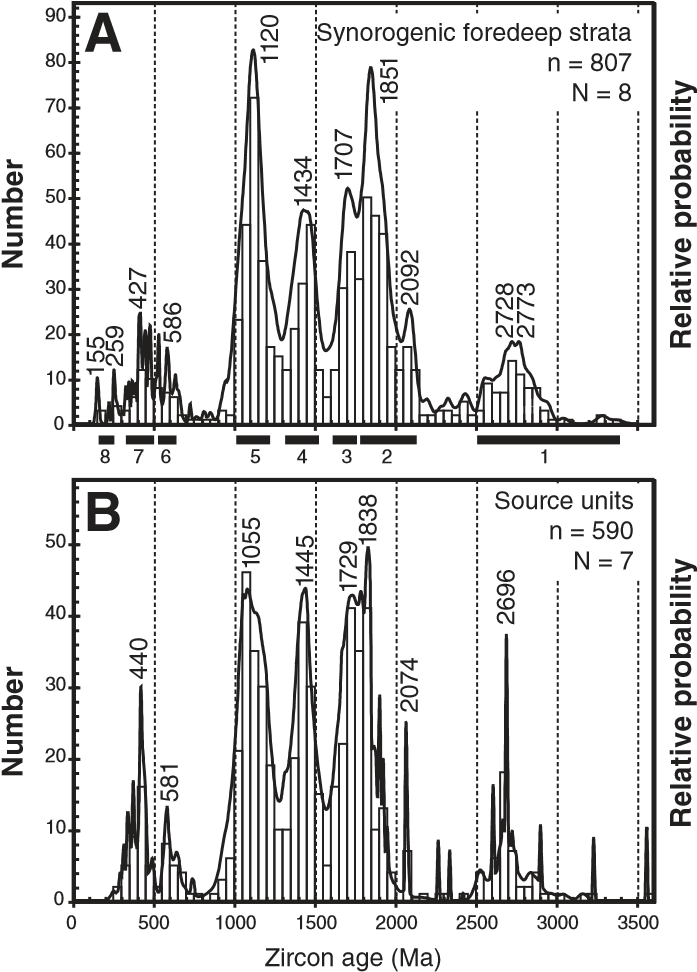
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| © 2010 Geological Society of America. For permission to copy, contact Copyright Permissions, GSA, or editing@geosociety.org.  *Geology*EOLOGY, May 2010 , May 2010; v. 38; no. 5; p. 463–466; doi: 10.1130/G30684.1; 4 fi gures; Data Repository item 2010125. 463 |

We defi ne eight separate zircon age populations in the synorogenic foredeep deposits



**Figure 1. Location map of central Utah, indicating distribution of Lower Cretaceous strata (Kl, which includes some Upper Cretaceous rocks in San Pitch Mountains), detrital zircon sample locations (black dots), and stratigraphic sections of Figure 4 (bold numerals). Adapted from Hintze et al. (2000). Early Cretaceous foredeep/forebulge depozones after Currie (2002); boundary indicated by dashed bold line.**

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| (Fig. 2). These populations consist of grain age groups present in a merged data set of individual DZ analyses (n = 807) from eight separate synorogenic conglomerate samples (Figs. 3 and 4). The populations are (1) Archean grains | (ca. 3400–2500 Ma) with age peaks near 2773 and 2728 Ma, (2) older Paleoproterozoic grains (ca. 2124–1750 Ma) with a minor peak near 2092 Ma and a dominant peak near 1850 Ma, (3) younger Paleoproterozoic grains (ca. 1745– 1600 Ma) with a peak near 1707 Ma, (4) older |

Mesoproterozoic grains (ca. 1510–1320 Ma) with a peak near 1434 Ma, (5) younger Mesoproterozoic grains (ca. 1265–1000 Ma) with a peak near 1120 Ma (informally abbreviated as Grenville grains for their dominant ultimate source in the Grenville orogen and their near omnipresence in North American DZ data sets; e.g., Dickinson and Gehrels, 2003; Moecher and Samson, 2006), (6) Neoproterozoic–Early Cambrian grains (ca. 643–517 Ma) grains with peaks near 642, 586 and 536 Ma, (7) early Paleozoic grains (ca. 500–330 Ma) with multiple peaks, and (8) a small population of latest Paleozoic to Mesozoic grains (ca. 265–154 Ma) with a

peak near 155 Ma. Broad age spans in Archean, Paleoproterozoic, and Mesoproterozoic populations result from generally large analytical errors for grains older than 1000 Ma relative to grains younger than 1000 Ma (e.g., Gehrels, 2000) (Table DR1).

Signifi cantly, not all eight grain age populations are present in each foredeep sample; more-

**Figure 2. U-Pb relative probability age dis-** over, the age populations that are present vary

**tributions and histograms of synorogenic** among samples and serve to differentiate sets of

**foredeep strata (A) and thrust belt source** samples (Fig. 3). Accordingly, we herein defi ne

**units (B). Numbered age populations il-**

the term *chronofacies* as a group of sedimentary

**lustrated by bars, discussed in text, were**

**derived from analyses in A. N—number of** rocks that contains a specifi ed suite of DZ age

**samples; n—number of U-Pb analyses.** populations. The synorogenic samples contain

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three such population suites, termed chronofacies A–C: (1) Chronofacies A contains a spread of Paleoproterozoic grains, some Archean grains, and groups of grains in the Neoproterozoic and early Paleozoic (samples UT06-8A and -8B, UT07-10 and -16); (2) chronofacies B contains rare Grenville grains, a prominent group of Paleoproterozoic grains with a peak near 1850 Ma, and Archean grains (samples UT06-4, UT07-9 and -15); (3) chronofacies C contains three prominent Proterozoic grain populations with peaks near 1750 Ma, 1450 Ma, and 1140 Ma (samples UT06-3, UT07-11 and -14). Some samples in chronofacies A also contain

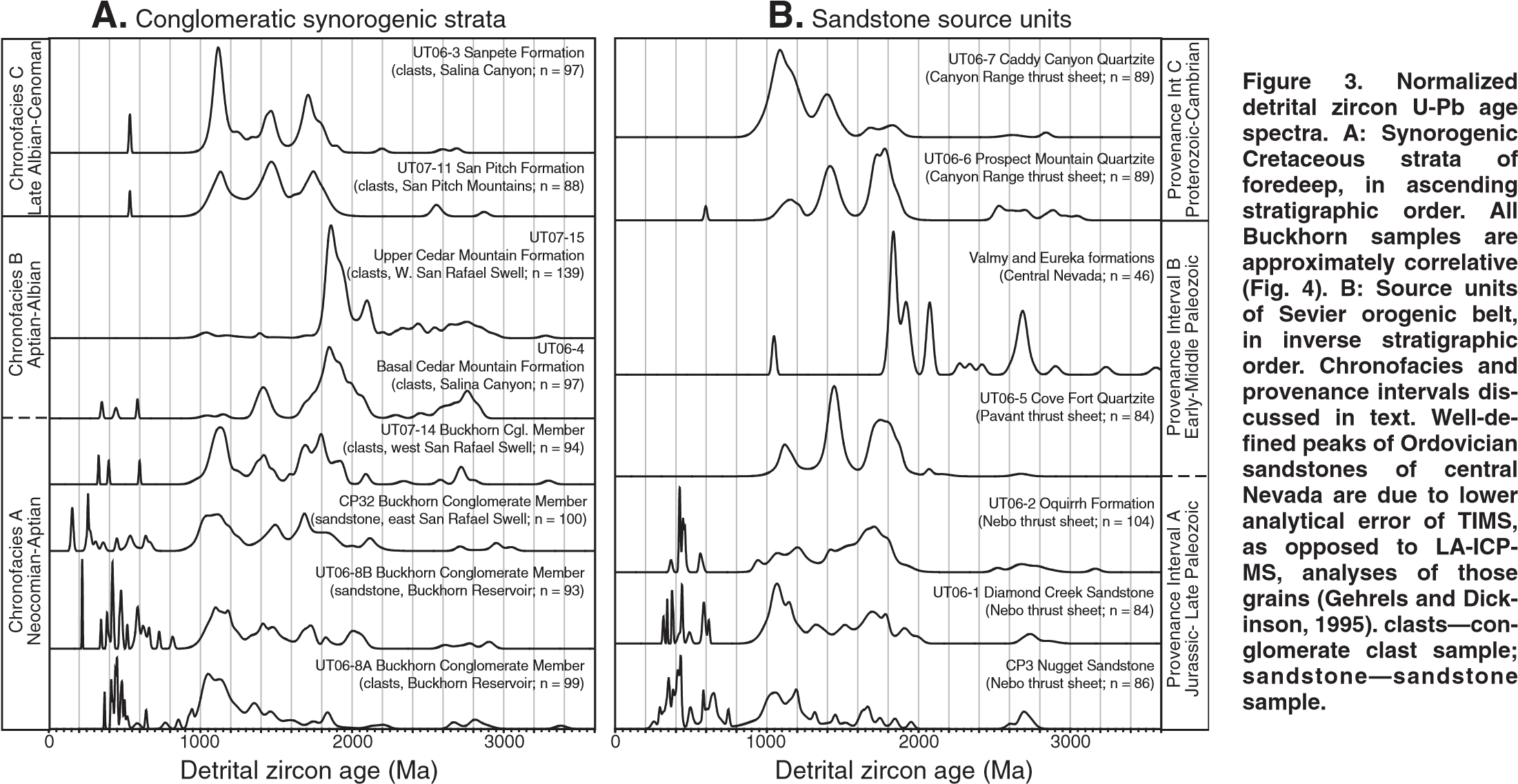
Mesozoic grains (samples UT06-8B and UT0716). Most samples have prominent populations of Grenville grains, which are present in almost all Proterozoic quartzite formations of western North America (e.g., Stewart et al., 2001) (Fig. 3); therefore it is noteworthy that Grenville grains are rare in Cedar Mountain samples (UT06-4 and UT07-15, Fig. 3).

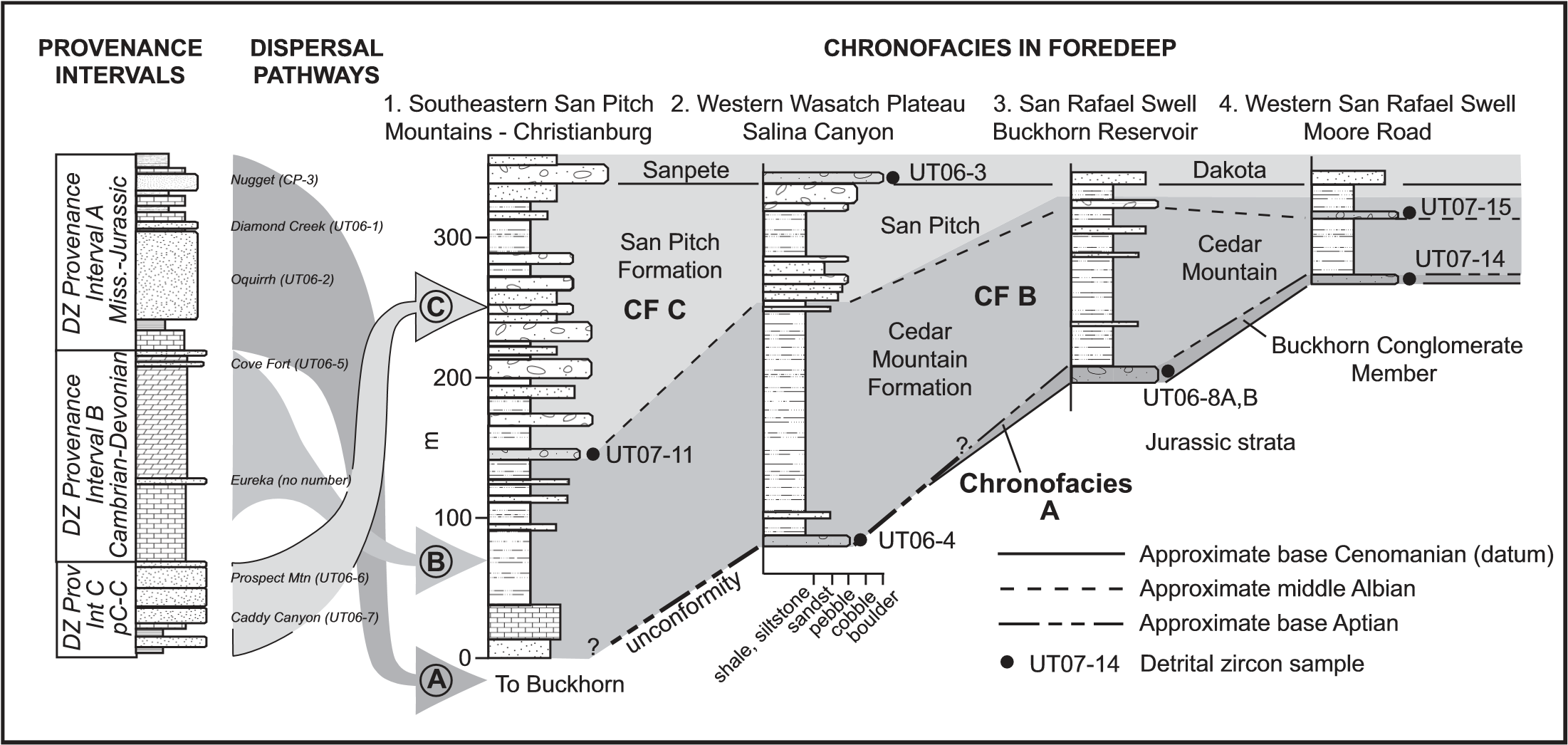
Proterozoic through Mesozoic strata in the thrust belt can be divided into three distinctive provenance intervals with DZ age populations that generally correspond to those of the synorogenic units. Three samples, representing Pennsylvanian–Jurassic sandstones of the thrust belt, strongly resemble the DZ age distribution of chronofacies A (Fig. 3; Table DR2). Analyses of Ordovician sandstones from central Nevada (Gehrels and Dickinson, 1995) contain Archean grains and a prominent Paleoproterozoic group with an age peak near 1850 Ma, similar to the grain age distributions observed in the synorogenic Cedar Mountain samples. The Proterozoic Caddy Canyon Quartzite and Lower Cambrian Prospect Mountain Quartzite have a distinctive trimodal Proterozoic DZ age distribution matching that of chronofacies C in the two youngest synorogenic conglomerate samples. Our Devonian quartzite sample (UT06-5) does not conform well to the composition of chronofacies B, resembling instead the trimodal grain age distribution of chronofacies C, and may explain the grain age distribution in our basal Cedar Mountain sample (UT06-4, Fig. 3), which contains an age peak near 1400 Ma and age populations around 2950 and 1850 Ma.

# DISCUSSION

Our data indicate that the three DZ chronofacies of the synorogenic foredeep deposits contain zircon grains derived from different combinations of source units, termed provenance intervals A–C, in the Sevier orogenic belt (Fig. 4). Provenance interval A, with Neoproterozoic and Paleozoic grains and a diverse population of older Proterozoic grains, spans Pennsylvanian, Permian, and Jurassic sandstones, which contain a similar spectrum of grain ages. The type Buckhorn Conglomerate

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**Figure 4. Model for detrital zircon (DZ) provenance intervals in source units of thrust belt (left column), dispersal pathways (arrows), and stratigraphic distribution of chronofacies (CF) in foredeep of Cordilleran foreland basin. Source unit samples indicated adjacent to source unit column. Proterozoic–Devonian of Canyon Range thrust plate and localities to west adapted from Hintze and Davis (2003); Mississippian–Jurassic of Nebo thrust plate adapted from Hintze (1988). Age boundaries of synorogenic strata adapted from Sprinkel et al. (1999) and Greenhalgh and Britt (2007). Section locations in Figure 1. Sections 1 and 2 from Sprinkel et al. (1999); section 3 from Stokes (1952). Sample CP32, collected southeast of Cedar Mountain (Fig. 1) correlates with UT06-8A, UT06-8B, and UT07-14.**

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| contains these grain ages in both sandstone interbeds (UT06-8B, CP32) and conglomerate clasts (UT06-8A), indicating that the Permian or Jurassic eolianites were locally suffi ciently indurated to yield clasts. Thus, chronofacies A | contains detritus derived from provenance interval A of an incipiently eroded thrust belt.  Provenance interval B, containing two populations of Paleoproterozoic grains and common Archean grains, is defi ned to include | lower Paleozoic quartzite units, particularly the Eureka Quartzite in Nevada and Utah, and the Valmy Formation, a deepwater equivalent of the Eureka, in Nevada. The corresponding chronofacies B was deposited in the foredeep |
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prior to widespread exposure of Proterozoic and lowermost Paleozoic strata in the thrust belt, because those source units contain abundant Grenville grains, which are scarce in chronofacies B. Chronofacies B deposits in the foreland therefore record intermediate erosion of the thrust belt down to strata of the lower to middle Paleozoic.

Provenance interval C includes Neoproterozoic and lowermost Paleozoic quartzites in the thrust belt, with a prominent trimodal population of Paleoproterozoic and Mesoproterozoic grain ages. Chronofacies C deposits in the foredeep, with a similar age distribution and typically composed exclusively of quartzite clasts, thus indicate widespread exposure of Proterozoic quartzite strata in the thrust belt.

The use of DZ chronofacies has the potential to better defi ne exposure gates in thrust sheets and document their along-strike variability in thrust orogens. For example, Proterozoic quartzite clasts have been reported from the basal Cedar Mountain Conglomerate, a representative of chronofacies B in Salina Canyon (section 2, Fig. 4) (Currie, 2002). The conglomerate also contains upper Paleozoic chert clasts and clasts of silicifi ed wood likely derived from Triassic strata. The absence of Grenville zircons in this conglomerate indicates that Proterozoic or Lower Cambrian strata were not yet unroofed in the Sevier orogenic belt and precludes the scenario that the whole preorogenic section, roughly 16,000 m of strata, was exposed when the lowermost preserved synorogenic conglomerate was deposited.

Whether these geochronologic provenance distinctions can improve conglomerate correlations remains to be determined. The boundary between chronofacies B and C crosses a correlation line between sites in the San Rafael Swell (sections 3 and 4, Fig. 4), indicating possible miscorrelation and a need for more detailed sampling. In addition, chronofacies A remains undetected in thick western sections of the foredeep (Fig. 4). This may have resulted from sediment bypass at the base of the section (indicated by an unconformity in the western section of Fig. 4), or from along-strike variation in structure and stratigraphic exposure in the thrust belt.

# CONCLUSIONS

Synorogenic conglomerates in the foredeep of the Cordilleran foreland basin in central Utah composed of quartzite clasts and mixed populations of chert, carbonate, and quartzite clasts contain different DZ U-Pb age distributions. The synorogenic deposits have eight discrete DZ age populations ranging in age from Archean through Mesozoic. These grain age populations

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are also present in the formations that provided sediment to the foreland basin. The individual grain age populations combine with one another to form distinctive groups, termed chronofacies, that record systematic progressive erosion through three corresponding provenance intervals in the adjacent Sevier orogenic belt.

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1. GSA Data Repository item 2010125, supplemental text, Table DR1 (U-Pb detrital zircon geochronologic analyses), and Table DR2 (KolomogorovSchmirnov P-values for compared pairs of detrital zircon probability spectra), is available online at www.geosociety.org/pubs/ft2010.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA. [↑](#footnote-ref-1)