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EVIDENCE FOR MESOZOIC EXTENSION IN THE INTERNAL ZONE

Recent structural, geochronologic, and petrologic studies in the Internal zone have produced evidence of Mesozoic extensional deformation in sixteen localities (Figure 1b). We have reviewed the evidence briefly in Table 1, but the following paragraphs contain more detailed documentation of our arguments for specific localities.

Castle Dome - Orocopia Region, Arizona-California

The Pelona, Orocopia, and Rand Schists of southern California and western Arizona are oceanic rocks, metamorphosed at blueschist to amphibolite facies, that lie structurally below the Mesozoic continental arc (Jacobson et al., 1988). It seems probable that these units correspond to a subduction complex thrust eastward beneath North America in late Mesozoic time (Burchfiel and Davis, 1981). The Orocopia Schist is exposed beneath the Chocolate Mountains "thrust" in a series of fensters in several mountain ranges between the Castle Dome Mountains of Arizona and the Orocopia Mountains of California (Haxel and Dillon, 1978). Although this fault was interpreted as part of the actual subduction contact between the Orocopia Schist and overlying continental rocks by Haxel and Dillon, 1978 and Haxel and Tosdal, 1986, recent studies have shown several of the contacts bounding the Orocopia fensters exhibit evidence of major normal displacement (Haxel et al., 1985; Haxel et al., 1988; Jacobson et al., 1988; Richard and Haxel, 1991). Some of these faults developed during middle Tertiary extension, but others are demonstrably Late Cretaceous to earliest Tertiary in age (Haxel et al., 1985; Jacobson, 1990). One example is the Sortan fault, exposed in the Picacho Hills on the California-Arizona border, which places weakly metamorphosed units on amphibolite facies Orocopia Schist and may have a tectonostratigraphic throw on the order of 10 km (Haxel et al., 1985; Haxel et al., 1988; Jacobson et al., 1988).

Little Maria and Big Maria Mountains, California

The Little Maria Mountains lie at the western end of the Maria fold and thrust belt, an anomalous east-west-trending zone of Mesozoic basement-involved shortening (Reynolds et al., 1986b). Detailed mapping of metamorphosed Precambrian-Mesozoic strata and plutonic rocks in the Little

Maria Mountains (Ballard and Ballard, 1990) revealed evidence of at least two generations of southeast- to southwest-vergent, ductile compressional structures that were subsequently modified by high-temperature extensional deformation. Extensional structures include ductile shear zones and asymmetric folds indicating low-angle, northeast-directed, normal-sense displacement. Geochronologic data (K-Ar hornblende, muscovite, biotite, and K-feldspar) indicate that the extensional event must have occurred prior to 50 Ma ((Ballard and Ballard, 1990), and Ballard, 1990 has interpreted Late Cretaceous-Early Eocene rapid cooling of the Little Maria block as a consequence of tectonic denudation.

Units of the Little Maria Mountains continue eastward into the Big Maria Mountains (Hamilton, 1982; Hamilton, 1984; Hamilton, 1987). In this range, easily recognizable metamorphosed equivalents of Paleozoic cratonal strata were thinned to less than one percent of their original stratigraphic thicknesses (Hamilton, 1982) during high temperature deformation of probable Late Cretaceous age (Hoisch et al., 1988). Although many of the structures in the Big Maria Mountains (e.g., large-scale isoclinal folds) are typical of those found in compressional settings, Hamilton, 1982 suggests that they were produced largely by laminar flow subparallel to lithologic boundaries rather than by compression. Similar structures were produced by Tertiary extension in several of the Cordilleran metamorphic core complexes (e.g., Snoke and Lush, 1984; Hodges et al., 1987). In light of the convincing evidence for Createaceous extensional deformation in the Little Maria Mountains, it seems reasonable to infer that the extreme attenuation of units observed in the Big Maria Mountains was a product of Createaceous extension as well.

Old Woman and Piute Mountains, California

The Old Woman and Piute Mountains consist of Proterozoic - early Mesozoic metamorphic rocks that were intruded by a Cretaceous composite batholith and both unconformably and structurally overlain by middle Tertiary volcanic and sedimentary units (Miller et al., 1982). The area has a long and complex geologic history that included: Jurassic(?) - Early Cretaceous plutonism and thrusting; Late Cretaceous plutonism, metamorphism, recument folding, and thrusting; and mid-Tertiary extensional faulting

(Miller et al., 1982; Howard et al., 1987; Hoisch et al., 1988; Foster et al., 1989; Fletcher and Karlstrom, 1990; Foster et al., 1990; Hileman et al., 1990). Hornblende, muscovite, biotite, and K-feldspar $^{40}Ar/^{39}Ar$ data indicate that pre-Tertiary units in the Old Woman Mountains and parts of the Piute Mountains cooled very rapidly in latest Cretaceous time (Foster et al., 1989; Foster, 1989). In the northwestern Old Woman Mountains, a large, west-dipping ductile shear zone with normal-sense displacement was active during this interval, suggesting that Late Cretaceous cooling was related to extensional unroofing (Carl et al., 1991; Foster et al., 1989; Foster et al., 1990).

Turtle Mountains, California

Pre-Tertiary units in the Turtle Mountains of southeastern California include Proterozoic crystalline rocks and discordant Mesozoic plutons (Howard et al., 1982). Despite geologic similarities between the Turtle Mountains and the nearby Old Woman Mountains, the two ranges experienced very different Mesozoic thermal histories. U-Pb, Rb-Sr, and $^{40}Ar/^{39}Ar$ thermochronologic data from the Turtle Mountains demonstrate that Mesozoic plutonism spanned the Early Cretaceous to Cenomanian interval, and that the central and southern parts of the range had cooled below roughly 500 K by 90 Ma (Allen et al., 1990; Foster et al., 1990). In the west-central Turtle Mountains, an east-dipping mylonitic shear zone shows evidence amphibolite-facies thrust displacement and greenschist-facies reactivation as a normal fault, leading Allen and O'Hara, 1991 to speculate that the normal displacement on this structure as well as general cooling of the range were related to an Early Cretaceous extensional episode.

Rand Mountains, California

In the Rand Mountains, the Rand Schist is exposed in a composite tectonic window through allochthonous gneisses and intrusive rocks. Postlewaite and Jacobson, 1987 described the southwest-dipping shear zone separating the allochthon from the Rand Schist in the southwestern Rand Mountains as a normal fault juxtaposing middle-crustal and deep-crustal units. This structure must have developed after 87 ± 1 Ma, the U-Pb zircon crystallization age of a monzogranite in the allochthon that is cut by the shear zone (Silver and Nourse, 1986). Although the minimum age of normal faulting is not constrained well (Postlewaite and Jacobson, 1987), nearly concordant

$^{40}Ar/^{39}Ar$ cooling ages for hornblende and muscovite from the footwall suggest that the Rand Schist cooled quickly over the 75-70 Ma interval and imply that structural unroofing related to normal faulting occurred in Late Cretaceous time (Jacobson, 1990).

Panamint Mountains, California

Greenschist to amphibolite facies metamorphic rocks and granitic intrusive rocks in the footwall of the Panamint Mountains metamorphic core complex were unroofed as a consequence of diachronous movement on three families of normal faults. The oldest major normal fault in the area is the Harrisburg detachment, which places greenschist facies, upper Proterozoic strata on older, greenschist to amphibolite facies rocks and the Cretaceous Skidoo monzogranite ((Hodges et al., 1990). Hodges et al., 1987 described ductile fabrics related to the Harrisburg detachment that are indicative of displacement of the hanging wall to the NNW relative to the footwall. Because the detachment truncates the Skidoo monzogranite, this movement must be younger than the pluton, which has yielded a Rb-Sr whole-rock "errorchron" age of 101 ± 8 Ma (Hodges et al., 1990). An upper age constraint follows from the observation that the Harrisburg fault was intruded by the Miocene Little Chief Stock (Rb-Sr mineral isochron: 10.8 ± 0.6 Ma - Hodges et al., 1990; 40Ar/39Ar biotite plateau and orthoclase isochron: 11.2 ± 0.4 Ma and 11.1 ± 0.1 Ma, respectively - McKenna et al., submitted).

Several geologists working in the Death Valley area, including us (e.g., Hodges et al., 1987), have assumed that the Harrisburg detachment developed in the Miocene Epoch, but some of the geologic observations in the Panamint Mountains are more easily explained by a Cretaceous age for the fault. Principal among these are $^{40}Ar/^{39}Ar$ data suggesting that the Harrisburg footwall in the central Panamint Mountains had cooled below Ar retention temperatures in muscovite and biotite (nominally, 690 K and 580 K, respectively: Hodges, 1991) by Late Cretaceous to Eocene time (Labotka et al., 1985; McKenna et al., submitted). Textural relationships clearly demonstrate that mylonitic fabrics related to the Harrisburg detachment in the northern Panamint Mountains were developed at greenschist facies conditions (Hodges et al., 1987), at or above the Ar closure temperature for biotite. Either the cooling histories of the northern and central Panamint Mountains were quite different (a possibility that is unsupported by existing geological data), or the Harrisburg detachment began moving in Late Cretaceous or early Tertiary time.

Funeral Mountains, California

The Funeral Mountains of SE California consist of a metamorphic core overlain structurally by upper Proterozoic to Tertiary sedimentary and volcanic units (Troxel, 1988). The contact between these structural packages is marked by a diachronous system of extensional structures: the Boundary Canyon detachment on the north and northwest, and the younger, predominantly dextral Keane Wonder fault on the west (Troxel and Wright, 1989). Geochronologic and stratigraphic constraints indicate that both structures developed in the last 10 Ma (Reynolds et al., 1986a; Holm and Dokka, 1991).

The metamorphic core of the range includes: 1) amphibolitic, granitic, and pelitic gneisses of Early Proterozoic(?) age; 2) metasedimentary rocks of Late Proterozoic - Cambrian age; and 3) muscovite-bearing granitoid rocks of Cretaceous age (Troxel, 1988; DeWitt et al., 1988). Pre-Cretaceous units contain mineral assemblages indicative of upper greenschist to upper amphibolite facies metamorphism (Labotka, 1980; Hoisch and Simpson, 1989). Hodges and Walker, 1990 reported the results of a study of pelitic schist samples from the highest grade part of the area using conventional thermobarometry and Gibbs' Method modeling (Spear and Selverstone, 1983) of garnet inclusion suites. Samples from a single structural level were subjected to peak metamorphic conditions of at least 800-850 K and 800-1000 MPa (30-37 km paleodepths). During the late stages of metamorphism, these rocks experienced roughly 400-600 MPa (15-22 km) of decompression with no substantial change in temperature. Given the position of the Funeral Mountains within the highly extended Death Valley region (Wernicke et al., 1988), we might reasonably expect that this near-isothermal decompression of the metamorphic core rocks was caused by Neogene tectonic denudation. However, two lines of evidence imply that it was produced by Late Cretaceous extension instead.

First, $^{40}Ar/^{39}Ar$ muscovite ages obtained by DeWitt et al., 1988 for metamorphic core rocks at this structural level range from 110 Ma to 55 Ma.

Because the entire PT path reconstructed by Hodges and Walker, 1990 lies at temperatures in excess of the Ar closure temperature of muscovite, the absence of post-Early Eocene muscovite ages in the Funeral Mountains strongly suggests that the metamorphic core had undergone extreme tectonic denudation prior to Neogene extension in the Death Valley region.

The second line of evidence for Cretaceous extension involves geochronologic constraints on the timing of ductile structures in the Funeral Mountains. Troxel and Wright, 1989 mapped several large low-angle ductile shear zones in the metamorphic core that omit stratigraphic section or place lower grade metamorphic rocks on higher grade rocks. Mesoscopic and microscopic fabrics associated with these structures are consistent with normal-sense movement (Hoisch and Simpson, 1989; J.D. Applegate, work in progress, 1991). The age of these structures is bracketed by a 74 Ma U-Pb zircon date for a deformed monzogranite body and a 70 Ma U-Pb zircon date for an undeformed granitic pegmatite that cuts the extensional fabric (Applegate et al., submitted). We can therefore assign a significant portion (roughly half) of the unroofing of the metamorphic core and the majority of ductile extensional structures in the core to a Late Cretaceous event.

Ruby Mountains and East Humboldt Range, Nevada

The metamorphic core complex of the Ruby Mountains and East Humboldt Range, northeastern Nevada, experienced amphibolite facies regional metamorphism in three distinct pulses of Late Jurassic, Cretaceous, and Oligo-Miocene ages (Snoke et al., 1979; Dallmeyer et al., 1986; Dokka et al., 1986; Wright and Snoke, 1986; Hudec and Wright, 1990). The latest of these accompanied development of the Ruby-East Humboldt mylonitic shear zone, a major west-dipping extensional structure that dominates the western half of the core complex (Snoke et al., 1990). Thermobarometric data from the central East Humboldt Range indicate that movement on this structure excised 11-12 km of crustal section in mid-Tertiary time (Hurlow et al., 1991). In the northeastern East Humboldt Range, outside of the Ruby-East Humboldt mylonitic shear zone, rim thermobarometry and Gibbs' Method modeling (Hodges et al., in press) suggest that at least some portions of the core complex were buried to depths in excess of 35 km in Jurassic(?) or Early

Cretaceous time, and then stripped of as much as 20 km of overburden prior to middle Cretaceous cooling below the roughly 780 K closure temperature for Ar diffusion in hornblende (Hodges, 1991). The topology of PT paths associated with this unroofing led Hodges et al., in press to infer that decompression occurred during a previously unrecognized extensional event.

Pilot Range Area, Nevada-Utah

The Pilot Range contain exposures of greenschist to amphibolite facies, upper Proterozoic - Ordovician rocks that structurally underlie weakly metamorphosed Upper Cambrian - Upper Permian miogeoclinal strata (Snoke and Miller, 1988). The low-angle structure separating metamorphosed and unmetamorphosed rocks - the Pilot Peak décollement - has been interpreted as a normal fault, and several generations of low-angle faults and shear zones attenuate units in the hanging wall and footwall of the detachment (Miller and Lush, 1981; Snoke and Miller, 1988). The ages of these structures are constrained by geochronologic data for the Pilot Range obtained by Miller et al., 1987. A synmetamorphic muscovite-biotite granite that intrudes several fault blocks bound by low-angle shear zones yielded U-

Pb zircon data indicative of a crystallization age in the range of 165-155 Ma. Metamorphic hornblende from a Cambrian schist sample has a $^{40}Ar/^{39}Ar$ plateau age of 149 ± 2 Ma. Together with the observation that the earliest structures of probable extensional origin were syn-metamorphic, these data imply that some extension in the Pilot Range area is at least as old as Late Jurassic (Miller et al., 1987). However, the most significant extension in the Pilot Range area, including development of the Pilot Range décollement, was late- to post-metamorphic.. The Pilot Range décollement is cut by granitic dikes that are probably related to a granodiorite pluton dated at 39 Ma (U-Pb zircon: Miller et al., 1987), but the maximum age of the structure is only constrained to be younger than Jurassic. Conventional K-Ar ages for biotite and muscovite from the footwall reveal that the metamorphic core of the range cooled through the ~ 690-580 K interval in Late Cretaceous - Early Paleocene time, prompting Snoke and Miller, 1988 to suggest that unroofing of the core by movement on the Pilot Range décollement might have occurred in Late Cretaceous time.

Toano Range, Nevada

The Toano Range has geologic characteristics similar to those of the adjacent Pilot Range, and Snoke and Miller, 1988 have suggested that the low-angle detachment separating the unmetamorphosed suprastructure and metamorphic infrastructure of the Toano Range is part of the Pilot Range décollement. Field relationships indicate that greenschist to amphibolite facies metamorphism in the core predated intrusion of a Late Jurassic granodiorite pluton (Glick, 1987; Miller et al., 1990). However, K-Ar and $^{40}Ar/^{39}Ar$ muscovite and biotite ages from metasedimentary rocks and a two-mica monzogranite are Late Cretaceous to Paleocene (Lee et al., 1980; Lee and Marvin, 1981; Miller et al., 1990). Such late cooling ages may be related to an episode of tectonic denudation (Miller et al., 1990).

Black Pine Mountains, Idaho

Structural horses of low-grade Devonian-Permian metasedimentary rocks are separated by low-angle normal faults in the Black Pine Mountains of southern Idaho (Smith, 1982; Smith, 1983; Snoke and Miller, 1988). Although the detachments responsible for this imbrication are thought to be related to mid-Tertiary extension, Wells and Allmendinger, 1990 demonstrated that an earlier episode of east-west, bedding-parallel extension accompanied very low-grade (anchizonal) retrograde metamorphism. Whole-rock K-Ar (Smith, 1982) and $^{40}Ar/^{39}Ar$ (Wells et al., 1990) data for slates strongly affected by the retrograde event imply that the first extensional event occurred in late Early Cretaceous to Late Cretaceous time (Wells et al., 1990; Wells and Allmendinger, 1990).

Albion - Raft River - Grouse Creek Metamorphic Core Complex, Idaho-Utah

The Albion - Raft River - Grouse Creek metamorphic core complex can be thought of as a nested sequence of normal fault-bound, structural sheets that can be grouped, from bottom to top, into a Parautochthon, a Metamorphosed Allochthon, and an Unmetamorphosed Allochthon. The Parautochthon consists of an Archean gneiss complex unconformably overlain by a thin, greenschist to amphibolite facies veneer of Upper Proterozoic(?) - Cambrian(?) metasedimentary rocks (Armstrong, 1968; Compton et al., 1977). The Metamorphosed Allochthon is a composite of several structural sheets of Upper Proterozoic to Carboniferous quartzites, schists, and metacarbonate rocks that have been subjected to at least three greenschist to upper amphibolite facies metamorphic events (Armstrong, 1968; Compton et al., 1977; Miller, 1983; Miller et al., 1983; Snoke and Miller, 1988). The Unmetamorphosed Allochthon includes essentially unmetamorphosed Carboniferous-Triassic strata and Middle Miocene volcanic and sedimentary rocks (Compton, 1983; Miller et al., 1983).

Contacts between the Unmetamorphosed Allochthon and the metamorphic core below correspond to diachronous low-angle normal faults of Oligocene to Middle Miocene age (Compton et al., 1977; Compton, 1983; Snoke and Miller, 1988). These brittle structures are superimposed on a major, west-dipping, mylonitic shear zone, with a total thickness of up to 4 km, that dominates the structural architecture of the western ARRGC. The shear zone operated in a normal sense, with vergence toward the WNW, during Late Eocene to Late Oligocene sillimanite grade metamorphism and granitoid magmatism (Saltzer and Hodges, 1988; Compton et al., 1977; Miller et al., 1983; Malavieille, 1987b).

Structural relationships between the Metamorphosed Allochthon and the Parautochthon are best studied in the northern Albion Mountains and eastern Raft River Mountains, where the effects of Tertiary metamorphism are less pronounced. In the northern Albion Mountains, the contact is marked by a zone of kilometer-scale structural imbrication (the Basin-Elba fault zone) that was first mapped by R.L. Armstrong (unpublished manuscript; Miller et al., 1983) and studied in more detail by Hodges and McKenna, 1986. The amount of displacement on the Basin-Elba fault is poorly constrained but must have been large; it juxtaposes distinctively different facies of Upper Proterozoic strata that had different pre-faulting metamorphic histories (Miller, 1983; Armstrong, unpublished manuscript; Miller et al., 1983). Based on preliminary thermobarometric data from the hanging wall and footwall, Hodges and McKenna, 1986 interpreted the Basin-Elba fault as a major thrust fault that developed at intermediate crustal levels. However, this interpretation does not account for two of the more enigmatic characteristics of the fault zone (Miller et al., 1983; Armstrong, unpublished manuscript; Hodges and McKenna, unpublished mapping): 1) structural slices of fossiliferous Carboniferous and unfossiliferous, probable Ordovician strata are sandwiched between hanging wall and footwall Upper Proterozoic units; and 2) the Paleozoic slices contain mineral assemblages characteristic of upper greenschist to lower amphibolite facies, whereas structurally higher and lower Proterozoic units were metamorphosed to middle or upper amphibolite facies. These relationships suggest to us a tectonic scenario in which an east-directed, post-metamorphic thrust fault placed rocks of the Metamorphosed Allochthon on Parautochthon units as high stratigraphically as Carboniferous, and subsequently the entire package was cut by a more shallowly dipping, west-directed normal fault that dropped hanging wall Proterozoic units of the Metamorphosed Allochthon back down onto Proterozoic units of the Parautochthon. As movement occurred on the later structure (the Basin-Elba fault), slices of low-grade Paleozoic rocks from the footwall were dragged down with the hanging wall, producing the observed unusual older-on-younger-on-older fault relationship. Other scenarios are possible, of course, but we contend that the simplest interpretation of the observed relationships is that the Basin-Elba fault is an extensional structure.

Basin-Elba faulting was accompanied by the widespread development of northwest-trending mineral and stretching lineations in the northern Albion Mountains, by retrograde metamorphism of the hanging wall and footwall near the fault zone, and by prograde, greenschist facies metamorphism in the zone itself. In areas not affected by Tertiary metamorphism and outside of the Basin-Elba fault zone, amphiboles yield Middle to Late Jurassic K-Ar cooling dates, implying a Jurassic age for amphibolite facies regional metamorphism (Armstrong, 1976; Armstrong, unpublished manuscript). Retrogressed amphibolite facies samples collected near the Basin-Elba fault and greenschist facies rocks from outside the fault zone provide K-Ar and $^{40}Ar/^{39}Ar$ hornblende, muscovite, and biotite ages ranging from 90-68 Ma (Armstrong and Hills, 1967; Armstrong, 1976; K.V. Hodges and others, manuscript in preparation). These data imply strongly that the Basin-Elba fault developed in Late Cretaceous time (Armstrong, unpublished manuscript).

In the eastern Raft River Mountains, the contact between the Metamorphosed Allochthon and the Parautochthon is a brittle low-angle fault that dips eastward beneath the Black Pine Mountains and is an important detachment of probable Miocene age (Covington, 1983; Wells and Allmendinger, 1990; Wells et al., 1990). This fault is superimposed on a well-developed mylonitic shear zone that accommodated east-directed normal displacement between the Metamorphic Allochthon and the Parautochthon (Sabisky, 1985; Malavieille, 1987a). The age of this shear zone is not constrained well. Miocene sphene and apatite fission track (Compton et al., 1977) and $^{40}Ar/^{39}Ar$ muscovite (Malavieille, 1987b) cooling ages from the Parautochthon in the northern Raft River Mountains have been used to argue that the shear zone is a Tertiary structure (Malavieille, 1987b), but Eocene conventional K-Ar biotite ages from the same area (Armstrong and Hansen, 1966) suggest a complex thermal history for the Parautochthon that may not be simply interpretable in terms of Miocene tectonic denudation. In any event, ductile extensional structures in the Metamorphosed Allochthon clearly predate the brittle detachment between the Metamorphosed Allochthon and the Parautochthon in the eastern Raft River Mountains; $^{40}Ar/^{39}Ar$ muscovite plateau ages ranging from 82 to 90 Ma led Wells et al., 1990 to assign a Late Cretaceous age to the extensional structures in the Metamorphosed Allochthon.

Bitterroot Dome, Idaho-Montana

The eastern part of the northern Bitterroot lobe of the Idaho batholith forms a structural culmination with an east-west dimension of roughly 50 km and a north-south dimension of about 100 km. This culmination (referred to hereafter as the Bitterroot dome) constitutes the largest metamorphic core complex in the western United States Cordillera (Hyndman, 1980). The footwall or core of the Bitterroot dome predominantly consists of Upper Cretaceous - Eocene granitic rocks of the Idaho batholith and their country rocks, which represent high-grade equivalents of the Proterozoic Belt Supergroup and minor pre-Belt crystalline basement (Hyndman, 1980; Hyndman, 1983). Middle to upper amphibolite facies conditions prevailed in the migmatitic country rocks during intrusion (Hietanen, 1956; Wehrenberg, 1972; Chase, 1973; Cheney, 1975). The structural cover of the Bitterroot core includes large tracts of Belt Supergroup rocks intruded by predominantly granitic, Upper Cretaceous - Eocene plutons of the Idaho batholith suite (Hyndman et al., 1988).

The core of the Bitterroot dome and its structural cover are separated by the Bitterroot mylonite zone, which runs along the eastern margin of the dome for a distance of roughly 100 km (Hyndman, 1980). Mylonitic foliation in the zone dips less than 30° eastward and a related stretching lineation plunges shallowly to the ESE; well-defined S-C fabrics and other sense-of-shear indicators suggest a top-to-the-east movement direction (Garmezy and Sutter, 1983; Hyndman and Myers, 1988). Stable isotopic and petrologic data (Kerrich and Hyndman, 1986; LaTour and Barnett, 1987), coupled with field observations (Hyndman and Sixt, 1989), strongly suggest that the early stages of mylonitization occurred at amphibolite facies conditions concurrent with emplacement of some phases of the Idaho batholith. Based on evidence for resetting of U-Pb and $^{40}Ar/^{39}Ar$ mineral ages in granitic plutons during shearing, Chase et al., 1983 and Garmezy, 1983 proposed a Middle Eocene age for the Bitterroot mylonite zone.

We agree that at least a portion of the Bitterroot mylonite zone moved in Eocene time, but some aspects of the thermal evolution of the Bitterroot dome seem to indicate the possibility of earlier tectonic denudation. First, the southernmost exposures of the mylonite zone appear to be overlain unconformably by volcanic rocks of probable Eocene age (Hyndman et al., 1988). Second, essentially undeformed Middle Eocene intrusive rocks in the eastern Bitterroot dome show evidence (e.g., miarolitic cavities) of a shallow level of intrusion that seems difficult to reconcile with high-temperature Middle Eocene mylonitization in nearby rocks (Hyndman et al., 1988). Finally, existing studies of metapelitic assemblages in the footwall rocks have found persistent evidence of polymetamorphism: an early event produced kyanite + sillimanite-bearing assemblages and a later event resulted in the crystallization of andalusite (Hyndman and Alt, 1972; Cheney, 1975). These relationships strongly suggest high-temperature decompression during the metamorphic history of the Bitterroot footwall (cf., Hyndman, 1980; Hyndman et al., 1988). If regional metamorphism in the country rocks of the core is a Late Cretaceous phenomenon as is widely believed (Chase et al., 1983; Hyndman and Myers, 1988), then decompression related to tectonic denudation could be a Late Cretaceous phenomenon.

Priest River Complex, Idaho-Washington

The Priest River metamorphic core complex includes amphibolite facies metasedimentary rocks of probable Precambrian age that have been intruded by Mesozoic granitic plutons (Rhodes and Hyndman, 1988). The complex is bound on the west and north by the Newport fault, a north- and west-dipping extensional structure of Eocene age (Miller, 1971; Harms and Price, 1983), and on the east by the Purcell Trench fault, a poorly exposed, east-dipping normal fault of probable Eocene age (Rehrig and Reynolds, 1981). Parrish et al., 1988 has suggested that the Newport and Purcell Trench faults are the same east-vergent structure, modified by later west-directed normal faulting and doming of the Priest River complex. These structures are superimposed on 4 km-thick mylonite zone that dominates the southern part of the Priest River complex and defines the Spokane dome (Rhodes and Hyndman, 1988). Fabrics within this zone indicate a top-to-the-east sense of shear (Rhodes and Hyndman, 1984). Although this structure is commonly interpreted as a compressional feature (e.g., Rhodes and Hyndman, 1984), Parrish et al., 1988 pointed out that an extensional origin is equally consistent with geologic constraints. Based on cross-cutting relationships between intrusive rocks and mylonitic fabrics, mylonitization occurred in Late Cretaceous - Early Eocene(?) time (Bickford et al., 1985; Rhodes, 1986).

Kettle Complex, Washington - British Columbia

In many ways, the Kettle metamorphic core complex is structurally analogous to the Priest River complex: amphibolite facies core rocks are flanked by Eocene normal faults with opposing dips (Rhodes and Cheney, 1981; Rhodes and Hyndman, 1988). An east-dipping, sillimanite-grade mylonite zone is exposed beneath the Kettle River fault, the detachment on the eastern side of the Kettle dome (Rhodes and Cheney, 1981); seismic reflection profiles indicate that this zone projects eastward in the subsurface beneath the Kettle River valley (Hurich et al., 1985). Kinematic indicators suggest eastward vergence, consistent with normal-sense movement (Rhodes and Hyndman, 1988). The age of the Kettle mylonite zone is unknown. Parrish et al., 1988 proposed an Early to Middle Eocene age based on the inference that the the demonstrably Eocene Kettle River fault and the mylonite zone were genetically related, and on the observation that mica cooling ages in the Kettle core rocks are Tertiary. Rhodes and Hyndman, 1988 suggested both Mesozoic - early Tertiary contractional and Eocene extensional episodes of movement. Based on similarities between the Kettle mylonite zone and other east-dipping shear zones on the eastern sides of the Priest River and Okanagan core complexes nearby, we propose that the Kettle mylonites may have been produced during Late Cretaceous extension.

Okanagan Complex, Washington - British Columbia

The Okanagan complex is another north-south-elongate metamorphic culmination that is bound in the east by normal faults of the Republic Graben system and on the west by the west-dipping Okanagan Valley fault (Hansen and Goodge, 1988). The core consists of paragneisses of uncertain age (Precambrian?) and multiple generations of Mesozoic-Eocene plutonic rocks (Parkinson, 1985; Parrish et al., 1988; Potter et al., 1991). All pre-Late Cretaceous units have been affected by an amphibolite facies regional metamorphic event, and a greenschist facies retrograde event was associated with the development of a west-dipping mylonite zone along the western margin of the complex (Hansen and Goodge, 1988). This mylonite zone is a predominantly Eocene structure (Atwater, 1985; Parkinson, 1985; Hansen and Goodge, 1988; Parrish et al., 1988). An older, east-dipping mylonitic fabric is developed locally in the core, and a well-defined east-dipping mylonitic shear zone separates the metamorphic infrastructure and allochthonous metasedimentary rocks of pre-Late Triassic age (Orr, 1985; Hansen and Goodge, 1988; Ross, 1981). Orr, 1985 determined that the shear zone accomodated eastward displacement synchronous with regional metamorphism, and interpreted the structure as a Mesozoic thrust fault. Potter et al., 1991 presented U-Pb geochronologic data for plutonic rocks that indicate development of east-directed mylonites between 85 Ma and 55 Ma. Based on these constraints, we speculate that the east-directed fabrics may record a previously unrecognized period of Late Cretaceous - Paleocene extension.

REFERENCES

Allen, C. M., Foster, D. A. and Wooden, J. L., 1990, Sources of plutons and P-T-t paths of southern Turtle Mountains, southeastern California: Geological Society of America Abstracts with Programs, v. 22, p. 1.

Allen, C. M. and O'Hara, K., 1991, The West Turtle shear zone, Turtle Mtns., S.E. California: A thrust reactivated in extension?: Geological Society of America Abstracts with Programs, v. 23, p. 2.

Armstrong, R. L., 1968, Mantled gneiss domes in the Albion Range, southern Idaho: Geological Society of America Bulletin, v. 79, p. 1295-1314.

Armstrong, R. L., 1976, The geochronometry of Idaho: Isochron/West, v. 15, p. 1-33.

Armstrong, R. L. and Hansen, E., 1966, Cordilleran infrastructure in the eastern Great Basin: American Journal of Science, v. 254, p. 112-127.

Armstrong, R. L. and Hills, F. A., 1967, Rubidium-strontium and potassium-argon geochronologic studies of mantled gneiss domes, Albion Mountains, southern Idaho: Earth and Planetary Science Letters, v. 3, p. 114-124.

Atwater, B. F., 1985, Contemporaneity of the Republic Graben and Okanogan gneiss dome - Evidence from the Coyote Creek pluton, southern Okanogan County, Washington: Geological Society of America Abstracts with Programs, v. 17, p. 338.

Ballard, S. N., 1990, Thermal evolution and gravitational collapse of the Little Maria - Big Maria Mountains, Maria tectonic belt, southeastern Mohave Desert, California: Geological Society of America Abstracts with Programs, v. 22, p. A227.

Ballard, S. N. and Ballard, P. D., 1990, Geology of the Little Maria Mountains, western end of the Maria tectonic belt, southeastern Mohave, California: Geological Society of America Abstracts with Programs, v. 22, p. A140.

Bickford, M. E., Rhodes, B. P. and Hyndman, D. W., 1985, Age of mylonitization in the southern Priest River complex, northern Idaho and northeastern Washington: Geological Society of America Abstracts with Programs, v. 17, p. 341.

Burchfiel, B. C. and Davis, G. A., 1981, Mojave desert and environs, *in* W. G. Ernst eds., The Geotectonic Development of California: Englewood Cliffs, NJ, Prentice Hall, p. 217-252.

Carl, B. S., Miller, C. F. and Foster, D. A., 1991, Western Old Woman Mountains shear zone: Evidence for late ductile extension in the Cordilleran orogenic belt: Geology, v. 19, p. 893-896.

Chase, R. B., 1973, Petrology of the northeastern border zone of the Idaho batholith, Bitterroot Range, Montana: Montana Bureau of Mines and Geology Memoir, v. 43, p. 1-28.

Chase, R. L., Bickford, M. E. and Arruda, E. C., 1983, Tectonic implications of Tertiary intrusion and shearing within the Bitterroot dome, northeastern Idaho batholith: Journal of Geology, v. 91, p. 462-470.

Cheney, J. T., 1975, Kyanite, sillimanite, phlogopite, cordierite layers in the Bass Creek anorthosites, Bitterroot Range, Montana: Northwest Geology, v. 4, p. 77-82.

Compton, R. R., 1983, Displaced Miocene rocks on the west flank of the Raft River-Grouse Creek core complex, Utah, *in* D. M. Miller, V. R. Todd and K. A. Howard eds., Tectonic and Stratigraphic Studies in the Eastern Great Basin: Boulder, CO, Geological Society of America Memoir 157, p. 271-279.

Compton, R. R., Todd, V. R., Zartman, R. E. and Naeser, C. W., 1977, Oligocene and Miocene metamorphism, folding, and low-angle faulting in northwestern Utah: Geological Society of America Bulletin, v. 88, p. 1237-1250.

Covington, H. R., 1983, Structural evolution of the Raft River Basin, Idaho, *in* D. M. Miller, V. R. Todd and K. A. Howard eds., Tectonic and Stratigraphic Studies in the Eastern Great Basin: Boulder, CO, Geological Society of America Memoir 157, p. 229-237.

Dallmeyer, R. D., Snoke, A. W. and McKee, E. H., 1986, The Mesozoic-Cenozoic tectonothermal evolution of the Ruby Mountains - East Humbolt Range, Nevada - A Cordilleran metamorphic core complex: Tectonics, v. 5, p. 931-954.

DeWitt, E., Sutter, J. F., Wright, L. A. and Troxel, B. W., 1988, Ar-Ar chronology of Early Cretaceous regional metamorphism, Funeral Mountains, California--A case study of excess argon: Geological Society of America Abstracts with Programs, v. 20, p. A16-A17.

Dokka, R. K., Mahaffie, M. J. and Snoke, A. W., 1986, Thermochronologic evidence of major tectonic denudation associated with detachment faulting, northern Ruby Mountains - East Humbolt Range, Nevada: Tectonics, v. 5, p. 995-1006.

Fletcher, J. M. and Karlstrom, K. E., 1990, Late Cretaceous ductile deformation, metamorphism, and plutonism in the Piute Mountains, eastern Mojave Desert: Journal of Geophysical Research, v. 95, p. 487-500.

Foster, D. A., 1989, Mesozoic and Cenozoic thermal history of the eastern Mohave Desert, California and western Arizona, with emphasis on the Old Woman Mountains area and the Chemehuevi metamorphic core complex [Ph.D. Thesis]: N.Y. State University at Albany, pp.

Foster, D. A., Harrison, T. M., Miller, C. F. and Howard, K. A., 1990, The 40Ar/39Ar thermochronology of the eastern Mojave Desert, California, and adjacent western Arizona with implications for the evolution of metamorphic core complexes: Journal of Geophysical Research, v. 95, p. 20005-20024.

Foster, D. A., Miller, C. F. and Harrison, T. M., 1989, The age and character of Late Cretaceous metamorphism, plutonism, and denudation in the Old Woman Mountains area: Evidence from 40Ar/39Ar thermochronology and thermobarometry: EOS, v. 70, p. 1404.

Garmezy, L., 1983, Geology and geochronology of the southeast border of the Bitterroot dome: Implications for the structural evolution of the mylonitic carapace [Ph.D. Thesis]: The Pennsylvania State University, pp.

Garmezy, L. and Sutter, J. F., 1983, Mylonitization coincident with uplift in an extensional setting, Bitterroot Range, Montana-Idaho: Geological Society of America Abstracts with Programs, v. 15, p. 578.

Glick, L. L., 1987, Structural geology of the northern Toano Range, Elko County, Nevada [M.S. Thesis]: San Jose State University, pp.

Hamilton, W., 1984, Generalized geologic map of the Big Maria Mountains region, northeastern Riverside County, southeastern California: United States Geological Survey Open-File Report, v. 84-407, p. 1-7.

Hamilton, W. B., 1982, Structural evolution of the Big Maria Mountains, northeastern Riverside County, southeastern California, *in* E. G. Frost and D. L. Martin eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, CA, Cordilleran Publishers, p. 1-27.

Hamilton, W. B., 1987, Mesozoic geology and tectonics of the Big Maria Mountains region, southeastern California, *in* W. R. Dickinson and M. A. Klute eds., Mesozoic Rocks of Southern Arizona and Adjacent Areas: Arizona Geological Society Digest, volume 18, p. 33-47.

Hansen, V. L. and Goodge, J. W., 1988, Metamorphism, structural petrology, and regional evolution of the Okanogan complex, northeastern Washington, *in* W. G. Ernst eds., Metamorphism and Crustal Evolution of the Western United States: Englewood Cliffs, NJ, Prentice Hall, p. 233-270.

Harms, T. A. and Price, R. A., 1983, The Newport fault, Eocene crustal stretching, necking, and listric normal faulting in NE Washington and NW Idaho: Geological Society of America Abstracts with Programs, v. 15, p. 309.

Haxel, G. B. and Dillon, J., 1978, The Pelona-Orocopia Schist and the Vincent-Chocolate Mountain thrust system, southern California, *in* D. G. Howell and K. A. McDougall eds., Mesozoic Paleogeography of the Western United States: Pacific Section, Society of Economic Paleontologists Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 453-469.

Haxel, G. B., Jacobson, C. E. and Tosdal, R. M., 1988, Multiple low-angle faults atop the Orocopia Schist, southwestern Arizona and southeastern California: Geological Society of America Abstracts with Programs, v. 20, p. A383.

Haxel, G. B. and Tosdal, R. M., 1986, Significance of the Orocopia Schist and Chocolate Mountains thrust in the late Mesozoic tectonic evolution of the southeastern California - southwestern Arizona region, *in* B. Beatty and P. A. K. Wilkinson eds., Frontiers in Geology and Ore Deposits of Arizona and the Southwest: Arizona Geological Society Digest, vol 16, p. 52-61.

Haxel, G. B., Tosdal, R. M. and Dillon, J. T., 1985, Tectonic setting and lithology of the Winterhaven Formation: A new Mesozoic stratigraphic unit in southeasternmost California and southwestern Arizona: United States Geological Survey Bulletin, v. 1599, p. 1-19.

Hietanen, A., 1956, Kyanite, andalusite, and sillimanite in Boehls Butte Quadrangle, Idaho: American Mineralogist, v. 41, p. 1-27.

Hileman, G. E., Miller, C. F. and Knoll, M. A., 1990, Mid-Tertiary structural evolution of the Old Woman Mountains area: Implications for crustal extension across southeastern California: Journal of Geophysical Research, v. 95, p. 581-597.

Hodges, K. V., 1991, Pressure-Temperature-Time Paths: Annual Reviews of Earth and Planetary Science, v. 19, p. 207-236.

Hodges, K. V. and McKenna, L. W., 1986, Structural and metamorphic characteristics of the Raft River-Quartzite Assemblage juxtaposition, Albion Mountains, southern Idaho: Geological Society of America Abstracts with Programs, v. 18, p. 117.

Hodges, K. V., McKenna, L. W. and Harding, M. B., 1990, Structural unroofing of the central Panamint Mountains, Death Valley region, SE California, *in* B. P. Wernicke eds., Basin and Range Extensional Tectonics Near the Latitude of Las Vegas, NV: Boulder, CO, Geological Society of America Memoir 176, p. 377-390.

Hodges, K. V., Snoke, A. W. and Hurlow, H. A., in press, Thermal Evolution of a portion of the Sevier hinterland: the northern Ruby Mountains - East Humboldt Range and Wood Hills, northeastern Nevada: Tectonics, v. p.

Hodges, K. V. and Walker, J. D., 1990, Thermobarometric constraints on the unroofing history of a metamorphic core complex, Funeral Mountains, SE California: Journal of Geophysical Research, v. 95, p. 8437-8445.

Hodges, K. V., Walker, J. D. and Wernicke, B. P., 1987, Footwall structural evolution of the Tucki Mountain detachment system, Death Valley region, southeastern California, *in* M. P. Coward, J. F. Dewey and P. L. Hancock eds., Continental Extensional Tectonics: Oxford, Geological Society of London, p. 393-408.

Hoisch, T. D., Miller, C. F., Heizler, M. T., Harrison, T. M. and Stoddard, E. F., 1988, Late Cretaceous regional metamorphism in southeastern California, *in* W. G. Ernst eds., Metamorphism and Crustal Evolution of the Western United States: Englewood Cliffs, NJ, Prentice Hall, p. 538-571.

Hoisch, T. D. and Simpson, C., 1989, P-T-t movement history of metamoprhic rocks from the Funeral Mountains, California, and Bare Mountain, Nevada: Geological Society of America Abstracts with Programs, v. 21, p. 93.

Holm, D. K. and Dokka, R. K., 1991, Major Late Miocene cooling of the middle crust associated with extensional orogenesis in the Funeral Mountains, California: EOS, v. 18, p. 1775-1778.

Howard, K. A., John, B. E. and Miller, C. F., 1987, Metamorphic core complexes, Mesozoic ductile thrusts, and Cenozoic detachments: Old Woman Mountains -Chemehuevi Mountains transect, California and Arizona, *in* G. A. Davis and E. M. VandenDolder eds., Geologic Diversity of Arizona and Its Margins: Excursions to Choice Areas: Tucson, AZ, Arizona Bureau of Geology and Mineral Technology Special Paper, v. 5, p. 365-382.

Howard, K. A., Stone, P., Pernokas, M. A. and Marvin, R. F., 1982, Geologic and geochronologic reconaissance of the Turtle Mountains area, California: West border of the Whipple Mountains detachment terrane, *in* E. G. Frost and D. L. Martin eds., Mesozoic-Cenozoic Tectonic Evolution of the

Colorado River Region, California, Arizona, and Nevada: San Diego, CA, Cordilleran Publishers, p. 341-345.

Hudec, M. R. and Wright, J. E., 1990, Mesozoic history of the central part of the Ruby Mountains - East Humboldt Range metamorphic core complex, Nevada: Geol. Soc. Amer. Abs. w. Prog., v. 22, p. 30.

Hurich, C. A., Smithson, S. B., Fountain, D. M. and Humphries, M. C., 1985, Seismic evidence of mylonite reflectivity and deep structure in the Kettle dome metamorphic core complex, Washington: Geology, v. 13, p. 577-580.

Hurlow, H. A., Snoke, A. W. and Hodges, K. V., 1991, Temperature and pressure of mylonitization in a Tertiary extensional shear zone, Ruby Mountains - East Humboldt Range, Nevada: Tectonic implications: Geology, v. 19, p. 82-86.

Hyndman, D. W., 1980, Bitterroot dome - Sapphire tectonic block, an example of a plutonic-core gneiss-dome complex with its detached suprastructure, *in* M. D. Crittenden, P. J. Coney and G. H. Davis eds., Cordilleran Metamorphic Core Complexes: Boulder, CO, Geological Society of America Memoir 153, p. 427-443.

Hyndman, D. W., 1983, The Idaho batholith and associated plutons, Idaho and western Montana: Geological Society of America Memoir 159, v. p. 213-240.

Hyndman, D. W. and Alt, D., 1972, The kyanite-andalusite-sillimanite problem on Goat Mountain, Idaho: Northwest Geology, v. 1, p. 42-46.

Hyndman, D. W., Alt, D. and Sears, J. W., 1988, Post-Archean metamorphic and tectonic evolution of western Montana and northern Idaho, *in* W. G.

Ernst eds., Metamorphism and Crustal Evolution of the Western United States: Englewood Cliffs, NJ, Prentice Hall, p. 332-361.

Hyndman, D. W. and Myers, S. A., 1988, The transition from amphibolite-facies mylonite to chloritic breccia and role of the mylonite in formation of Eocene epizonal plutons, Bitterroot dome, Montana: Geologische Rundschau, v. 77, p. 211-226.

Hyndman, D. W. and Sixt, K. C., 1989, Crystallization hardening of mylonites in granitoid plutons: Geological Society of America Abstracts with Programs, v. 21, p. A180-A181.

Jacobson, C. E., 1990, The $^{40}Ar/^{39}Ar$ geochronology of the Pelona Schist and related rocks, southern California: Journal of Geophysical Research, v. 95, p. 509-528.

Jacobson, C. E., Dawson, M. R. and Postlewaite, C. E., 1988, Structure, metamorphism, and tectonic significance of the Pelona, Orocopia, and Rand Schists, southern California, *in* W. G. Ernst eds., Metamorphism and Crustal Evolution of the Western United States: Englewood Cliffs, NJ, Prentice-Hall, p. 976-997.

Kerrich, R. and Hyndman, D., 1986, Thermal and fluid regimes in the Bitterroot lobe - Sapphire block detachment zone, Montana: Evidence from 18O/16O and geologic relations: Geological Society of America Bulletin, v. 97, p. 147-155.

Labotka, T. C., 1980, Petrology of a medium-pressure regional metamorphic terrane, Funeral Mountains, California: American Mineralogist, v. 65, p. 670-689.

Labotka, T. C., Warasila, R. L. and Spangler, R. R., 1985, Polymetamorphism in the Panamint Mountains, California: A ^{39}Ar-^{40}Ar study: Journal of Geophysical Research, v. 90, p. 10359-10371.

LaTour, T. E. and Barnett, R. L., 1987, Mineralogical changes accompanying mylonitization in the Bitterroot dome of the Idaho Batholith: Implications for timing of deformation: Geological Society of America Bulletin, v. 98, p. 356-363.

Lee, D. E. and Marvin, R. F., 1981, Markedly discordant K-Ar ages for coexisting biotite and muscovite from a two-mica granite in the Toano Range, Elko County, Nevada: Isochron/West, v. 32, p. 19.

Lee, D. E., Marvin, R. F. and Mehnert, H. H., 1980, A radiometric-age study of Mesozoic-Cenozoic metamorphism in eastern White Pine County, Nevada and nearby Utah: U.S. Geological Survey Professional Paper, v. 1158, p. C1-C28.

Malavieille, J., 1987a, Extensional shearing deformation and kilometer-scale "a"-type folds in a Cordilleran metamorphic core complex (Raft River Mountains, northwestern Utah): Tectonics, v. 6, p. 423-448.

Malavieille, J., 1987b, Kinematics of compressional and extensional ductile shearing deformation in a metamorphic core complex of the northeastern Basin and Range: Journal of Structural Geology, v. 9, p. 541-554.

McKenna, L. W., Snee, L. W. and Hodges, K. V., submitted, Time-temperature history of extension in the Panamint and Black Mountains, Death Valley, California: Tectonics, v. p.

Miller, C. F., Howard, K. A. and Hoisch, T. D., 1982, Mesozoic thrusting, metamorphism, and plutonism, Old Woman-Piute Range, southeastern California, *in* E. G. Frost and D. L. Martin eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River Region, California, Arizona, and Nevada: San Diego, Cordilleran Publishers, p. 561-581.

Miller, D. M., 1983, Allochthonous quartzite sequence in the Albion Mountains, Idaho, and proposed Proterozoic Z and Lower Cambrian correlatives in the Pilot Range, Utah, and Nevada, *in* D. M. Miller, V. R. Todd and K. A. Howard eds., Tectonic and Stratigraphic Studies in the Eastern Great Basin: Boulder, CO, Geological Society of America Memoir 157, p. 191-213.

Miller, D. M., Armstrong, R. L., Compton, R. R. and Todd, V. R., 1983, Geology of the Albion-Raft River-Grouse Creek area, northwestern Utah and southern Idaho: Utah Geological and Mineral Survey Special Studies, v. 59, p. 1-62.

Miller, D. M., Hillhouse, W. C., Zartman, R. E. and Lanphere, M. A., 1987, Geochronology of intrusive and metamorphic rocks in the Pilot Range, Utah and Nevada, and comparison with regional patterns: Geological Society of America Bulletin, v. 99, p. 866-879.

Miller, D. M. and Lush, A. P., 1981, Preliminary geologic map of the Pilot Peak and adjacent quadrangles, Elko County, Nevada, and Box Elder County, Utah: U.S. Geological Survey Open File Report, v. 81-658, p. 1-18.

Miller, D. M., Nakata, J. K. and Glick, L. L., 1990, K-Ar ages of Jurassic to Tertiary plutonic and metamorphic rocks, northwestern Utah and northeastern Nevada: U.S. Geological Survey Bulletin, v. 1906, p. 1-18.

Miller, F. K., 1971, The Newport fault and associated mylonites, northeastern Washington: U.S. Geological Survey Professional Paper, v. 750-D, p. D77-D79.

Orr, K. E., 1985, Structural features along the margin of Okanogan dome, Tenas Mary Creek area, NE Washington: Geological Society of America Abstracts with Programs, v. 17, p. 398.

Parkinson, D., 1985, Geochronology of the western side of the Okanagan metamorphic core complex, southern British Columbia: Geological Society of America Abstracts with Programs, v. 17, p. 399.

Parrish, R. R., Carr, S. D. and Parkinson, D. L., 1988, Eocene extensional tectonics and geochronology of the southern Omenica Belt, British Columbia and Washington: Tectonics, v. 7, p. 181-212.

Postlewaite, C. E. and Jacobson, C. E., 1987, Early history and reactivation of the Rand thrust, southern California: Journal of Structural Geology, v. 9, p. 195-205.

Potter, C. J., Zartman, R. E. and Jha, K., 1991, New U-Pb zircon ages provide improved constraints on structural evolution of the Okanogan core complex, Wash.: Geological Society of America Abstracts with Programs, v. 23, p. 90.

Rehrig, W. A. and Reynolds, S. J., 1981, Eocene metamorphic core complex tectonics near the Lewis and Clark zone, western Montana and northern Idaho: Geological Society of America Abstracts with Programs, v. 13, p. 102.

Reynolds, M. W., Wright, L. A. and Troxel, B. W., 1986a, Geometry and chronology of late Cenozoic detachment faulting, Funeral and Grapevine Mountains, Death Valley, California: Geological Society of America Abstracts with Programs, v. 18, p. 175.

Reynolds, S. J., Spencer, J. E., Richard, S. M. and Laubach, S. E., 1986b, Mesozoic structures in west-central Arizona, *in* B. Beatty and P. A. K. Wilkinson eds., Frontiers in geology and ore deposits of Arizona and the southwest: Tucson, Arizona Geological Society Digest, p. 35-51.

Rhodes, B. P., 1986, Metamorphism of the Spokane Dome mylonitic zone, Priest River complex - contraints on the tectonic evolution of northeastern Washington and northern Idaho: Journal of Geology, v. 94, p. 539-556.

Rhodes, B. P. and Cheney, E. S., 1981, Low-angle faulting and the origin of Kettle dome, a core complex in northeastern Washington: Geology, v. 9, p. 366-369.

Rhodes, B. P. and Hyndman, D. H., 1984, Kinematics of mylonites in the Priest River "metamorphic core complex", northern Idaho and northeastern Washington: Canadian Journal of Earth Sciences, v. 21, p. 1161-1170.

Rhodes, B. P. and Hyndman, D. W., 1988, Regional metamorphism, structure and tectonics of northeastern Washington and northern Idaho, *in* W. G. Ernst eds., Metamorphism and Crustal Evolution of the Western United States: Englewood Cliffs, NJ, Prentice Hall, p. 271-295.

Richard, S. M. and Haxel, G. B., 1991, Progressive exhumation of the Orocopia and Pelona Schists along a composite normal fault system, southeastern

California and southwestern Arizona: Geological Society of America Abstracts with Programs, v. 23, p. 92.

Ross, J. V., 1981, A geodynamic model for some structures within and adjacent to the Okanagan Valley, southern British Columbia: Canadian Journal of Earth Sciences, v. 18, p. 1581-1598.

Sabisky, M., 1985, Ductile flow and folding in the Raft River Mountains, northwestern Utah: EOS, v. 66, p. 1089.

Saltzer, S. and Hodges, K. V., 1988, The Middle Mountain shear zone, southern Idaho: Kinematic analysis of a Tertiary, high-temperature detachment: Geological Society of America Bulletin, v. 100, p. 96-103.

Silver, L. T. and Nourse, J. A., 1986, The Rand Mountains "thrust" complex in comparison with the Vincent Thrust - Pelona Schist relationship, southern California: Geological Society of America Abstracts with Programs, v. 18, p. 185.

Smith, J. F., 1982, Geologic map of the Strevell 15 minute quadrangle, Cassia County, Idaho: Full Journal, v. p.

Smith, J. F., 1983, Paleozoic rocks of the Black Pine Mountains, Cassia County, Idaho: U.S. Geological Survey Bulletin, v. 1536, p. 1-36.

Snoke, A. W. and Lush, A. P., 1984, Polyphase Mesozoic-Cenozoic deformational history of the northern Ruby Mountains - East Humbolt Range, Nevada, *in* J. Lintz eds., Western Geological Excursions: Geological Society of America 1984 Annual Meeting Field Trip Guide: Reno, Nevada, Geological Society of America, p. 232-260.

Snoke, A. W., McGrew, A. J., Valasek, P. A. and Smithson, S. B., 1990, A crustal cross-section for a terrain of superimposed shortening and extension: Ruby Mountains - East Humboldt Range metamorphic core complex, Nevada, *in* M. H. Salisbury and D. M. Fountain eds., Exposed Cross-Sections of the Continental Crust: Dordrecht, Holland, Kluwer Academic Publishers, p. 103-135.

Snoke, A. W., McKee, E. H. and Stern, T. W., 1979, Plutonic, metamorphic, and structural chronology in the northern Ruby Mountains, Nevada - A preliminary report: Geological Society of America Abstracts with Programs, v. 11, p. 520-521.

Snoke, A. W. and Miller, D. M., 1988, Metamorphic and tectonic history of the northeastern Great Basin, *in* W. G. Ernst eds., Metamorphism and Crustal

Evolution of the Western United States: Englewood Cliffs, NJ, Prentice-Hall, p. 606-648.

Spear, F. S. and Selverstone, J., 1983, Quantitative P-T paths from zoned minerals: theory and tectonic applications.: Contributions to Mineralogy and Petrology, v. 83, p. 348-357.

Troxel, B. W., 1988, A geologic traverse of the northern Funeral Mountains, Death Valley, California, *in* D. L. Weide and M. L. Faber eds., This Extended Land, Geological Journeys in the Southern Basin and Range, Field Trip Guidebook: Las Vegas, Cordilleran Section, Geological Society of America, p. 45-49.

Troxel, B. W. and Wright, L. A., 1989, Geologic map of the central and northern Funeral Mountains and adjacent areas, Death Valley Region, southern California: USGS Open-File Report, 89-348.

Wehrenberg, J. P., 1972, Geology of the Lolo Peak area, northern Bitterroot Range, Montana: Northwest Geology, v. 1, p. 25-32.

Wells, M. L. and Allmendinger, R. W., 1990, An early history of pure shear in the upper plate of the Raft River metamorphic core complex, Black Pine Mountains, southern Idaho: Journal of Structural Geology, v. 12, p. 851-867.

Wells, M. L., Dallmeyer, R. D. and Allmendinger, R. W., 1990, Late Cretaceous extension in the hinterland of the Sevier thrust belt, northwestern Utah and southern Idaho: Geology, v. 18, p. 929-933.

Wernicke, B., Axen, G. J. and Snow, J. K., 1988, Basin and Range extensional tectonics at the latitude of Las Vegas, Nevada: Geological Society of America Bulletin, v. 100, p. 1738-1757.

Wright, J. E. and Snoke, A. W., 1986, Mid-Tertiary mylonitization in the Ruby Mountains - East Humbolt Range metamoprhic core complex, Nevada: Geological Society of America Abstracts with Programs, v. 18, p. 795.