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Regional correlation of extension directions in Cordilleran metamorphic core complexes

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ABSTRACT

Cordilleran metamorphic core complexes exhibit Tertiary extensional deformation, expressed either as detachment faults or detachment faults plus ductile mylonitic shear zones. Extension directions, as indicated by stretching lineations within mylonite and striations along detachment faults, fall into regional groups in which the directions are similar in trend throughout each group. Asymmetric fabrics on both small and large scale give a sense of shear and indicate that tectonic vergence within groups is directed outward from a central axis. The regional consistency of extension directions implies a regional control of extension in metamorphic core complexes.

INTRODUCTION

Metamorphic core complexes are major tectonic features of the North American Cordillera (Crittenden et al., 1980) and have counterparts in orogenic systems in other parts of the world (Lister et al.,1984; Sturchio et al., 1983; Ollier and Pain, 1980). Core complexes are characterized by a central window or lower plate of high-grade metamorphic and igneous rocks, separated by a detachment fault from an upper plate of less metamorphosed, but highly deformed, crystalline rocks as old as Precambrian and overlying sedimentary and volcanic units as young as Miocene (Coney, 1980). It is becoming increasingly apparent that within a core complex the ductile (mylonitic) and brittle (breccia) deformations of the detachment system are genetically related to the same Tertiary extensional event (Davis et al., 1986; Reynolds, 1985; Davis, 1983). Structural styles in different core complexes are similar, and lineated mylonites and striated detachment surfaces lend themselves to structural analysis. This paper shows that regional extension directions in core complexes of the North American Cordillera, based on direction of movement of the upper plate and on stretching lineations in the core rocks, are consistent and may reflect regional tectonic controls.

METHOD

The extension direction for individual core complexes was obtained from field study or from published maps and articles (see sources listed in Fig. 1 caption). Directions are based on mineral lineations in mylonites of the lower plate rocks, or striations along detachment faults. Shear-sense determination ("top to" direction) used one or more of three criteria: (1) asymmetric mylonitic fabrics (e.g., Simpson and Schmid, 1983); (2) published cross sections and maps showing listric and low-angle normal faults that have a dominant vergence (see references listed in Fig. 1 caption); in general, these reflect vergence of the underlying shear zone (Coney, 1980; Davis, 1983); and (3) assumption that mylonitization is best developed on the side of the core complex toward which the upper plate moved; this follows from the interpretation that the mylonites reflect deeper levels of the shear zone (Davis, 1983). Shear-sense indicators were consistent for complexes in which more than one criterion was applied. It should be emphasized, however, that vergence directions are not necessarily noted by the referenced authors, but are my interpretations based on their data.

DISCUSSION

Extension directions for core complexes fall into distinct regional groups (Fig. 1). The extension direction for the southern group is northeast-southwest, for the central group it is northwest-southeast, and for the northern group it is mostly east-west. Vergence directions are also consistent within a given area. Upper plates in core complexes tended to move outward from an inferred tectonic axis that is approximately parallel to the sinuous trend of the Mesozoic fold and thrust belt. In general, the same rule holds true for non-core complex detachment systems, though there are exceptions (Fig. 1).

Extension directions in the northern group of core complexes are mostly east-west to northeast-southwest, although the directions are more variable, possibly reflecting later tectonism. Fox and Beck (1985), using paleomagnetic data, suggested that northeastern Washington, northern Idaho, northwestern Montana, and southern British Columbia have undergone a 25° clockwise rotation since the Eocene. They interpreted the rotation as occurring after mid-Tertiary extension. Internal deformation within their "Sanpoil Block" could have created differential rotations of the structural domes, thus giving rise to the variations seen in present-day extension orientations.

The regional correlation of extension directions in core complexes is not related to age of extension in any simple way. The extensional deformation in Idaho core complexes north of the Snake River Plain (Pioneer and Bitterroot complexes) is Eocene in age, whereas to the south of the Snake River Plain (Albion–Grouse Creek–Raft River, Ruby–East Humboldt, and Snake Range complexes), the deformation is Oligocene and Miocene (Armstrong, 1982). Yet similar extension directions are seen for both regions.

The consistent correlation in both direction and vergence of extension of core complexes suggests a fundamental control that is regional in scale. The direction and vergence of extension could be related to (1) the trend of a belt of overthickened crust caused primarily by thrusting but also possibly by intrusion, (2) orientation of existing minor or major thrust ramps that were reactivated as normal faults, and (3) stresses produced at the North American plate margin by plate interactions. Extension directions that are perpendicular to the general trend of the frontal part of the Cordilleran fold and thrust belt indicate that the presence of overthickened crust may have dictated the direction of extension in Tertiary time. Overthickened crust may have been present over a broad region, or as a crustal "welt," as postulated by Coney and Harms (1984). Dominant vergence of extension in core complexes may also have been controlled by the location and trend of this zone or axis of thickened crust. This may be true only for extensional systems that have large amounts of offset, reflecting regional variations in crustal thickness; detachment systems that have less displacement do not show this relationship. This behavior may be analogous to that of any structural system in which dominant large-scale faults are those having a particular orientation and vergence—e.g., thrust belts.

Wernicke et al. (1985) have shown that the locations of low-angle normal faults, such as detachments, are not necessarily controlled by the presence of preexisting thrust faults; this suggests that the thrust faults may not have been a controlling factor for the geometry of extension in core complexes. Plate boundary conditions may very well have allowed extension to take place, but England et al. (1985) concluded that boundary conditions alone cannot account for extension in the Cordillera. Boundary conditions may have had no influence at all on vergence.

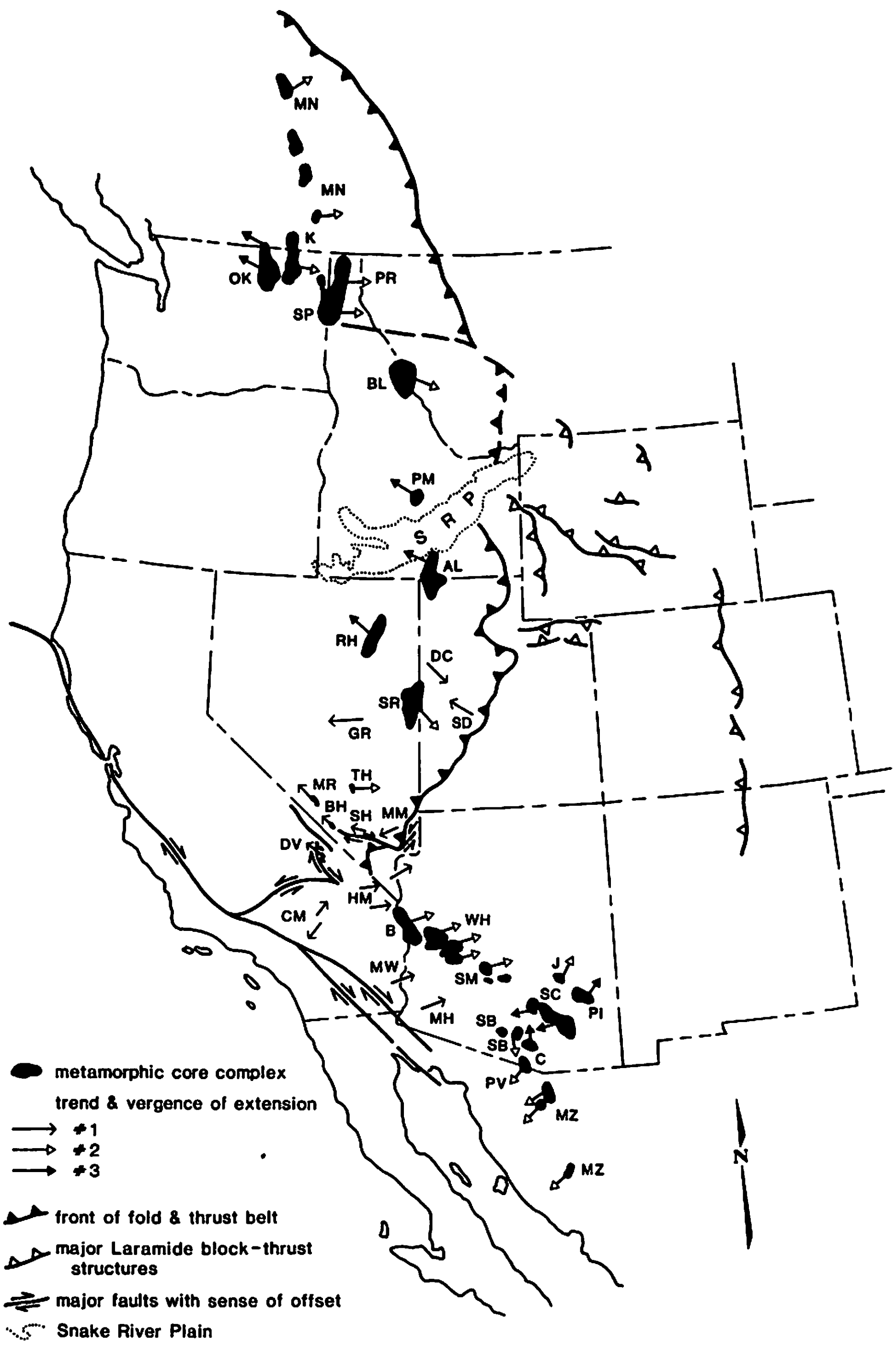

Figure 1. Map of western North America showing major tectonic elements, trend and vergence of extension directions of core complexes, and major detachment systems. Base map modified from Coney (1980). Directions of extension and sources for data are as follows. Core complexes: MZ = Magdalena, Madera, Mazatan (southwest; Anderson et al., 1980); SC = Picacho, Tortolita, Santa Catalina-Rincon (S60°W); PI = Pinaleno (N40°E); J = Jackson Mountain (N30°E); PV = Pozo Verde (N30°E); C = Coyote, Alvarez (north); SB = Sierra Blanco, Comobabi, Kupk Hills (S10° E) (Davis, 1980; Rehrig and Reynolds, 1980; Gardulski, 1980); WH = White Tank Mountains, Harquahalas, Harcuvars (N60°E); B = Buckskin, Rawhide, Whipple (N60°E) (Davis et al., 1980; Rehrig and Reynolds, 1980; Reynolds and Spencer, 1985; Spencer and Reynolds, in prep.); SM = South Mountain (N60°E; Reynolds, 1985); DV = Death Valley turtlebacks (northwest; Hunt and Mabey, 1966); BH = Bullfrog Hills (northwest); TH = Trappman Hills (east) (Cornwall, 1972; McKee, 1983); MR = Mineral Ridge (west; Albers and Stewart, 1972; McKee, 1983); SR = Snake Range (S55°E; Miller et al., 1983; Bartley and Wernicke, 1984); RH = Ruby Mountains-East Humboldt Range (west-northwest; Snoke and Lush, 1984); AL = Albion-Raft River-Grouse Creek (N65°W; Saltzer and Hodges, 1986); PM = Pioneer Mountains (N65°W; Wust, 1986); BL = Bitterroot lobe (S74°E; Hyndman, 1980); SP = Spokane dome (N60°-90°E; Rhodes, 1983); PR = Priest River (N70°-80°E; Rehrig and Reynolds, 1982); K = Kettle Dome (east; Cheney, 1980); OK = Okanogan (N50°-65°W; Goodge, 1983; Hansen, 1983); MN = Monashee (east-northeast; Brown, 1981; east-southeast; Brown and Murphy, 1982). Non-core complex detachment systems: MH = Mohawk Mountains/Copper Mountains (northeast; Mueller and Frost, 1982; Pridmore and Craig, 1982). MW = Midway Mountains (N70°E; Berg et al., 1982); HM = Homer Mountain area (east-northeast, N60°E; Spencer, 1985); CM = central Mojave (N50°E-S50°W; Dokka and Glazner, 1982); SH = Sheep Range (N80°W; Guth, 1981); MM = Mormon Mountains (west-southwest; Wernicke et al., 1985); GR = Grant Range (west; Moores et al., 1968); SD = Sevier Desert detachment (northwest; Allmendinger et al., 1983); DC = Deep Creek Range (S55°E; Nelson, 1966). Numbered classification of extension arrows refers to numbered criteria used to determine vergence of extension (see text): #1 = criterion 1; #2 = criteria 1+2; #3 = criteria 1+2+3.

CONCLUSIONS

North American Cordilleran core complexes exhibit Tertiary extensional deformation, expressed either as brittle detachment faults or as brittle detachment faults plus ductile mylonitic shear zones. The direction and vergence of extension are correlative within regional groups of core complexes. In the southern Cordillera, extension is northeast-southwest, in the central Cordillera it is northwest-southeast, and in the northern Cordillera it is mostly east-west. Extension in all regions has a decided vergence outward from a central axis; extension in complexes to the east of the axis shows easterly vergence, and extension in those to the west of the axis shows westerly vergence. Extension in core complexes may have been controlled by an inherited structural framework upon which Tertiary extensional deformation acted consistently within each region and independently of the age of extension. The framework may have been the presence and orientation of overthickened crust within the thrust belt. Extension was directed perpendicular to the trend of the belt, the largest amount of extension being taken up by those systems that had a regionally consistent orientation and vergence. The observed regional consistency of the direction and vergence of extension provides an important additional constraint for evaluating models proposed for the development of core complexes.

REFERENCES CITED

Albers, J.P., and Stewart, J.H., 1972, Geology and mineral deposits of Esmeralda County, Nevada: Nevada Bureau of Mines and Geology Bulletin 78, 80 p.

Allmendinger, R.W., Sharp, J.W., von Tish, D., Serpa, L., Brown, L., Kaufman, S., Oliver, J., and Smith, R.B., 1983, Cenozoic and Mesozoic structure of the eastern Basin and Range province, Utah, from COCORP seismic-reflection data: Geology, v. 11, p. 532–536.

Anderson, T.H., Silver, L.T., and Salas, G.A., 1980,

Distribution and U-Pb isotope ages of some lineated plutons, northwestern Mexico, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 269–283.
Armstrong, R.L., 1982, Cordilleran metamorphic core complexes—From Arizona to southern Canada: Annual Review of Earth and Planetary Sciences, v. 10, p. 129–154.
Bartley, J.M., and Wernicke, B.P., 1984, The Snake Range decollement interpreted as a major extensional shear zone: Tectonics, v. 3, p. 647–657.
Berg, L., Leveille, G., and Geis, P., 1982, Mid-Tertiary detachment faulting and manganese mineralization in the Midway Mountains, Imperial County, California, *in* Frost, E.G., and Martin, D.L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, California, Cordilleran Publishers, p. 298–311.
Brown, R.L., 1981, Metamorphic complex of SE Canadian Cordillera and relationship to foreland thrusting, *in* McClay, K.R., and Price, N.J., eds., Thrust and nappe tectonics: Geological Society of London Special Publication 9, p. 463–473.
Brown, R.L., and Murphy, D.C., 1982, Kinematic interpretation of mylonitic rocks in part of the Columbia River fault zone, Shuswap terrane, British Columbia: Canadian Journal of Earth Sciences, v. 19, p. 456–465.
Cheney, E.S., 1980, Kettle Dome and related structures of northeastern Washington, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 463–483.
Coney, P.J., 1980, Cordilleran metamorphic core complexes: An overview, *in* Crittenden, M.D., Jr., et al., eds. Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 7–31.
Coney, P.J., and Harms, T.A., 1984, Cordilleran metamorphic core complexes: Cenozoic extension relics of Mesozoic compression: Geology, v. 12, p. 550–554.
Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 49 p.
Crittenden, M.D., Jr., Coney, P.J., and Davis, G.H., editors, 1980, Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, 490 p.
Davis, G.A., Anderson, J.L., Frost, E.G., and Shackelford, T.J., 1980, Mylonitization and detachment faulting in the Whipple-Buckskin-Rawhide Mountains terrane, southeastern California and western Arizona, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 79–129.
Davis, G.A., Lister, G.S., and Reynolds, S.J., 1986, Structural evolution of the Whipple and South mountains shear zones, southwestern United States: Geology, v. 14, p. 7–10.
Davis, G.H., 1980, Structural characteristics of metamorphic core complexes, southern Arizona, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 35–77.
—— 1983, Shear-zone model for the origin of metamorphic core complexes: Geology, v. 11, p. 342–347.
Dokka, R.K., and Glazner, A.F., 1982, Aspects of early Miocene extension of the central Mojave Desert, *in* Geologic excursions in the California desert (Geological Society of America Cordilleran Section meeting guidebook): Shoshone, California, Death Valley Publishing Company, p. 31–45.
England, P.C., Sonder, L.J., Christiansen, R.L., and Wernicke, B.P., 1985, Thermal and mechanical investigations of Basin and Range deformation, *in* Continental extensional tectonics (Proceedings from a special meeting of the Geological Society of London): Durham, England, University of Durham, paper no. 37.
Fox, K.F., Jr., and Beck, M.E., Jr., 1985, Paleomagnetic results for Eocene volcanic rocks from northeastern Washington and the Tertiary tectonics of the Pacific Northwest: Tectonics, v. 4, p. 323–341.
Gardulski, A.F., 1980, A structural and petrologic analysis of a quartzite-pegmatite tectonite, Coyote Mountains, southern Arizona [M.S. thesis]: Tucson, University of Arizona, 69 p.
Goodge, J.W., 1983, Reorientation of folds by progressive mylonitization, Okanogan Dome, north-central Washington: Geological Society of America Abstracts with Programs, v. 15, p. 323.
Guth, P.L., 1981, Tertiary extension north of the Las Vegas Valley shear zone, Sheep and Desert ranges, Clark County, Nevada: Geological Society of America Bulletin, v. 92, p. 763–771.
Hansen, V.L., 1983, Kinematic interpretation of mylonitic rocks in the Okanogan Dome, north-central Washington: Geological Society of America Abstracts with Programs, v. 15, p. 323.
Hunt, C.B., and Mabey, D.R., 1966, Stratigraphy and structure, Death Valley, California: U.S. Geological Survey Professional Paper 494-A, 162 p.
Hyndman, D.W., 1980, Bitterroot Dome–Sapphire tectonic block, an example of a plutonic-core gneiss-dome complex with its detached suprastructure, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 427–443.
Lister, G.S., Banga, G., and Feenstra, A., 1984, Metamorphic core complexes of Cordilleran type in the Cyclades, Aegean Sea, Greece, Geology, v. 12, p. 221–225.
McKee, E.H., 1983, Reset K-Ar ages: Evidence for three metamorphic core complexes, western Nevada: Isochron/West, no. 38, p. 17–20.
Miller, E.L., Gans, P.B., and Garing, J., 1983, The Snake Range decollement: An exhumed mid-Tertiary ductile-brittle transition: Tectonics, v. 2, p. 239–263.
Moores, E.M., Scott, R.B., and Lumsden, W.W., 1968, Tertiary tectonics of the White Pine—Grant Range region, east-central Nevada, and some regional implications: Geological Society of America Bulletin, v. 79, p. 1703–1726.
Mueller, K.J., and Frost, E.G., 1982, Mid-Tertiary detachment faulting in the Mohawk Mountains of southwestern Arizona, *in* Frost, E.G., and Martin, D.L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, California, Cordilleran Publishers, p. 448–457.
Nelson, R.B., 1966, Structural development of northernmost Snake Range, Kern Mountains, and Deep Creek Range, Nevada and Utah: American Association of Petroleum Geologists Bulletin, v. 50, p. 921–951.
Ollier, C.D., and Pain, C.F., 1980, Actively rising gneiss domes in Papua New Guinea: Geological Society of Australia Journal, v. 27, p. 33–44.
Pridmore, C.L., and Craig, C., 1982, Upper-plate structure and sedimentation of the Bakers Peak area, Yuma County, Arizona, *in* Frost, E.G., and Martin, D.L., eds., Mesozoic-Cenozoic tectonic evolution of the Colorado River region, California, Arizona, and Nevada: San Diego, Cordilleran Publishers, p. 356–375.
Rehrig, W.A., and Reynolds, S.J., 1980, Geologic and geochronologic reconnaissance of a northwest-trending zone of metamorphic core complexes in southern and western Arizona, *in* Crittenden, M.D., Jr., et al., eds., Cordilleran metamorphic core complexes: Geological Society of America Memoir 153, p. 131–157.
—— 1982, Geochronology and tectonic evolution of the Priest River crystalline/metamorphic complex of northeastern Washington and northern Idaho: Geological Society of America Abstracts with Programs, v. 14, p. 227.
Reynolds, S.J., 1985, Geology and geochronology of the South Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Bulletin 195, 61 p.
Reynolds, S.J., and Spencer, J.E., 1985, Evidence for large-scale transport on the Bullard detachment fault, west-central Arizona: Geology, v. 13, p. 353–356.
Rhodes, B.P., 1983, Kinematic analysis of mylonites from Spokane Dome in northeastern Washington and northern Idaho: Geological Society of America Abstracts with Programs, v. 15, p. 297.
Saltzer, S.D., and Hodges, K.V., 1986, Mylonitic fabric analysis at Middle Mountain, southern Idaho: Geological Society of America Abstracts with Programs, v. 18, p. 180.
Simpson, C., and Schmid, S.M., 1983, An evaluation of criteria to deduce the sense of movement in sheared rocks: Geological Society of America Bulletin, v. 94, p. 1281–1288.
Snoke, A.W., and Lush, A.P., 1984, Polyphase Mesozoic-Cenozoic deformational history of the northern Ruby Mountains–East Humboldt Range, Nevada, *in* Lintz, J., Jr., ed., Western Geological Excursions (Geological Society of America annual meeting guidebook): Reno, Nevada, Mackay School of Mines, Department of Geological Sciences, v. 4, p. 232–260.
Spencer, J.E., 1985, Miocene low-angle normal faulting and dike emplacement, Homer Mountain and surrounding areas, southeastern California and southernmost Nevada: Geological Society of America Bulletin, v. 96, p. 1140–1155.
Sturchio, N.C., Sultan, M., and Batiza, R., 1983, Geology and origin of Meatiq Dome, Egypt: A Precambrian metamorphic core complex?: Geology, v. 11, p. 72–76.
Wernicke, B., Walker, J.D., and Beaufait, M.S., 1985, Structural discordance between Neogene detachments and frontal Sevier thrusts, central Mormon Mountains, southern Nevada: Tectonics, v. 4, p. 213–246.
Wust, Stephen L., 1986, Extensional deformation with northwest vergence, Pioneer core complex, central Idaho: Geology, v. 14, p. 712–714.

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