Jurassic onset of foreland basin deposition in northwestern Montana, USA: Implications for along-strike synchronicity of Cordilleran orogenic activity

F. Fuentes*, P.G. DeCelles, G.E. Gehrels
Department of Geosciences, University of Arizona, Tucson, Arizona 85721, USA

ABSTRACT

Stratigraphic, provenance, and subsidence analyses suggest that by the Middle to Late Jurassic a foreland basin system was active in northwestern Montana (United States). U-Pb ages of detrital zircons and detrital modes of sandstones indicate provenance from accreted terranes and deformed miogeoclinal rocks to the west. Subsidence commenced ca. 170 Ma and followed a sigmoidal pattern characteristic of foreland basin systems. Thin Jurassic deposits of the Ellis Group and Morrison Formation accumulated in a backbulge depozone. A regional unconformity and/or paleosol zone separates the Morrison from Early Cretaceous foredeep deposits of the Kootenai Formation. The model presented here is consistent with regional deformation events registered in hinterland regions, and challenges previous interpretations of a strongly diachronous onset of Cordilleran foreland basin deposition from northwestern Montana to southern Canada.

INTRODUCTION

One of the most controversial aspects of the Cordilleran thrust belt and foreland basin system is also one of the most fundamental, i.e., when did this system initially develop? Estimates for the onset of foreland basin accumulation in the western interior of the United States span ~75 m.y. from Early Jurassic to Aptian time (Heller et al., 1986; Bjerrum and Dorsey, 1995; DeCelles and Currie, 1996; Allen et al., 2000, Dorsey and Lamaskin, 2007), whereas most workers agree that a foreland basin was established in southern Canada by the Middle to Late Jurassic (Cant and Stockmal, 1989; Fermor and Moffat, 1993; McMechan and Thompson, 1993; Poulton et al., 1994; Ross et al., 2005). Gillespie and Heller (1995) inferred that foreland basin development in the western United States was ~40 m.y. later than in Canada, giving rise to the notion of strongly diachronous orogeny. In this paper we present stratigraphic, geochronologic, and provenance data from northwestern Montana that support the hypothesis that Middle Jurassic deposition took place in a retroarc foreland basin system. We conclude that initial foreland basin development was nearly synchronous along the United States and southern Canadian portions of the Cordilleran thrust belt.

REGIONAL SETTING AND JURASSIC–EARLY CRETACEOUS STRATIGRAPHY

Three major tectonic elements compose the Cordilleran orogenic system at the latitude of northwestern Montana and southern Canada (Fig. 1): a western region of accreted terranes (e.g., Colpron et al., 2007; Giorgis et al., 2008); a fold-and-thrust belt involving Paleozoic and Mesozoic sedimentary rocks in its frontal part, and mainly Proterozoic strata in the hinterland; and a Mesozoic–early Paleogene foreland basin system that has been partially incorporated into the fold-and-thrust belt. In northwestern Montana an unconformity representing ~150 m.y. separates the youngest preorogenic strata of the Mississippian Madison Group from the oldest strata that possibly could be linked to Cordilleran orogenic evolution, the Middle Jurassic Ellis Group (Fig. 2).

The Ellis Group consists of ~100–200 m of Bajocian–Oxfordian clastic and carbonate marine deposits of the Sawtooth, Rierdon, and Swift Formations (Mudge, 1972). The Ellis Group correlates with the upper part of the Fernie Formation of southwest Alberta and southeast British Columbia (Poulton et al., 1994). The overlying Morrison Formation consists of ~60–80 m of fine-grained estuarine to nonmarine strata, its upper part usually overprinted by strong pedogenesis. Palynology of three Morrison samples yielded Oxfordian–Kimmeridgian ages (GSA Data Repository Table DR1), suggesting temporal continuity between the Ellis Group and the Morrison Formation.

A regional unconformity or zone of extreme stratigraphic condensation separates the Morrison from the overlying Lower Cretaceous Kootenai Formation. In places this unconformity cuts into the lower part of the Ellis Group along incised paleovalleys (Dolson and Piombino, 1994). The Kootenai consists of ~200–400 m of fluvial and minor lacustrine deposits. This and correlative units have been sparsely dated as Barremian(?)–Aptian (DeCelles, 2004). New palynology and detrital zircon data extend this age range into the lower Albian (Tables DR1 and DR2). The Lower Cretaceous, as well as the overlying 2500 m succession of Albian–early Eocene age, was deposited in the foredeep depozone of the Cordilleran foreland basin system (Suttner et al., 1981; Gillespie and Heller, 1995; DeCelles, 2004).

DETRITAL ZIRCON U-Pb AGES

A total of 476 U-Pb ages of detrital zircon grains from five samples of Jurassic and Early Cretaceous sandstones was obtained by laser-ablation–multicollector inductively coupled plasma–mass spectrometry at the University of Arizona LaserChron Center (analytical procedures in Gehrels et al., 2008). Analyses that yielded isotopic data with acceptable discordance, precision, and in-run fractionation are shown in Table DR2. The ages are plotted on relative probability diagrams (Fig. 3); peaks on these diagrams are considered robust if defined by three or more analyses. In addition to provenance information, the youngest cluster of ages for each sample gives a maximum depositional age.

*E-mail: fuentes@email.arizona.edu.

© 2009 The Geological Society of America. For permission to copy, contact Copyright Permissions, GSA, or editing@geosociety.org. Geology, April 2009; v. 37; no. 4; p. 379–382; doi: 10.1130/G25557A.1; 4 figures; Data Repository item 2009091.
Sample Eb from the Sawtooth Formation produced age clusters with a miogeoclinal signature (Gehrels and Ross, 1998). Most detrital zircons yielded ages older than ca. 1 Ga; a few grains provided ages in the range 419–467 Ma, typical of upper Paleozoic–Triassic strata in the thrust belt; two grains have Late Proterozoic ages; and one zircon yielded a syndepositional age of ca. 171 Ma. The range of grains older than 1 Ga suggests that the zircons of this sample were recycled from several intervals within the miogeoclone, and perhaps reflects an early fold-and-thrust belt involving Paleozoic strata in the hinterland region. However, because zircons in the miogeoclone were mainly recycled from North American basement and Grenville sources, a potential eastern contribution cannot be ruled out. The single Jurassic grain supports a western source.

Samples 1GR14 from the Swift Formation and 1GRZ from the Morrison Formation provided zircons with a similar age spectrum. Most grains are older than 1 Ga, a few provided Late Proterozoic ages, and sample 1GRZ produced an additional cluster in the range 403–457 Ma. However, the key aspect of these samples is that they contain clusters of ages in the ranges 223–329 Ma and 156–180 Ma. The Mississippian–Triassic range is characteristic of igneous rocks of the eastern part of the Intermontane belt (Monger et al., 1982). The lack of other sources of zircons with those ages in the area indicates that terranes in the Intermontane belt were structurally elevated and supplying sediments to a basin located hundreds of kilometers to the east. Relatively abundant Jurassic, arc-derived grains, further substantiate a western provenance as early as Oxfordian time.

Sample 1GR100 from the basal sandstone of the Kootenai Formation yielded abundant grains with a miogeoclinal signature, a few Permian and Triassic zircons, and a relative increase in zircons derived from Middle Jurassic-Lower Cretaceous volcanic centers, a pattern that is amplified in sample 1FG70 from the middle part of the unit. Sample 1FG70 provided abundant grains in the range 104–238 Ma, indicating predominant sources in the magmatic arc and Intermontane belt.

Most samples contained grains of Late Proterozoic ages, with unknown sources in the region. A possible scenario is transport along axial fluvial systems from the south, in the Colorado Plateau region, where zircons of that age have been identified (Dickinson and Gehrels, 2008).

**Figure 1. A:** General location map of Cordilleran orogenic system showing area of B. **B:** Simplified tectonic map of the fold-and-thrust belt and foreland basin of study area with accreted terranes to the west (terranes based on Dickinson, 2004; Colpron et al., 2007). Blue box indicates area of sample collection. Red circle shows location of section used for subsidence curve in Figure 2.

**Figure 2.** Chart showing local Middle Jurassic–Early Cretaceous stratigraphy, main tectonic events in northwestern Montana and southwestern Canada, and tectonic subsidence curve for northwestern Montana foreland basin system. Time scale is from Palmer and Geissman (1999) and tectonic events are from sources discussed in text. Location of subsidence curve is in Figure 1B; paleobathymetric uncertainty is shown in gray.

**MODAL SANDSTONE PETROGRAPHY**

Framework modes of 12 medium-grained sandstones from the Ellis Group and Morrison and Kootenai Formations were determined by point-counting ~450 grains per slide according to the Gazzi-Dickinson method. Raw data and recalculated norms are available in Table DR3. On QmFLt (monocrystalline quartz–feldspar–total lithic) and QtFL diagrams (Fig. 4), the samples plot in the recycled orogen fields of Dickinson and Suczek (1979), indicating provenance from a suture or fold-and-thrust belt. The
Omineca belt occurred between ca. 180 and 162 Ma (Archibald et al., Dickinson, 2004; Colpron et al., 2007; Dorsey and LaMaskin, 2007), America during the Middle Jurassic (e.g., Coney and Evenchick, 1994; western Montana (Fig. 2). The Intermontane terranes accreted to North consistent with Middle to Late Jurassic foreland basin initiation in north-
clinal strata to the west.

Timing of terrane accretion and deformation in the hinterland is
Timing of thrusting is poorly constrained in hinterland regions, but is
pre–middle Cretaceous in the United States–Canada border region (Price
and Sears, 2000), and perhaps as old as late Middle Jurassic (McMechan and
Thompson, 1993).

The principal argument for a later Cretaceous onset of fore-
land basin development in this region is based on the assumption that
foreland basin sediment is confined to a relatively thick moat of flexural
subsidence directly adjacent to the thrust belt load (Gillespie and Heller,
1995). Ellis Group and Morrison deposits do not thicken westward as
expected for foredeep deposits. However, sediment derived from the
thrust belt can be deposited on top of the flexural forebulge as well as
in the backbulge depozone (e.g., Horton and DeCelles, 1997; Yu and Chou,
2001; Roddaz et al., 2005). We suggest that relatively tabular and thin
Ellis and Morrison deposits in northwestern Montana were deposited in a
backbulge depozone, and that the unconformity and/or condensation zone
that caps them was produced in part by migration of a forebulge through
the region. The model presented here is consistent with previous interpre-
tations to the south that suggest the onset of foreland basin sedimentation
during the Jurassic, and supports synchronous development of a foreland
basin system from as far south as central Utah (Bjerrum and Dorsey, 1995;
DeCelles and Currie, 1996) to southern Canada. This is consistent with
coeval growth of the western Cordillera in response to rapid westward
movement of North America as heralded by Middle Jurassic seafloor
spreading in the North Atlantic (Coney and Evenchick, 1994).

SUBSIDENCE HISTORY

Middle Jurassic–Danian strata in northwestern Montana were
decompressed and backstripped according to the methods described in
Angevice et al. (1990) and Allen and Allen (2005). The resulting tec-
tonic subsidence curve (Fig. 2) has a sigmoidal shape, as expected from
progressive stacking of foreland basin depozones in front of a migrating
orogenic load (DeCelles and Currie, 1996). The period 171–151 Ma,
during deposition of the Ellis Group and Morrison Formation, repres-
ents initial, moderate subsidence in the region inboard of the flexural
forebulge. The multistory paleosols in the uppermost Morrison Forma-
tion indicate a continental condensed section, which is transitional into
the interval 151–127 Ma, marking a regional unconformity between
Morrison and Kootenai strata. This unconformity has been recognized
throughout the Cordilleran foreland basin, and attributed to the migration
of a flexural forebulge (DeCelles, 2004). The Late Jurassic–Valanginian
eustatic fall (Haq et al., 1987) may have contributed to erosion and low
net sediment accumulation. From ca. 127 Ma onward, subsidence rates
increased rapidly, a trend that is typical of foredeep deposits.

INTERPRETATION AND CONCLUSIONS

Data presented here demonstrate that a foreland basin system became
active in northwest Montana as early as Bajocian time. Onset of subsidence
and lithic-rich clastic sediment accumulation ca. 170 Ma, after a hiatus
of ~150 m.y., indicates the development of a tectonically active orogenic
belt to the west. Detrital zircon ages from Oxfordian–Kimmeridgian sand-
stones of the Swift and Morrison Formations provide unequivocal proof
of ~150 m.y., indicates the development of a tectonically active orogenic
belt to the west. Detrital zircon ages from Oxfordian–Kimmeridgian sand-
stones of the Swift and Morrison Formations provide unequivocal proof
that caps them was produced in part by migration of a forebulge through
the region. The model presented here is consistent with previous interpre-
tations to the south that suggest the onset of foreland basin sedimentation
during the Jurassic, and supports synchronous development of a foreland
basin system from as far south as central Utah (Bjerrum and Dorsey, 1995;
DeCelles and Currie, 1996) to southern Canada. This is consistent with
coeval growth of the western Cordillera in response to rapid westward
movement of North America as heralded by Middle Jurassic seafloor
spreading in the North Atlantic (Coney and Evenchick, 1994).

lithic fraction is dominated by chert, limestone, shale, and phyllite. These
data strongly implicate sediment sources in deformed (meta)sedimentary
rocks of the Cordilleran thrust belt.

Figure 3. Age-probability plots of U-Pb ages of detrital zircon samples. Black bars indicate depositional age of samples. Shaded areas indicate main origins of zircons (from Coney and Evenchick, 1994; Roback and Walker, 1995; Gehrels and Ross, 1998; Ross and Villeneuve, 2003; Ross et al., 2005; Link et al., 2007). Note change in horizontal scale in plots.

Figure 4. Ternary diagrams showing modal framework grain compositions of sandstones. Provenance fields after Dickinson and Suczek (1979). RO—recycled orogen; CB—continental block; MA—magmatic arc. Raw data are in Table DR3 (see footnote 1). Qm—monocrystalline quartz; Qt—total quartz; F—feldspar; L—nonquartzose lithic grains; Lm, Lv, Ls—metamorphic, volcanic, and sedimentary lithic grains.

Timing of thrusting is poorly constrained in hinterland regions, but is
pre–middle Cretaceous in the United States–Canada border region (Price
and Sears, 2000), and perhaps as old as late Middle Jurassic (McMechan
and Thompson, 1993).

The principal argument for a later Cretaceous onset of fore-
land basin development in this region is based on the assumption that
foreland basin sediment is confined to a relatively thick moat of flexural
subsidence directly adjacent to the thrust belt load (Gillespie and Heller,
1995). Ellis Group and Morrison deposits do not thicken westward as
expected for foredeep deposits. However, sediment derived from the
thrust belt can be deposited on top of the flexural forebulge as well as
in the backbulge depozone (e.g., Horton and DeCelles, 1997; Yu and Chou,
2001; Roddaz et al., 2005). We suggest that relatively tabular and thin
Ellis and Morrison deposits in northwestern Montana were deposited in a
backbulge depozone, and that the unconformity and/or condensation zone
that caps them was produced in part by migration of a forebulge through
the region. The model presented here is consistent with previous interpre-
tations to the south that suggest the onset of foreland basin sedimentation
during the Jurassic, and supports synchronous development of a foreland
basin system from as far south as central Utah (Bjerrum and Dorsey, 1995;
DeCelles and Currie, 1996) to southern Canada. This is consistent with
coeval growth of the western Cordillera in response to rapid westward
movement of North America as heralded by Middle Jurassic seafloor
spreading in the North Atlantic (Coney and Evenchick, 1994).