Detrital zircon reference for Cambrian to Triassic miogeoclinal strata of western North America

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ABSTRACT

U-Pb analyses of 656 single zircon grains from Cambrian to Triassic miogeoclinal strata provide a latitudinal and temporal reference for the ages of grains that accumulated along the western margin of North America. Comparisons between this detrital zircon reference and the ages of grains in potentially displaced terranes outboard (west) of the miogeocline should help establish when the terranes first arrived in sedimentary proximity to western North America. North-south variations in the ages of grains in Cambrian and Devonian to Triassic strata, which reflect the north-south changes in the age of cratonal rocks near the margin, should also help place constraints on a terrane's paleolatitude during these time periods. The technique cannot be used to determine paleolatitude during Ordovician time, however, because miogeoclinal strata from northern Canada to northern Mexico are dominated by grains shed from the Peace River arch (northwestern Canada).

INTRODUCTION

It has been known since the late 1960s and early 1970s that much of western North America consists of terranes (or crustal fragments) that may have been displaced considerable distances from their sites of origin (Wilson, 1968; Monger et al., 1972; Burchfiel and Davis, 1972; Berg et al., 1972). Most terranes formed in arc-type and ocean-floor environments outboard (west) of the Cordilleran miogeocline (Fig. 1), which delineates the passive western margin of North America from Late Proterozoic though early Mesozoic time (Stewart, 1972). Accretion of these terranes during Paleozoic and Mesozoic time records an important phase in the growth of the North American continent (Coney et al., 1980).

In spite of many years of study, utilizing techniques such as paleomagnetism, biogeography, lithostratigraphic comparisons, and whole-rock and isotope geochemistry, there is considerable debate about where many of the terranes formed and when they were accreted to western North America. This paper uses detrital zircon ages to help develop an additional technique for determining the displacement and accretionary history of these terranes. The technique involves comparisons of the ages of detrital zircons in the terranes with the ages of zircon grains in strata of the Cordilleran miogeocline. In a simple case, similar ages would record a provenance link between the terrane and the miogeocline at the time of deposition, whereas disparate ages would indicate that the terrane was not yet in sedimentary proximity to western North America. The technique can also be used to determine the paleolatitudinal position of terranes along the Cordilleran margin due to the north-south changes in the age of basement rocks of the North American craton (Hoffman, 1989) (Fig. 1).

An essential step in applying this technique is to establish a western North American reference that can be used for comparison with potentially displaced terranes. We have conducted U-Pb analyses on 656 detrital zircon grains from strata of the Cordilleran miogeocline in an effort to establish this reference. The zircons are from sandstones that range in latitudinal position from eastern Alaska to northern Sonora (Fig. 1) and in age from Cambrian (locally Late Proterozoic) to Triassic (locally Devonian) (Figs. 2 and 3). Each sample consisted of ~20 kg of the coarsest available sandstone, which was collected from a restricted stratigraphic interval at a single locality.

ANALYTICAL TECHNIQUES

The samples were processed by using standard separation and analysis techniques (as described by Gehrels, 1990). Grains from the coarsest available sieve size were grouped into populations according to color, morphology, rounding, and sphericity. Representatives of every population were selected for analysis, irrespective of their abundance in the total collection of grains. This strategy was adopted in an effort to maximize the number of different age groups recognized in each sample. The grains were then abraded to 50%–75% of their original size and analyzed as individual grains using conventional isotope dilution-thermal ionization techniques. Total procedural blanks were 2 to 10 pg for Pb and <1 pg for U.

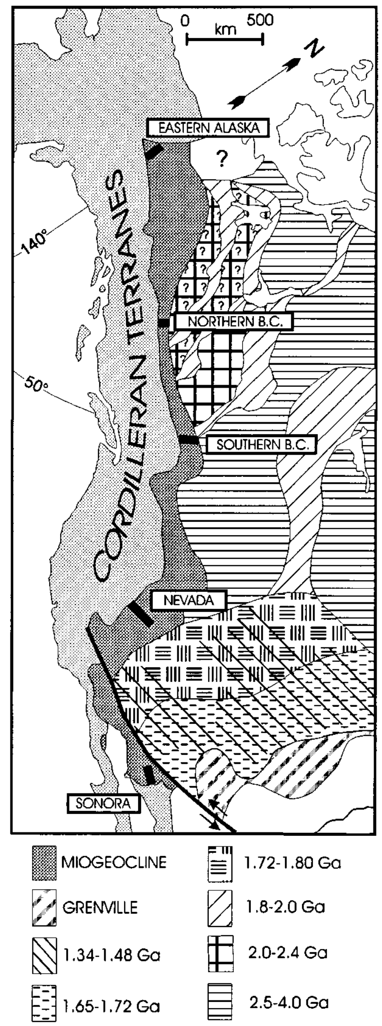

Figure 1. Simplified map showing: (1) distribution of Precambrian basement provinces in western North America (compiled largely from Hoffman, 1989; Ross, 1991), (2) Late Proterozoic to Triassic strata of Cordilleran miogeocline (compiled largely from Stewart, 1972; Stewart et al., 1990), (3) potentially displaced terranes of western North America (from Coney et al., 1980), and (4) locations of our five sampling transects through miogeocline.

Many of the larger (>100 μm) grains analyzed are concordant (at the 95% confidence level) and therefore interpreted to record crystallization ages, whereas most smaller grains yielded slightly to moderately discordant ages. The age interpretation for

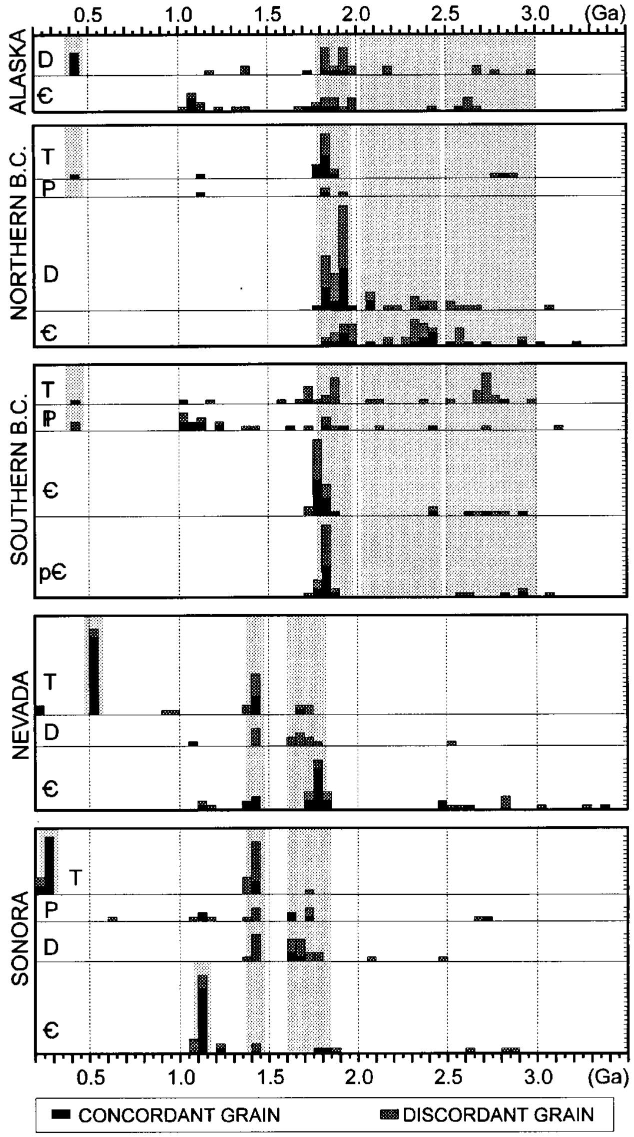

Figure 2. Detrital zircon ages for Cambrian and Devonian to Triassic miogeoclinal strata. Of 521 single-grain ages shown, 206 are analytically concordant and 315 are slightly to moderately discordant. Additional 55 grains were analyzed but are not shown due to their high degree of discordance. Solid boxes indicate ages that are concordant with analyses of high to moderate precision. Shaded boxes are for slightly to moderately discordant grains (i.e., discordant grains with $^{206*}Pb/^{238}U$ ages within 15% of their $^{207*}Pb/^{206*}Pb$ ages). Light shadings indicate ages of grains that are interpreted to have latitudinal significance. Analytical data shown are unpublished, except for most analyses from strata in Nevada (from Gehrels and Dickinson, 1995), seven analyses from Precambrian and Cambrian strata in southern British Columbia (B.C.) (from Smith and Gehrels, 1991), and 29 analyses from Devonian strata in northern British Columbia (from Ross et al., 1993).

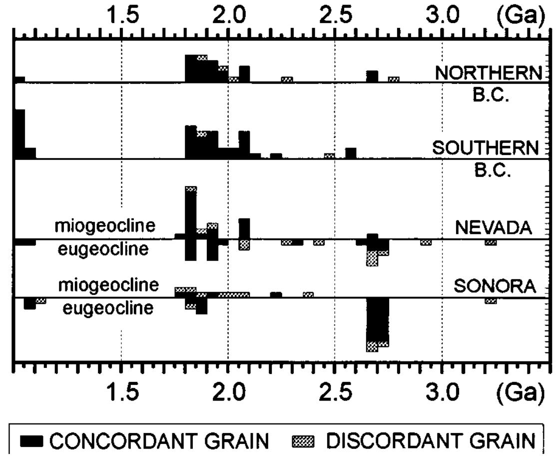

Figure 3. Detrital zircon ages for Middle Ordovician miogeoclinal and eugeoclinal strata. Of 158 analyses shown, 119 are concordant and of high to moderate precision (solid boxes), and 39 are slightly to moderately discordant (i.e., $^{206*}Pb/^{238}U$ ages within 15% of their $^{207*}Pb/^{206*}Pb$ ages) (shaded boxes). Additional 15 grains are moderately to highly discordant and are not shown. Analyses of eugeoclinal strata in Nevada are from Smith and Gehrels (1994).

the discordant grains is less certain because the discordance may result from inheritance, Pb loss (or U gain), multiple phases of grain growth, or a combination of these. To minimize the uncertainty in interpreting ages, in Figures 2 and 3 we show only concordant grains (solid boxes) and discordant grains with $^{206*}Pb/^{238}U$ ages that are within 15% of their $^{207*}Pb/^{206*}Pb$ ages (shaded boxes). For the discordant grains, the $^{207*}Pb/^{206*}Pb$ age is used as an estimate of the crystallization age unless several grains from the same sample define an apparent discordia line with a slightly older upper intercept. In the latter case, the upper intercept is used as the crystallization age in constructing Figures 2 and 3. Unless otherwise cited, the ages used in Figures 2 and 3 are unpublished.[1]

[1]Unpublished data are available on request from Gehrels.

RESULTS

Comparison of the ages of grains in various samples (Figs. 2 and 3) with the ages of basement rocks in western North America (Fig. 1) yields the following first-order conclusions.

Detrital Zircon Reference for Cambrian and Devonian to Triassic Strata

Figure 2 shows that there are significant latitudinal differences in the ages of detrital zircons in Cambrian and Devonian to Triassic strata. Some of the important north-south differences are as follows. (1) Grains of ~1.40–1.45 and 1.60–1.80 Ga are common in most strata in Nevada and Sonora, but not farther north; (2) grains of 1.80–1.95 Ga are dominant in most samples from the three northern transects, whereas grains of these ages are rare to the south; (3) grains of 2.05–2.45 Ga and 2.5–3.0 Ga are common in most samples from the three northern transects, but are rare to the south; (4) ~430 Ma grains are present in Devonian and younger strata only in the three northern transects; (5) the Triassic sample in Nevada is dominated by ~520 Ma grains that are not present in Triassic strata to the north or south; (6) the Triassic sample in Sonora is dominated by 250–280 Ma grains that are not found to the north; and (7) the Cambrian sample in Sonora is dominated by ~1.11 Ga grains that are much less common to the north. These differences, which are highlighted with a light shading in Figure 2, provide a reference for comparison with detrital zircon ages in potentially displaced strata outboard of the miogeocline.

This detrital zircon reference has been used in two different types of studies. An example of a specific application is one in which ~520 Ma and ~1.44 Ga grains have been found in both the Triassic miogeoclinal sample in eastern Nevada (Fig. 2) and in Triassic shelf-edge strata of the Golconda terrane (Silberling et al., 1987) in west-central Nevada (Gehrels and Dickinson, 1995). The presence of these distinctive ages in both samples supports Lupe and Silberling's (1985) conclusion that these two units were originally coextensive, and indicates that the Golconda terrane was in proximity to the Nevada segment of the margin during Late Triassic time. The reference has been used in a more general fashion by Bazard et al. (1994), who reported that Devonian strata in the Alexander terrane of southeastern Alaska contain a distinctive suite of 1.5–1.6 Ga detrital zircons: because grains of this age are extremely rare in the Cordilleran miogeocline, they concluded that the Alexander terrane was not in proximity to the Cordilleran margin during Devonian time.

Detrital Zircon Reference for Ordovician Strata

In contrast to older and younger strata, Ordovician sandstones from northwestern Canada to Sonora all yield similar ages of grains: 1.70–1.95, 2.05–2.40, and >2.5 Ga (Fig. 3). The lack of a north-south age variation in these samples prevents discriminating paleolatitudes of terranes along the margin during Ordovician time. The presence of this suite of ages in a potentially displaced terrane would, however, record proximity to the Cordilleran margin during Ordovician time. An example of this is shown in Figure 3 for Ordovician eugeoclinal assemblages in Nevada and Sonora. The similarity of detrital zircon ages in these off-shelf units and in generally coeval miogeoclinal strata suggests that the eugeoclinal strata formed near the Cordilleran margin, but their paleoposition along the margin is unconstrained.

Provenance of the Detrital Zircons

A comparison of the dominant zircon ages in Cambrian and Devonian through Triassic strata (Fig. 2) with the ages of basement rocks near the transects (Fig. 1) suggests that most of the detrital zircons in these samples were derived from cratonal rocks within several hundred kilometres to 1000 km of each sample site. This provenance link indicates that zircons reaching the Cordilleran margin were derived fundamentally from local basement rocks, even though most grains were probably cycled through older strata prior to final deposition. The correspondence between ages in the miogeocline and nearby basement rocks also demonstrates that longshore transport along the continental margin was not significant on a 1000 km scale during Cambrian and Devonian to Triassic time.

The exception to this pattern is the presence of Grenville age (~1.0–1.3 Ga) zircons in strata of the northern transects (Fig. 2), for which few nearby igneous sources have been recognized. These zircons may have been transported to the Cordilleran margin from the Grenville orogen of eastern Laurentia during Middle to Late Proterozoic time (Rainbird et al., 1992), or it is possible that Grenville-age magmatic activity was widespread along and outboard of the Cordilleran margin prior to Late Proterozoic rifting (Ross, 1991; Smith and Gehrels, 1994; Gehrels and Dickinson, 1995). In either case, grains of these ages are sufficiently widespread that they are of little use in reconstructing terrane displacements.

Comparison of the ages of zircons in Ordovician sandstones (Fig. 3) with the ages of grains in older and younger strata (Fig. 2) and with the ages of basement rocks along the Cordilleran margin (Fig. 1) indicates that most grains in Ordovician strata in Nevada and Sonora were not derived from nearby basement rocks. The most likely source of this material is the Peace River arch (Fig. 4), which exposed Early Proterozoic and Late Archean rocks during much of early Paleozoic time (Cook and Bally, 1975). Ketner (1968, 1986) suggested that Ordovician detritus along the margin was derived from the Peace River arch region on the basis of facies and thickness relations and a southward decrease in the size of quartz grains within these ultramature quartzites. Detritus from the Peace River arch was probably dominant along the margin in part because most cratonal rocks to the south were covered by pre-Ordovician platformal strata (Cook and Bally, 1975) and remained below sea level during much of Ordovician time.

The north-to-south transport of these grains was probably accomplished by longshore transport within the miogeocline. Assuming that oceanic circulation was clockwise in the northern paleo-Pacific, this direction of longshore current would be expected for western North America, given the position of the paleoequator shown by Van der Voo (1993). It is inconsistent, however, with the reconstruction of Scotese and Golonka (1992).

Longshore currents were probably not the transport mechanism for detritus in off-shelf (eugeoclinal) sandstones because zircons in these samples are considerably coarser than grains in the generally coeval miogeoclinal strata. Several possibilities exist to explain this difference in grain size. One option is that the off-shelf strata originated farther north along the margin and were tectonically transported southward to their present positions. This alternative is consistent with the late Paleozoic north to south margin-parallel transport of terranes proposed by Speed (1979), Eisbacher (1983), Walker (1988), Stevens et al. (1992), and Wallin (1993). Other possibilities are that the off-shelf grains were transported southward by turbidity current flow in a southward deepening trough or marginal basin, or perhaps by exceptionally strong southward-flowing contour currents.

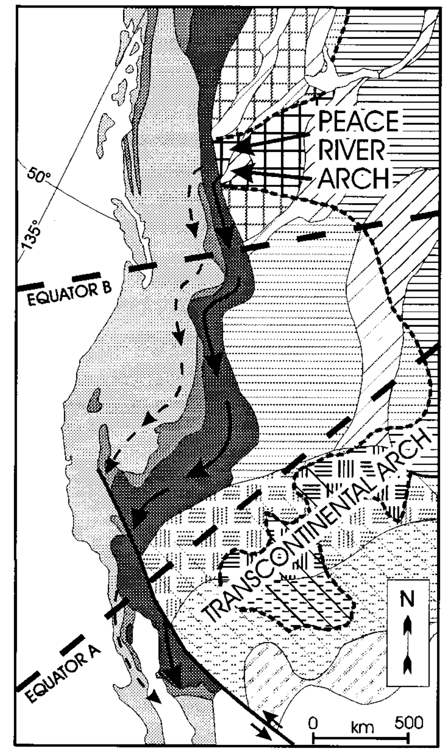

Figure 4. Map showing north to south transport of detrital zircons in miogeoclinal (dark shading) and eugeoclinal (medium shading) Ordovician quartzites. Symbols are as in Figure 1, except that cratonal rocks that were submerged or covered by pre-Ordovician strata (from Cook and Bally, 1975) are shown with shaded rather than solid patterns. Transport in shelf-facies strata was apparently accomplished by longshore currents, whereas coarser detritus in off-shelf units may have been transported southward by flow in southward sloping bathymetric features, exceptionally strong contour currents, or left-lateral transform motion along continental margin. North-to-south longshore transport is consistent with position of Equator A (from Van der Voo, 1993), but not Equator B (from Scotese and Golonka, 1992).

CONCLUSIONS

Single-grain detrital zircon studies have proven to be a valuable tool for determining provenance patterns and tectonic histories in many areas of the world. One of the major difficulties in applying this technique to Cordilleran terranes comes from the incomplete record of sediment dispersal patterns through time on the North American craton and within the miogeocline. Hence, it was not known whether zircons deposited along and outboard of the margin were derived from: (1) nearby basement rocks; (2) widespread cratonal sources; or (3) restricted suites of basement rocks located far from the sites of deposition. Physical characteristics of the detrital grains are generally not helpful in distinguishing between these different options because zircon is so resistant to processes of physical and chemical weathering. This survivability also increases the likelihood that the grains were cycled through older strata prior to their final deposition, thereby increasing the potential complexity of their transport histories.

The data reported herein address these uncertainties and establish the first-order provenance patterns of zircons in Paleozoic and Triassic miogeoclinal strata. Comparisons of Figures 1 and 2 indicate that during Cambrian and Devonian to Triassic time, sediment dispersal and recycling systems in western North America were sufficiently simple that most detrital zircons accumulating along the margin were derived from nearby basement rocks. There is no sign of significant fluvial transport of material from distant inland areas (except for the widespread Grenville-age grains), or of large-scale longshore transport along the margin. In contrast, south-directed longshore transport dominated the dispersal of sediment within the miogeocline during Ordovician time, blanketing the Cordilleran margin with quartz-rich sand derived from the Peace River arch of northwestern Canada (Fig. 4).

This information provides a powerful tool for reconstructing the displacement history of potentially displaced terranes outboard of the Cordilleran miogeocline, particularly when used in conjunction with biogeographic, paleomagnetic, lithostratigraphic, and geochemical arguments. For off-shelf strata of Cambrian and Devonian through Triassic age, the pattern of ages shown in Figure 2 serves as a reference for grains that were accumulating along the western edge of North America. The distinctiveness of these ages provides a tool for determining when terranes first arrived in proximity to western North America, and where along the margin they were located. Paleolatitude cannot be determined for Ordovician time, however, because there is no discernible north-south variation in the ages of grains in Ordovician miogeoclinal strata (Fig. 3).

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