The Mahogany Peaks Fault, a Late Cretaceous-Paleocene(?) Normal Fault in the Hinterland of the Sevier Orogen[1]

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ABSTRACT

The contact separating Ordovician rocks from the underlying lower part of the Raft River Mountains sequence, northwestern Utah, is reinterpreted as a large-displacement low-angle normal fault, the Mahogany Peaks fault, that excised 4–5 km of structural section. High $\delta^{13}C$ values identified in marble in the lower part of the Raft River Mountains sequence suggest a Proterozoic, rather than Cambrian age. Metamorphic conditions of hanging wall Ordovician and footwall Proterozoic strata are upper greenschist and middle amphibolite facies, respectively, and quantitative geothermometry indicates a temperature discontinuity of about 100°C. A discordance in muscovite $^{40}Ar/^{39}Ar$ cooling ages between hanging wall and footwall strata in eastern exposures, and the lack of a corresponding cooling age discordance in western exposures, suggest a component of west dip for the fault. The juxtaposition of younger over older and colder over hotter rocks, the muscovite cooling age discordance with older over younger, and top-to-the-west shearing down-structure are consistent with an extensional origin. The age of faulting is bracketed between 90 and 47 Ma, and may be synchronous with footwall cooling at about 60–70 Ma. Recognition of the Mahogany Peaks fault, its extensional origin, and its probable latest Cretaceous to Paleocene age provides further evidence that episodes of extension at mid-crustal levels in the hinterland of the Sevier orogenic belt were synchronous with protracted shortening in the foreland fold and thrust belt, and that the Sevier orogen acted as a dynamic orogenic wedge.

Introduction

Mid-crustal levels of the Mesozoic to early Cenozoic Sevier orogenic belt are exposed within the footwalls of some Cenozoic detachment faults in the Cordilleran metamorphic core complexes of the western United States (Crittenden et al. 1980; Armstrong 1982). The exposures record substantial crustal thickening that caused middle to upper amphibolite facies Barrovian metamorphism (Hodges et al. 1992; Hoisch and Simpson 1993; Wells et al. 1997*a*). Cenozoic extension played a major role in the exhumation of these midcrustal rocks. Increasing evidence suggests that Mesozoic extension was also important (Wells et al. 1990; Hodges and Walker 1992), but the magnitude and regional extent remains to be determined. Exposures in a metamorphic core complex in the Raft River, Albion, and Grouse Creek Mountains of northwestern Utah and southeastern Idaho (figure 1) provide an excellent opportunity to evaluate the importance of extensional exhumation during contractional orogenesis.

Despite extensive study of the structure and stratigraphy of the Raft River, Albion, and Grouse Creek Mountains (e.g., Armstrong 1968; Compton et al. 1977; Miller 1980; Todd 1980; Miller et al. 1983; Wells et al. 1990; Wells 1997), key strata remain undated, making the location and significance of some low-angle faults in this core complex conjectural (Compton and Todd 1979; Crittenden 1979). Particularly important is the nature of the contact separating Ordovician rocks from underlying rocks, termed the lower part of the Raft River Mountains sequence by Miller (1983) (hereafter referred to as the lower Raft River sequence) (figure 2). The lower Raft River sequence comprises mainly quartzite and schist, which contain no fossils and generally are strongly deformed and metamorphosed. The rocks have been correlated with strata ranging in age from Cambrian to Paleoproterozoic (figure 2), and no consensus exists regarding

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either their age or whether the overlying contact with Ordovician rocks is depositional or a fault (cf. Compton and Todd 1979; Crittenden 1979; Miller 1983). In this paper, we present carbon isotopic data, metamorphic petrology, $^{40}Ar/^{39}Ar$ thermochronology, and structural data suggesting that the contact is a large-displacement low-angle normal fault that excised 4–5 km of structural section.

Tectonostratigraphy of the Raft River Mountains

A tectonically thinned sequence of metasedimentary strata of Proterozoic to Triassic age overlies Archean basement over an area greater than 4000 km^2 in the Raft River, Albion, and Grouse Creek Mountains (figure 1) (Armstrong 1968; Compton et al. 1977; Wells 1997). The Green Creek complex (Armstrong and Hills 1967; Armstrong 1968) is composed of ~2.5 Ga gneissic adamellite that intrudes schist, amphibolite, and trondhjemite (Compton 1972, 1975; Compton et al. 1977). The Elba Quartzite unconformably overlies the Green Creek complex and forms the basal unit of a sequence of alternating quartzite and psammatic, pelitic, and amphibolitic schists of the lower Raft River sequence. Armstrong (1968), Compton (1972, 1975), Compton et al. (1977) and Compton and Todd (1979) assigned a Cambrian age to the schist of Mahogany Peaks and quartzite of Clarks Basin, the uppermost two rock units within this sequence, whereas Crittenden (1979) interpreted them as Paleoproterozoic strata (figure 2). Overlying the lower Raft River sequence along the contact that is the subject of this paper are calcitic and dolomitic marble, phyllite, and quartzite. These rocks have been correlated based on physical stratigraphy and megafossils to several formations of Ordovician miogeoclinal rocks that are common throughout the NE Great Basin (Compton 1972, 1975; Wells 1996). Lower Ordovician conodonts extracted from the Garden City Formation confirm this stratigraphic correlation (Wells et al. 1990).

The contact between the Ordovician Garden City Formation and the schist of Mahogany Peaks is widely exposed throughout the Raft River, Grouse Creek, and Albion Mountains (figure 1). This contact was interpreted to be depositional by Compton (1972, 1975), Compton et al. (1977), and Compton and Todd (1979), which led to the tentative assignment of a Cambrian age to the schist of Mahogany Peaks and quartzite of Clarks Basin (figure 2). Observations that led to the depositional interpretation include: conformity of layering above and below the contact; regional persistence of the <50 m thick schist of Mahogany Peaks below the contact (except where all units are dramatically thinned); local gradation upward from schist to interlayered schist and marble to marble; and absence of fragments of other rocks along the contact. However, Crittenden (1979) suggested that the quartzite of Clarks Basin and schist of Mahogany Peaks would be stratigraphically anomalous if Cambrian, and alternatively proposed that the lower Raft River sequence consisted of Paleoproterozoic strata, noting lithologic similarities to the Paleoproterozoic Facer Formation in the northern Wasatch Mountains (Crittenden 1979; Crittenden and Sorensen 1980; Miller 1983) (figure 2). Crittenden (1979) proposed that this contact was a fault that omitted 4500 to 7600 m of Neoproterozoic and Lower Cambrian clastic strata, and 1400 to 2000 m of Middle and Upper Cambrian carbonate rocks.

Carbon Isotope Stratigraphy and Stratigraphic Correlation of the Lower Raft River Sequence

The use of carbon isotopes in carbonate rocks for stratigraphic correlation is well established (e.g., Veizer and Hoefs 1976; Kaufman and Knoll 1995). Abundant data from Phanerozoic carbonate rocks worldwide reveal limited variation of $\delta^{13}C$ through time ($\delta^{13}C = 0‰ \pm 2$) (Veizer and Hoefs 1976; Veizer et al. 1980), with the exception of multiple positive $\delta^{13}C$ excursions of up to +4.5‰ in the Cambrian (e.g., Brasier et al. 1994; Saltzman et al. 1998). Studies of Neoproterozoic sequences show a much wider range of carbonate $\delta^{13}C$, to values in excess of +10‰ (e.g., Derry et al. 1992; Kaufman and Knoll 1995) and have been used to establish stratigraphic correlation of Neoproterozoic sequences worldwide. The limited data from Mesoproterozoic sequences reveal low $\delta^{13}C$ values and limited secular variation (cf. Mora and Valley 1991; Des Marais et al. 1992). A growing database from Paleoproterozoic rocks suggests generally low $\delta^{13}C$ values with limited secular variation (0‰ ± 2; Veizer et al. 1992*a,* 1992*b*), however a major positive excursion to values in excess of +10‰ between ~2.22 and 2.06 Ga has recently been documented (Baker and Fallick 1989; Karhu 1993; Karhu and Holland 1996).

Relatively pure calcitic marbles (>90% calcite) are likely to preserve their primary, or at least premetamorphic $\delta^{13}C$ signature through upper amphibolite facies metamorphism (Wickham and Peters 1993; see also Baker and Fallick 1989). This provides a powerful tool to correlate metamorphosed sequences with their unmetamorphosed equivalents (e.g., Wickham and Peters 1993).

We analyzed two samples each from two distinct

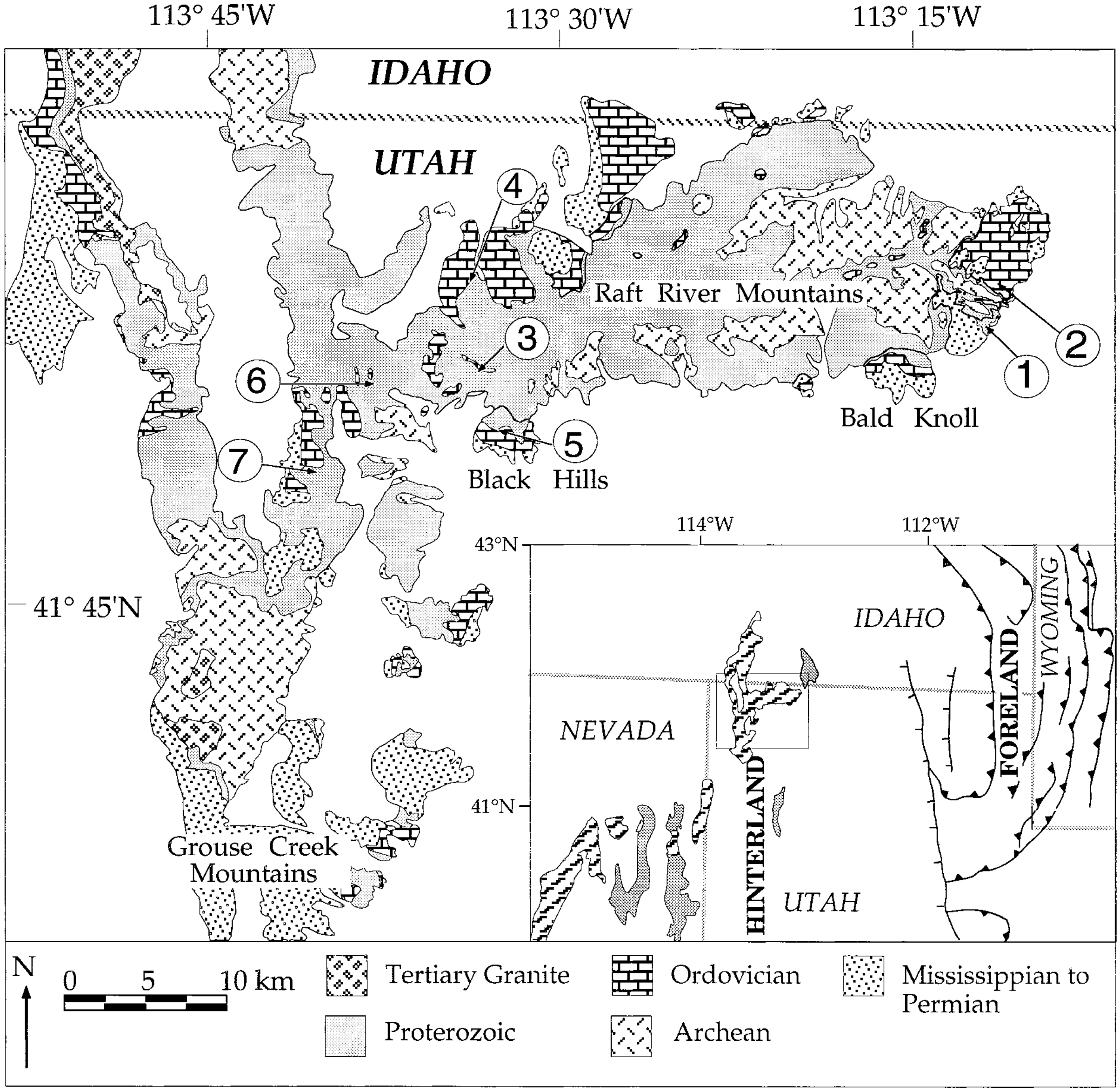

Figure 1. Simplified geologic and sample location map of the Raft River and Grouse Creek Mountains. Numbers indicate sample locations for calcite-dolomite and garnet-biotite thermometry, mineral assemblage, and $\delta^{13}C$ and $^{40}Ar/^{39}Ar$ analyses. Modified from Compton (1975), Compton et al. (1977), Todd (1980), and Wells (1996, 1997). Inset, generalized location and tectonic map of the northeastern Great Basin illustrating location of hinterland metamorphic rocks (shown in diagonal wavy pattern). Barbed lines are thrusts of the Sevier orogenic belt, hachured lines are normal faults of the Wasatch fault system.

one-meter-thick marble layers (>93% calcite) in the quartzite of Clarks Basin from the eastern Raft River Mountains (figure 1, location 1). These are the only two known calcitic marble layers within the lower Raft River sequence, and although the data set is not extensive, we interpret the analyses as representative for this stratigraphic interval. The marbles exhibit high $\delta^{13}C$ values (+6.4, +6.6‰ and +7.6, +7.5‰; table 1, which, with tables 2 and 3, are available from *The Journal of Geology's* Data Depository free of charge upon request), which following Wickham and Peters (1993), we interpret to represent primary $\delta^{13}C$ values. As a check that these $\delta^{13}C$ values were not greatly disturbed during metamorphism and therefore record the primary depositional $\delta^{13}C$ values, we analyzed upper greenschist facies Ordovician and Pennsylvanian marbles (location 2, figure 1), which yielded expected values for Ordovician and Pennsylvanian carbonate rocks (−1.0‰ and −0.6‰, table 1).

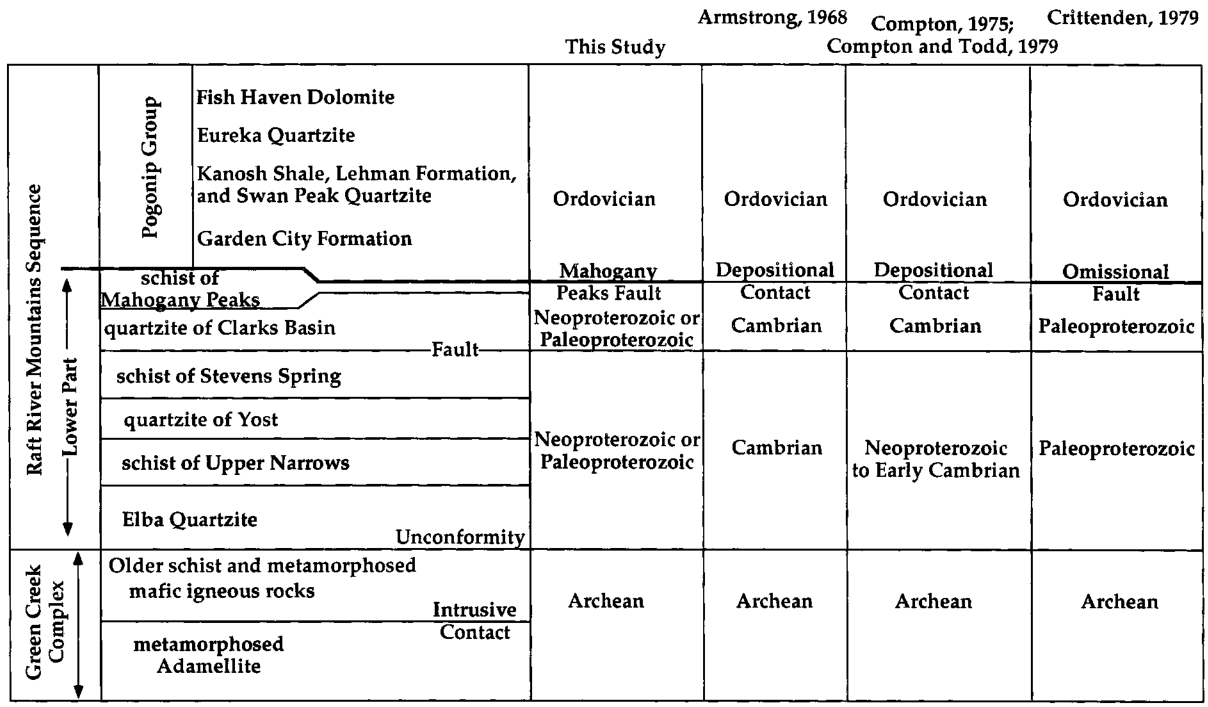

Figure 2. Tectonostratigraphic column for Archean to Ordovician rocks in the Raft River, Grouse Creek, and Albion Mountains. Age assignments of this and previous studies are indicated in right hand columns, as are interpretations of the Garden City Formation-lower Raft River sequence contact. Thicknesses are not to scale nor representative, due to large variations.

The high $\delta^{13}C$ values seen in marbles within the quartzite of Clarks Basin are not observed in Cambrian carbonate rocks in the western United States or worldwide, and thus suggest a correlation with either Neoproterozoic or Paleoproterozoic rock sequences. Analyses of two samples of the pale gray massive limestone unit of the Paleoproterozoic Facer Formation (Crittenden and Sorensen 1980) revealed $\delta^{13}C$ values (−0.1‰ and +0.7‰, table 1) that resemble those believed to be typical of most Paleoproterozoic carbonate rocks (Veizer et al. 1992*a*, 1992*b*) and suggest that the lower Raft River sequence does not correlate with the Facer Formation, as suggested by Crittenden (1979). However, high $\delta^{13}C$ values are present in the Paleoproterozoic Snowy Pass Supergroup of Wyoming (Bekker and Karhu 1996), and thus we cannot preclude a correlation with other Paleoproterozoic sequences in western North America. The high $\delta^{13}C$ values of marbles in the Clarks Basin quartzite resemble those measured in Neoproterozoic sequences worldwide (figure 3 and table 1). In the western Cordillera, high $\delta^{13}C$ values have been measured in the McCoy Creek Group of Nevada and Utah (Wickham and Peters 1993), the Brigham Group of Idaho (Smith et al. 1994), and the Windermere Supergroup and equivalents in Canada (Kaufman et al. 1992; Narbonne et al. 1994). The data are, therefore, consistent with either a Neoproterozoic or Paleoproterozoic age for the quartzite of Clarks Basin.

Metamorphism

Ordovician Marble. Three samples of Ordovician marble from the western Raft River Mountains were analyzed for calcite-dolomite thermometry (sample locations 3 and 4, figure 1) by analyzing many domains within a sample, where each domain consists of one or more calcite grains that surround a single dolomite grain. Each calcite grain was analyzed with one or more points to evaluate possible zoning (no zoning was found in any calcite grain). For each sample, temperatures were calculated for the individual domains using the Ca-Fe-Mg calibration of Anovitz and Essene (1987), then averaged. The three samples yielded very consistent temperatures of 473–503°C (standard deviations 11°–19°C; figure 3). The results are consistent with conodont color-alteration indices (CAI) >7 from the eastern Raft River Mountains (sample station 2, figure 1; Wells et al. 1990).

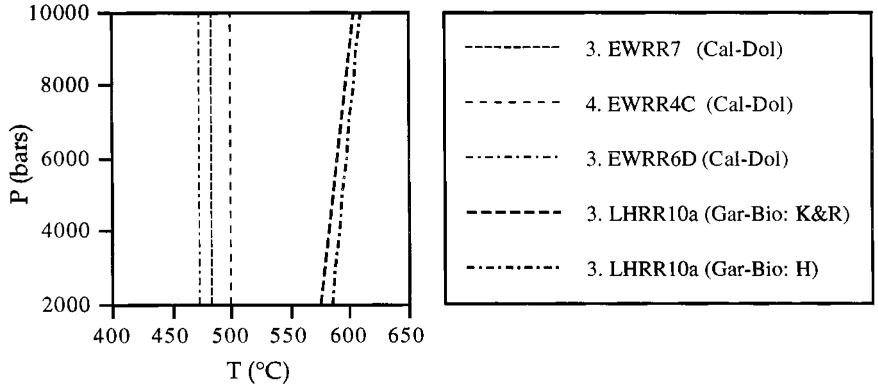

Figure 3. Calcite-dolomite (Cal-Dol) geothermometry (Anovitz and Essene 1987, their Fe-Mg-Ca calibration) of Ordovician carbonates from the Mahogany Peaks fault hanging wall (sample loc. 3 and 4, figure 1) and garnet-biotite (Gar-Bio) geothermometry (K&R: Kleeman and Reinhardt 1994; H: Holdaway et al. 1997) from the Mahogany Peaks schist footwall (sample loc. 3). Garnet-biotite thermometry calculations used data from table 3; for applying the calibration of Holdaway et al. (1997), 11.6% of the Fe in biotite was assumed to be Fe^{3+}, as they recommended. At location 3, Ordovician marble is from 10 m structurally above and Proterozoic schist from 20 m below contact.

Schist of Mahogany Peaks. Mineral assemblages within the schist of Mahogany Peaks (locations 1, 3 to 7, figure 1), include garnet + staurolite + muscovite + biotite + plagioclase + quartz ± kyanite ± plagioclase ± paragonite ± graphite and indicate peak metamorphic conditions in the amphibolite facies (table 2). The assemblages plot on single AKNa and AFM topologies (figure 4), suggesting that an approximately similar grade of metamorphism is recorded in all sampled locations, and that different mineral assemblages may be explained by variable bulk compositions. The pressure-temperature stability field consistent with these mineral assemblages requires temperatures >615°C and pressures >6.2 kb (figure 5). Garnet-biotite geothermometry on sample LHRR10a (table 3), which contains euhedral garnets, little alteration, and only very minor post-peak metamorphic ductile deformation, yielded temperatures of 600°C (using Holdaway et al. 1997) and 582°C (using Kleeman and Reinhardt 1994) at 7 kb of pressure (figure 3).

The reactions shown in figure 5 limit the stability field of the mineral assemblages and assume that a pure water fluid is in equilibrium. However, when graphite is present, as in LHRR10a, the dehydration reactions are displaced to lower temperatures because of the speciation of appreciable CO_2 and CH_4 in the fluid (e.g., Holloway 1984). This is consistent with the garnet-biotite temperatures obtained from LHRR10a which are 15–30° lower than the low-temperature limit of the stability field shown in figure 5. The analyzed garnet in LHRR10a preserves growth zoning (Hanson 1997). Because volume diffusion homogenizes garnets above 600°C at a rate which increases exponentially with

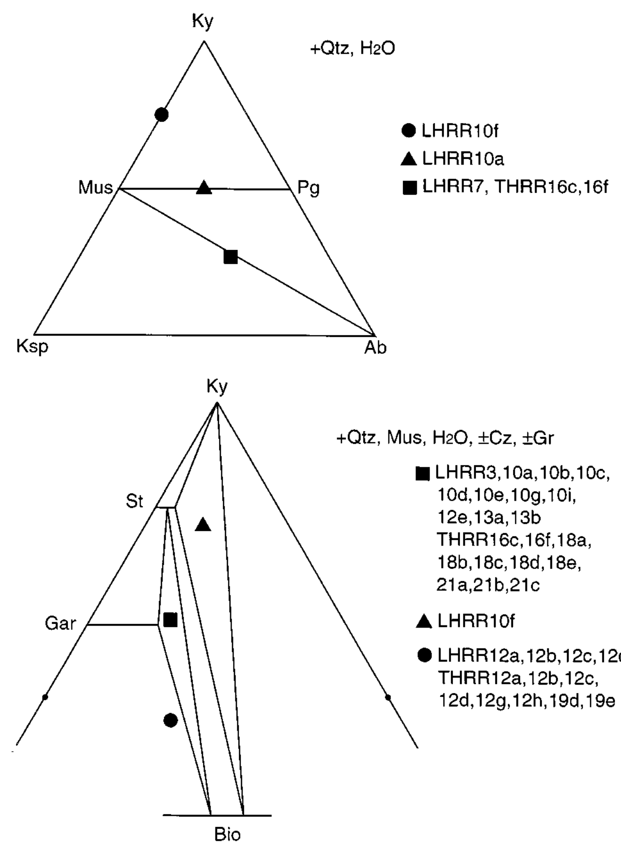

Figure 4. AKNa (upper diagram) and AFM (lower diagram) topologies for the schist of Mahogany Peaks. Samples containing primary mineral assemblages that correspond to individual fields on the diagrams are listed to the right. The diagrams demonstrate that samples from different locations are of approximately similar metamorphic grade.

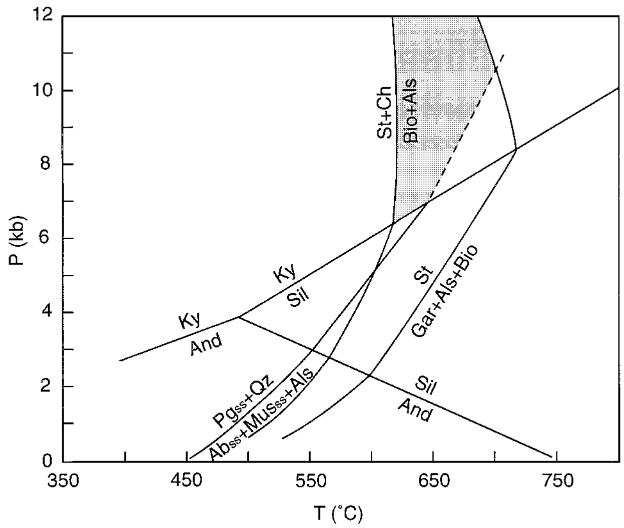

Figure 5. Limits on the stability of the mineral assemblage for sample LHRR10a (shaded area). The terminal reaction of paragonite in the quartz-bearing KNASH system is from Chatterjee and Flux (1986), with adjustment for a slightly different Ky-Sil curve. The subscript "ss" denotes solid solution rather than end members, to show that the reaction is the terminal reaction rather than the endmember reaction. The dashed portion of the curve extends beyond their published curve but maintains the given slope. All other reactions are for the KFMASH system as given by Spear and Cheney (1989). All abbreviations are given in table 2, except for "Als," which denotes the stable Al_2SiO_5 polymorph.

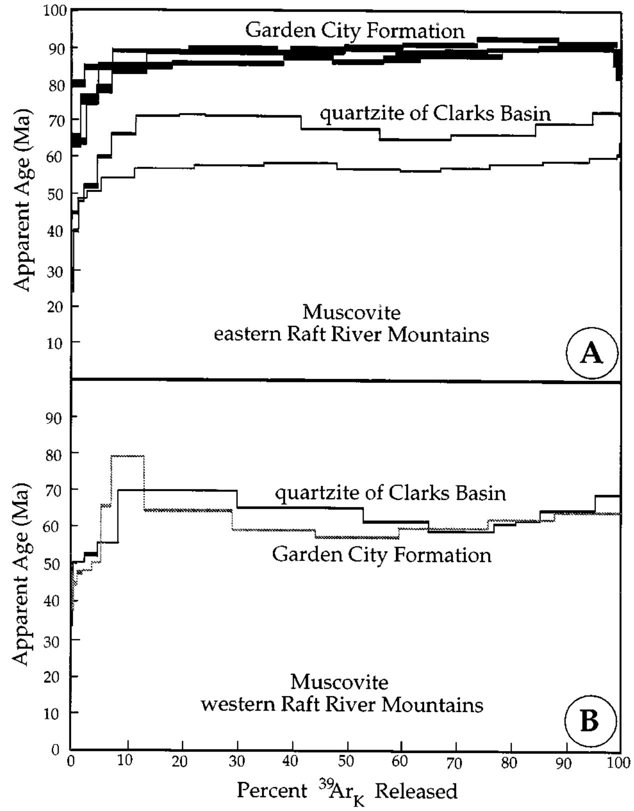

Figure 6. $^{40}Ar/^{39}Ar$ age spectra for muscovite from the quartzite of Clarks Basin and Garden City Formation. A, eastern Raft River Mountains (location 1 and 2, figure 1). Ordovician marble samples from structural positions about 85 m and greater above contact, and show no systematic age progression with structural level. Proterozoic schist and quartzite samples are from about 75 and 125 m below contact, respectively. B, western Raft River Mountains (Black Hills, location 5, figure 1). Ordovician and Proterozoic samples from about 50 m above and below contact.

increasing temperature (e.g., Spear 1989), the sample probably did not attain temperatures much above 600°C.

$^{40}Ar/^{39}Ar$ Muscovite Cooling Ages

Three muscovite separates from marble and schist of the Ordovician Garden City Formation in the eastern Raft River Mountains (location 2, figure 1) previously yielded $^{40}Ar/^{39}$ Ar plateau ages ranging from 82 to 90 Ma (Wells et al. 1990, figure 6). Two new analyses of muscovite from quartzite and muscovite-quartz schist from the quartzite of Clarks Basin in the eastern Raft River Mountains (location 1, figure 1) yield discordant age spectra with total gas ages of 67 and 57 Ma (figure 6). Despite the difference between the latter two ages, both are significantly younger than cooling ages from Ordovician rocks. In contrast, muscovite separates from the Garden City Formation and quartzite of Clarks Basin from the western Raft River Mountains (Black Hills, location 5, figure 1) yield internally discordant age spectra with similar total gas ages of about 63 and 61 Ma, respectively (figure 6).

Kinematics

The lack of a recognized high strain zone adjacent to the contact separating the Garden City Formation from the lower Raft River sequence led earlier workers to suggest that if the contact was a fault, it was pre-metamorphic (Crittenden 1979; Miller 1983). A prograde Mesozoic foliation (S_1) present throughout the stratigraphic sequence generally parallels the contact, making subsequent localized high strain adjacent to the contact difficult to distinguish. In addition, in the western Raft River, Grouse Creek, and Albion Mountains, the contact is overprinted by large-magnitude top-to-the-WNW ductile extensional shearing of late Eocene and early Miocene age and locally thermally metamorphosed in the contact aureoles of Oligocene plutons (Compton et al. 1977; Forrest and Miller 1994; Wells et al. 1997*b*). In contrast, in the eastern Raft River Mountains the contact lies in the hanging wall of the Miocene top-to-the-E Raft River detachment fault and shear zone and was probably not overprinted by either Eocene or Miocene top-to-the-WNW extensional shearing (Wells 1997).

The quartzite of Clarks Basin and schist of Mahogany Peaks in the eastern Raft River Mountains display a shallowly dipping foliation and generally NE-trending lineation defined by quartz grain-shape elongation and mica preferred orientation, which are more prominent in quartzite than schist. This fabric records top-to-the-NE simple shear and sub-vertical flattening and is part of a generally top-to-the-N shearing fabric present throughout the complex (D_1, Malavieille 1987; Wells 1997). Within the upper levels of the quartzite of Clarks Basin, low-temperature features are superimposed on higher-temperature features. Quartz grains that show evidence of grain boundary migration recrystallization and have lattice-preferred orientations that record a component of top-to-the-NE shearing (D_1, Wells 1997) exhibit quartz deformation lamellae that preferentially dip to the west, to which associated deformation bands are perpendicular and dip to the east. These quartz microstructures suggest minor, lower temperature, top-to-the-W shearing strains that overprint higher-temperature top-to-the-NE shearing. Overprinted on the D_1 fabric in the schist of Mahogany Peaks is a subparallel foliation and associated lineation defined by hingelines of crenulations in schist. This later fabric formed at lower metamorphic grade and records top-to-the-W shearing. Shear-sense indicators in schist include a preferred orientation of pre-shearing staurolite porphyroblasts that are inclined to the east with respect to the matrix foliation, retrograde shear bands, mica "fish," and sigma-shaped asymmetric recrystallized margins of garnet, in which garnet is retrograded to chlorite. Garden City Formation marbles preserve the D_1 fabric, and no fabrics have been noted that are spatially associated with the subjacent Garden City Formation–lower Raft River sequence contact. We propose that the retrograde top-to-the-W shearing fabrics, best exhibited in the schist of Mahogany Peaks, are related to shearing along the Garden City Formation–lower Raft River sequence contact, across which upper greenschist facies rocks are juxtaposed against underlying middle amphibolite facies strata.

Interpretation and Discussion

The combination of metamorphic temperature and cooling age discordances, stratigraphic omission, and deformation fabric support a fault interpretation for the Garden City Formation–lower Raft River sequence contact, termed the Mahogany Peaks fault. Criteria used to distinguish extensional from contractional origins for low-angle faults and shear zones include: juxtaposition of younger rocks over older rocks; discordances in metamorphic grade with lower grade over higher grade; older-over-younger discordances in isotopic cooling ages across faults; strain fields within and adjacent to faults and shear zones in which the pure shear component records shortening perpendicular to the shear plane (Wells and Allmendinger 1990; Wallis et al. 1993), and isothermal decompression P-T paths (Hodges et al. 1992). Although individually these criteria cannot definitively distinguish extension from contraction, several consistent lines of evidence suggest an extensional origin for the Mahogany Peaks fault, as discussed below.

Younger-Over-Older Juxtaposition. Carbon-isotope evidence of a Proterozoic age for the lower Raft River sequence requires stratigraphic omission along the Mahogany Peaks fault (figure 2). The amount of stratigraphic omission is between ~2400 and >9600 m (figure 2), depending on the exact correlation within either Neoproterozoic or Paleoproterozoic rock sequences. The apparent "depositional interlayering" of marble and schist across this contact (Compton and Todd 1979) can alternatively be explained by tectonic interlayering, which has been described along other omissional faults within this core complex (Miller 1978, 1980), and was first suggested as a possibility by Compton (1975, p. 3). Furthermore, none of the observations used by Compton and Todd (1979) to support a depositional origin exclude an origin as a mid-crustal omissional fault.

Metamorphic Break. Peak metamorphic temperatures for Ordovician and Proterozoic rocks separated by the Mahogany Peaks fault are discordant by about 100°C (figure 3). This juxtaposition of colder over hotter rocks suggests a juxtaposition of shallower over deeper, assuming isotherms did not significantly depart from subhorizontal during metamorphism. The absence of Mesozoic plutons in this area suggests that this is a reasonable assumption. For geothermal gradients of 20 to 25°C/km (as indicated by thermobarometry, Hanson 1997), the metamorphic temperature discordance is consistent with the omission of 4–5 km of structural section if the fault post-dated the peak of metamorphism.

Cooling Age Discordance. The muscovite $^{40}Ar/^{39}Ar$ cooling ages in the eastern Raft River Mountains are discordant, with older cooling ages above and younger cooling ages below. This discordance across the fault is consistent with slip on the fault postdating peak metamorphism, and an extensional origin. Older-over-younger discordances in cooling ages occur across many large-displacement low-angle normal faults (e.g., Jones et al. 1990), and are predicted by thermal modeling of normal faulting (Grasemann and Mancktelow 1993).

Shearing Down Inferred Structural Section. The difference in muscovite cooling ages of Ordovician rocks from the east and west ends of the range suggests that the metasedimentary rocks had a component of westward dip prior to faulting. Therefore, the top-to-the-W shearing determined for localities in the eastern Raft River Mountains was in the apparent downdip direction of strata. The metamorphic grade and cooling age discordances indicate that slip on the fault postdated peak metamorphic conditions, as well as muscovite Ar closure in hanging-wall Ordovician rocks in the east. The juxtaposition of younger strata over older and shallower (colder) over deeper (hotter), and shearing in the apparent downdip direction of strata, together indicate a normal fault.

Geometry and Magnitude of Faulting. The Mahogany Peaks fault crops out discontinuously for 70 km in a N-S direction, and for 50 km in an E-W direction (figure 1). The present N-S exposure of this fault gives a minimum original dimension because the only significant N-S strain event (D_1) predates slip. It is difficult to reconstruct the original E-W length because the amount of extension by normal faulting in the hanging wall of the Raft River detachment is indeterminate due to limited preservation of hanging-wall strata. Nonetheless, summing fault trace lengths where they have not been significantly overprinted indicates a minimum E-W dimension of about 20 km. Compton and Todd (1979) discounted the fault interpretation of Crittenden (1979) in part because of the large dimension of the proposed structure, and argued that it was improbable that a fault would have detached exactly and completely in the lower part of the Garden City Formation over an area of thousands of square kilometers, and transported rocks downsection to the stratigraphic level of the schist of Mahogany Peaks, without including slivers of omitted units along its trace. However, this is plausible as shown by other flat-on-flat normal faults of this dimension in this core complex (Wells 1997), and is the geometry that we propose here (figure 7). The regional-scale geometry of the Mahogany Peaks fault and the observation that hanging-wall and footwall stratigraphic levels do not significantly change over large distances suggests that the exposed segment of the Mahogany Peaks fault juxtaposes a footwall flat in the schist of Mahogany Peaks against a hanging-wall flat within Ordovician carbonate rocks (figure 7). The absence of either a footwall or hanging-wall ramp over the large region of exposure indicates >20 km of displacement.

Age of the Mahogany Peaks Fault. The previously established sequence of deformations and new muscovite $^{40}Ar/^{39}Ar$ cooling ages provide some limits on the age of top-to-the-W normal-sense movement along the Mahogany Peaks fault. The fault formed after development of an early prograde bedding-subparallel metamorphic foliation that predates 90 Ma (D_1 of Wells 1997), and before late Eocene (47–37 Ma) top-to-the-WNW extensional shearing (Wells 1997; Wells et al. 1997*b*). Furthermore, we interpret faulting to postdate 90 Ma cooling ages from hanging-wall strata to the east that define the cooling age discordance across the fault (figure 7). Additionally, the fault is deformed by N-trending recumbent folds that predate late Eocene ductile shearing (Compton 1972).

The age of faulting may be recorded in the $^{40}Ar/^{39}Ar$ cooling ages of the footwall, about 60–70 Ma. Alternative explanations in which the cooling ages predate or postdate faulting encounter greater difficulties in explanation. Geothermometry indicates a temperature discordance of 100°C across the fault and probably represents the minimum amount of cooling of Proterozoic footwall rocks during extensional exhumation. With 100°C of cooling during fault movement, the muscovite may have cooled through the closure temperature interval for argon diffusion in muscovite (nominally, 325–400°C, Snee et al. 1988; Hames and Bowring 1994). The principal difficulty with this interpretation is that it also requires cooling of the hanging wall at the down-dip end. However, this cooling need not be large because, according to this interpretation, the closure isotherm for muscovite would have lain between the current updip and down dip exposures of Ordovician rocks prior to faulting (figure 7).

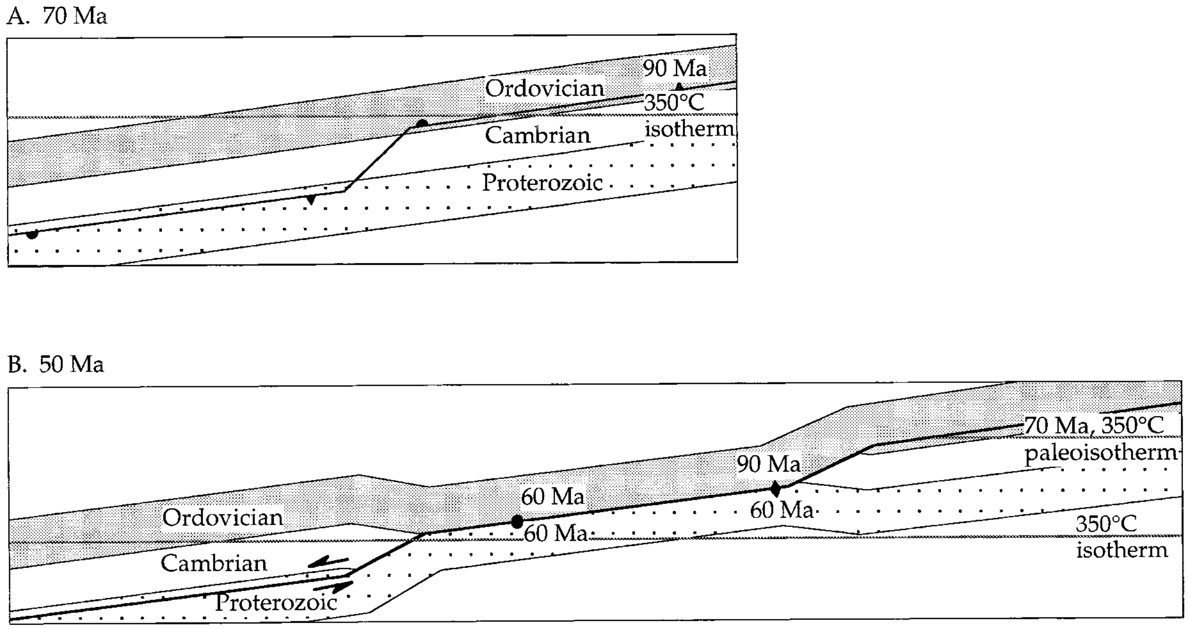

Figure 7. Schematic diagram illustrating the juxtaposition of Ordovician over Proterozoic rocks along the Mahogany Peaks fault, and the development of a cooling age discordance in the eastern Raft River Mountains. Note that the lack of a cooling age discordance in the western Raft River Mountains is best explained by a component of westward dip of strata at the time of faulting. The simplified kinematic model involves deformation of both hanging wall and footwall rocks, thought to best represent the deformation of rocks adjacent to mid-crustal low-angle normal faults. This proposed geometry may be applicable to many "attenuation faults" (Hintze 1978) common in the Sevier orogenic belt hinterland.

Conclusions and Implications

Mesozoic extension in the Sevier orogen has been interpreted within the context of the orogenic wedge model, which predicts dynamic adjustments of topography and crustal thickness in the hinterland of mountain belts during their growth and evolution (e.g., Platt 1986; Dahlen and Suppe 1988; Wells 1997). New data presented here from the lower Raft River sequence and overlying Ordovician rocks are interpreted to indicate that the intervening contact is a Late Cretaceous to early Paleocene(?) normal fault with >20 km of slip that excised 4–5 km of structural section. If correct, normal-sense motion along the Mahogany Peaks fault overlapped in time with thrust faulting in the foreland fold and thrust belt to the east (e.g., DeCelles 1994), supporting the interpretation that the Sevier orogenic belt behaved dynamically as an orogenic wedge. Additionally, the large magnitude of structural omission accommodated by the Mahogany Peaks fault provides further evidence that extension synchronous with contractional orogenesis played an important role in the exhumation of deep crustal levels of the Sevier orogen (Wells et al. 1990; Hodges and Walker 1992).

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