Fault Kinematics of the Western Lewis and Clark Line in Northern Idaho and Northwestern Montana: Implications for Possible Mechanisms of Mesozoic Arc Segmentation

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Abstract

Structural mapping, detailed kinematic studies, and ^{40}Ar/^{30}Ar thermochronological analyses were conducted in northwestern Montana and northern Idaho to investigate the origin of the Lewis and Clark line, an enigmatic feature in the northern Cordillera of the United States. This study indicates that the western Lewis and Clark line is a composite tectonic feature that consists of northwest-striking, mid-Tertiary normal-fault systems and an east west–striking, Late Cretaceous thrust system. This result implies that the apparent offset of the Mesozoic plutonic belt (Kaniksu and Idaho batholiths) was mostly inherited from the time of their emplacement. Thus, the shape of the Belt basin has not been modified by any significant strike-slip faulting since at least the Cretaceous. The authors interpret the pattern of apparent arc segmentation to be controlled either by the difference in basement composition or by the variation in dip angles of the subducting Farallon plate along its strike during the Late Cretaceous. The localized, north-directed thrusting and north-verging overturned folds in the Osburn fault zone may have been related to emplacement of the Idaho batholith, as it expanded in both the east–west and north–south directions during its intrusion.

Introduction

The study area is located in northwestern Montana and northern Idaho (figure 1a). Kinematic studies were conducted along the Hope, Osburn, Ninemile, Placer Creek, Thompson Pass, and St. Mary faults (figure 1b).

The origin of the Lewis and Clark line remains controversial (Hyndman *et al.* 1988, Rehrig *et al.* 1987, Harrison *et al.* 1986, Lorenz 1984, Reynolds 1979, Sales 1968) despite the speculation of large horizontal displacements ~105 miles (~170 km) and a long research history (Billingsley and Locke 1939). Recent understanding of the mid-Tertiary extension in conjunction with an improved knowledge of Mesozoic and early Tertiary shortening north and south of the Lewis and Clark line (Parrish *et al.* 1990, Harms and Price 1992, Fillipone and Yin` 1994) renews the interest in studying the deformational history of this enigmatic feature in the northern Cordillera of the United States. More importantly, understanding the geologic history of the Lewis and Clark line may be a key to reconstructing the original shape of the Middle Proterozoic Belt basin.

There are several reasons why the geologic history of the Lewis and Clark line remains poorly understood: 1) the appropriate geochronological markers are difficult to find because faults within the line lie almost entirely in the middle Proterozoic Belt strata, 2) in many places, the inferred faults within the Lewis and Clark line are covered by dense vegetation, and 3) there have been few, if any, detailed kinematic studies along faults in the Lewis and Clark line. In the past, direction and magnitude of horizontal slip along all the faults in the Lewis and Clark line were inferred from separation of stratigraphic contacts, intrusive contacts, and axial surfaces of folds (Harrison and Jobin 1963, Hobbs *et al.* 1965, Wallace *et al.* 1990). To constrain the movement history along faults in the Lewis and Clark line, kinematic analysis, ^{40}Ar/^{39}Ar thermochronological studies, and detailed field mapping along the Hope, Ninemile, Osburn, and Placer Creek fault systems were conducted. The work suggests that the western Lewis and Clark line is a composite feature consisting of mid-Tertiary normal faults, Late Cretaceous thrusts, and thrusts reactivated from older normal faults. Implications of the fault-kinematic data are discussed in the context of magmatic-arc segmentation in the northern U.S. Cordillera during the Cretaceous.

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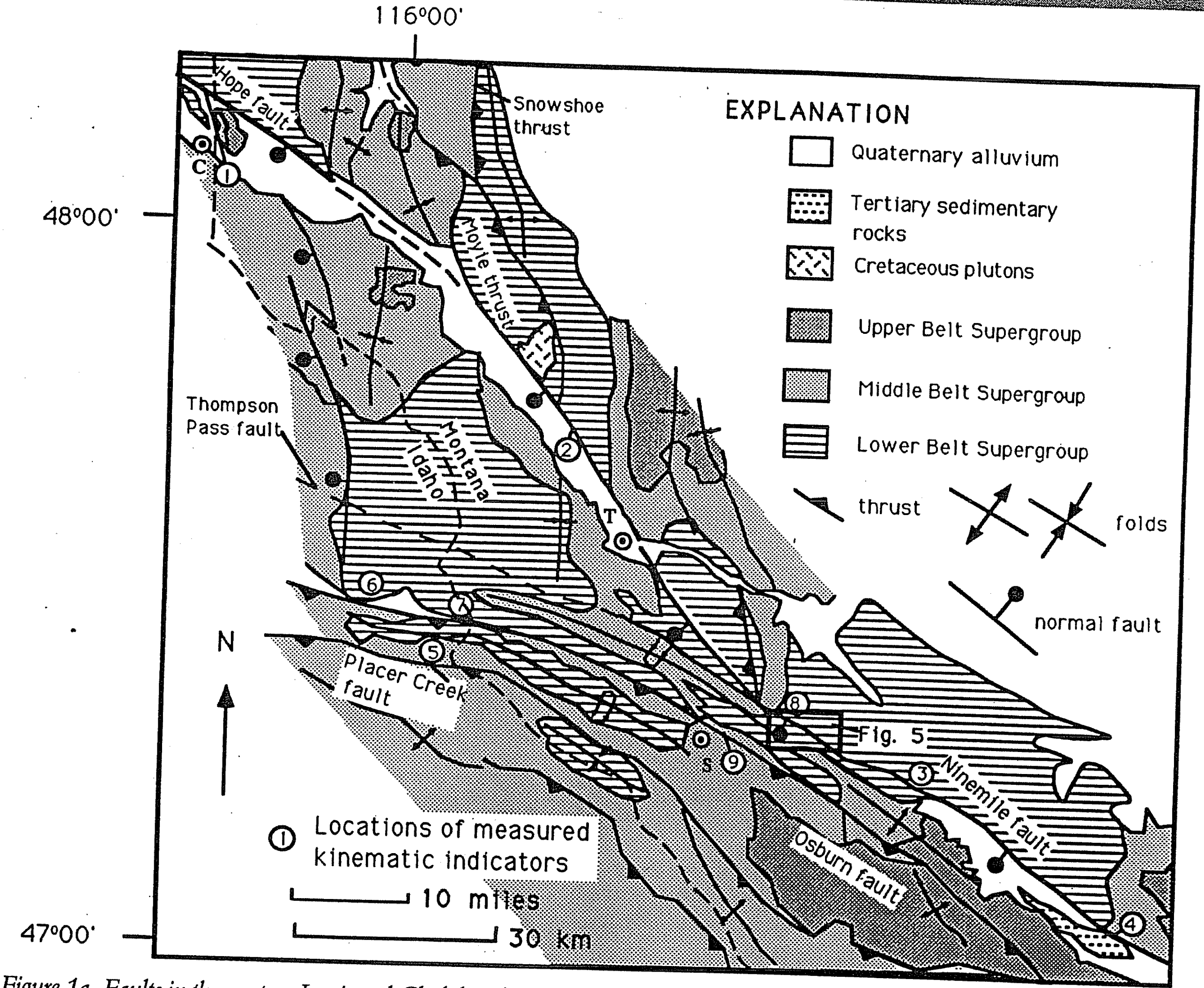

Figure 1a. Faults in the western Lewis and Clark line (a [above]) and stereographic projection of kinematic data (b [next page]). Circled numbers in (a) are locations where these data were collected. In (b), solid squares represent poles to normal faults, solid circles represent fault striations, triangles represent poles to thrusts, and open circles represent fold hinges. (C) Clark Fork; (T) Thompson Falls; (S) Superior. Geology is adapted from Harrison et al. *(1972, 1986, 1992), Gibson (1948), and Wells* et al. *(1981), with additional mapping from Fillipone and Yin (1994).*

Fault Kinematics and Age Constraints

Hope Fault

Although the Hope fault originally was not considered part of the Lewis and Clark line (Billingsley and Locke 1939), more recent work has related its development to the evolution of the structure (Harrison *et al.* 1986). The Hope fault zone near Blueslide, Montana *(location 2,* figure 1a), juxtaposes the lower Striped Peak Formation (upper Belt) over the Prichard Formation (lower Belt) and has a dip of 25°–35° to the southwest. The fault zone includes fault gouge, breccias, and numerous minor normal faults. As discussed below, the Hope fault is a normal fault. Using a dip angle of 35° for the fault and the stratigraphic relationship across the fault near Blueslide, Montana, the Hope fault has at least 5.9 mi (9.5 km) normal slip (Yin` 1991).

Near Hope, Idaho *(location 1,* figure 1a), numerous southwest-dipping faults occur in the Prichard Formation several tens of meters below the southwest-dipping Hope fault. These faults have normal slip as determined by displacements of granitic sills and beds in the Prichard Formation and by down-dip striations on the fault surfaces (figure 2). The granitic sills are early or middle Eocene as suggested by a ^{40}Ar/^{39}Ar hornblende age

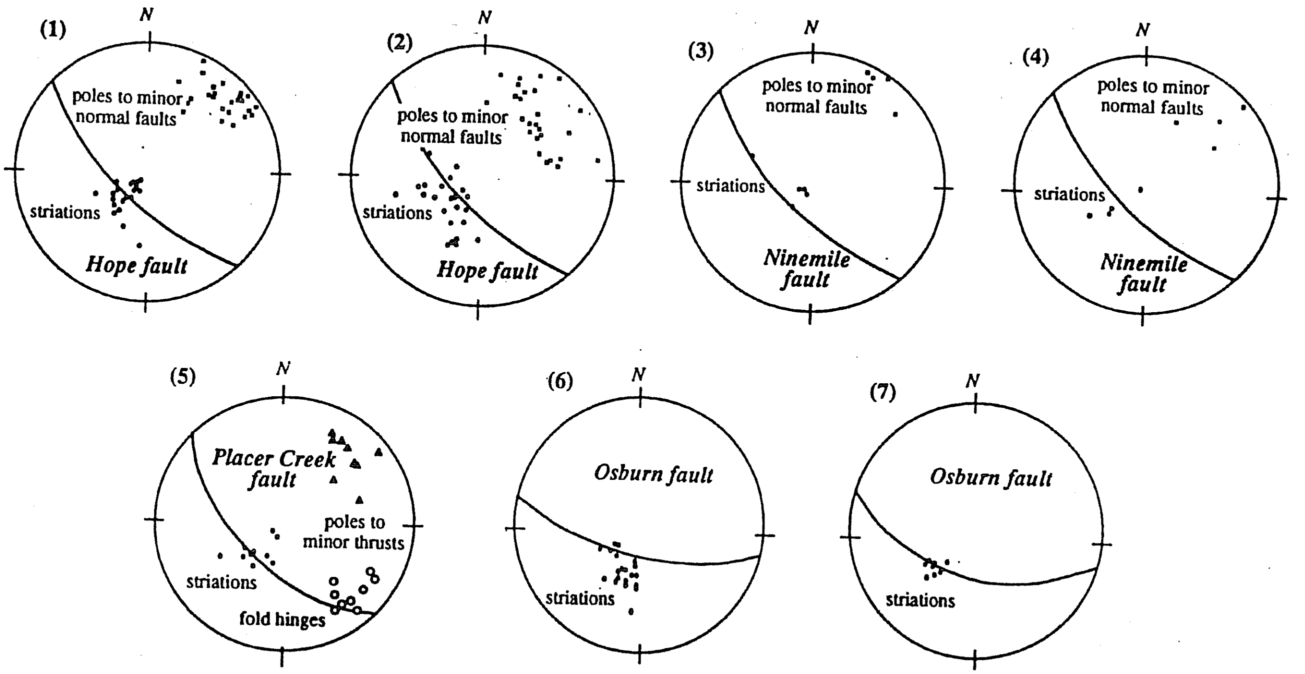

Figure 1b. Explanation previous page.

48.7±0.6 Ma and U-Pb zircon date of 58±5 Ma (Fillipone *et al.* 1992, Fillipone 1993, Fillipone *et al.* 1994). A minor normal fault in the Hope fault zone with several-meter displacement was intruded by a mafic dike that has a $^{40}Ar/^{39}Ar$ biotite age of 49±2 Ma (Fillipone 1993) to suggest that initiation of some small synthetic normal faults may have occurred by the beginning of the middle Eocene. This inferred age of movement along the Hope fault is coeval with movement along the Newport-Purcell trench detachment fault system (Harms and Price 1992).

Ninemile fault

West of Quinns, Montana, along the Clark Fork River, the Ninemile fault zone has a width of at least 50 ft (15 m) (its upper boundary is covered by Quaternary alluvium), dips between 45°– 55° to the southwest, and juxtaposes the younger Burke Formation over the older Prichard Formation (figure 1a). The fault zone in this area includes phyllitic schistosity containing down-dip lineations defined by stretched quartz grains (figures 3a,b, *location 8*; figures 1a,4). Asymmetric pressure shadows observed in thin section suggest normal slip (figure 3b). Likewise, displaced beds together with the observed fault striations within the shear zone also indicate normal-slip movement (figure 3c).

At Mill Creek, Montana (*location 4*, figure 1a), the Ninemile fault zone contains a similar phyllitic schistosity and down-dip stretching lineation. The southwest-dipping Ninemile fault in this locality has a greater down-dip stratigraphic offset, juxtaposing Tertiary sedimentary rocks dipping 20°–50° to the northeast in its hanging wall of the Ninemile fault over lower Belt strata in its footwall (Harrison *et al.* 1986). Here, the magnitude of the normal slip indicated by the stratigraphic separation in the dip direction is at least 4.3–5.0 mi (7–8 km) and may be as much as 7.5 mi (12 km). At Siegel Pass, Montana (*location 3*, figure 1a), minor normal faults are observed in the footwall directly below the Ninemile fault (figure 3c). This observation also supports the suggestion that the Ninemile fault is a normal fault.

The inferred normal slip along the Ninemile fault is consistent with the field relationship that the southwest-dipping fault juxtaposes younger strata in its hanging wall and older strata in its footwall (figure 1a). The juxtaposition of the northeast-dipping Tertiary sedimentary rocks in the hanging wall over the Belt strata in the footwall across the Ninemile fault suggests that the fault is a Tertiary or post-Tertiary normal fault. Because the Ninemile fault lies along strike with and dips in the same direction as the Hope fault, and the two faults show normal-slip as indicated by the aforementioned kinematic data, it is suggested that the two compose a single Tertiary normal fault.

Although the above kinematic data together with the observed stratigraphic separations suggest normal movement along the Ninemile fault, it may be argued that the fault could have experienced earlier strike-slip movement. Riedel shears, *en echelon* folds, and rotation of earlier geologic features, all characteristic of strike-slip fault systems (Sylvester 1988), are lacking in the area where bedrock is well exposed along the Clark Fork River (figure 4). Geologic mapping conducted in the footwall along the Clark Fork River reveals only the presence of minor normal and re-

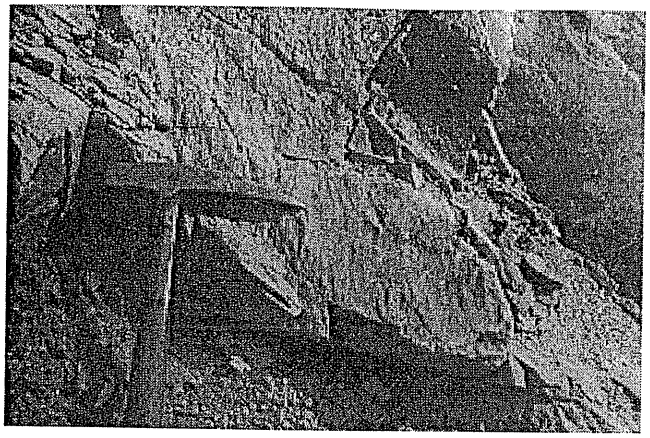

Figure 2. Down-dip striations on a minor normal fault in the footwall of the Hope fault that offsets a granitic sill. The age of the sill is determined by a $^{40}Ar/^{39}Ar$ hornblende age of 48.7±0.6 Ma and a U-Pb zircon date of 58±5 Ma (Fillipone et al. *1992).*

verse faults. Neither bedding nor the spaced cleavage (S_1), possibly related to Late Cretaceous thrusting, are rotated systematically adjacent to the Ninemile fault (figure 4). Thus, it is concluded that normal faulting is the only motion that occurred along the Ninemile fault.

Osburn Fault System

The Osburn fault system is defined by a zone of north to north-northeast-verging folds and thrust faults (figures 1a, 5a). Rocks in this zone consist of ductilely sheared schists, quartzite, and limestone that are strongly foliated and lineated (figure 5b; *location 9,* figure 1a). Foliation is west-northwest striking and parallels the Osburn fault zone. Lineations are oriented dominantly down dip and are defined by crystal–plastically stretched grains of quartz, calcite, and pyrite, and by elongated limestone breccias (figure 5c). Stretching lineations and striations in the Osburn fault zone were measured *(locations 6, 7,* figure 5a), and the trend of all measured lineations is perpendicular to the regional trend of hinge lines of large overturned folds that change strike from east-west to northwest-southeast along the northern margin of the Idaho batholith (figure 1). This geometric relationship and kinematic compatibility suggest that the folds and the Osburn fault zone could have developed synchronously during eastward thrusting east of the Idaho batholith (Hyndman *et al.* 1988).

Placer Creek Fault

The Placer Creek fault is exposed south of Wallace, Idaho, along Placer Creek (figure 1a). The fault strikes west northwest and dips about 40°– 60° to the southwest. Rocks are intensely folded within and adjacent to the fault zone. Orientations of striations and fold vergence in and adjacent to the fault zone indicate north to north northeast–directed thrust movement *(location 5,* figure 1a). However, the fault juxtaposes younger rocks over older rocks as observed by Harrison *et al.* (1986). This apparent contradiction may be resolved, if the fault were an out-of-sequence thrust and initiated as a normal fault and was later reactivated by reverse faulting. The age of the fault is not constrained. The reverse-faulting episode may have been coeval with movement along the Osburn fault as the two faults are parallel.

Thompson Pass and St. Mary Faults

The Thompson Pass fault was not located in the field because of the heavy vegetation. Thus, its age and kinematics were not constrained in this study. It is im-

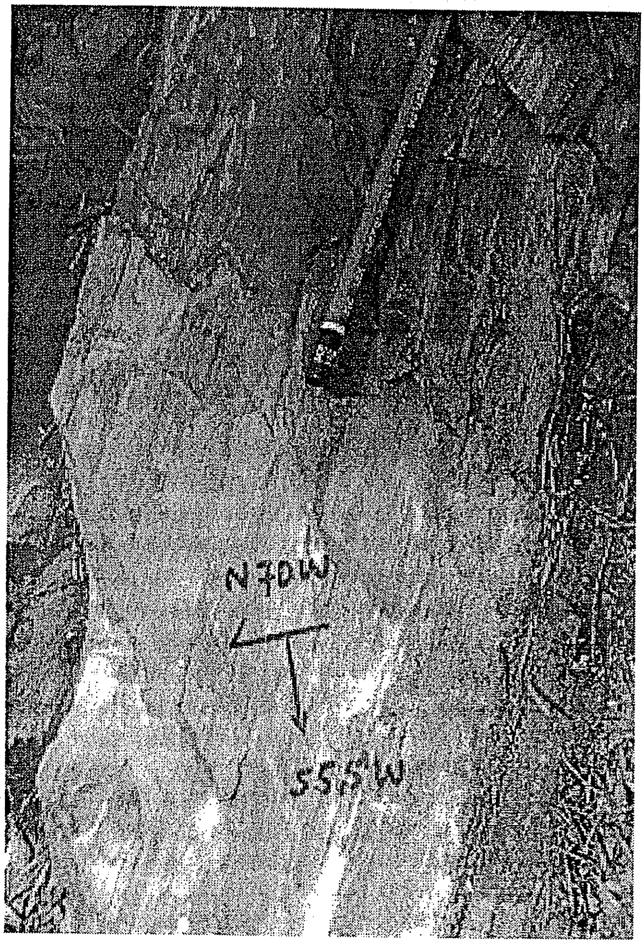

Figure 3a. Down-dip lineations on phyllitic schistosity surfaces in the Ninemile fault zone near Paradise, Montana. See figure 4 for distribution of schistosity and lineation directly below the Ninemile fault.

Figure 3b. Microscopic view of structural fabric in the Ninemile fault zone. The section is cut parallel to the lineation but perpendicular to the foliation. The asymmetric pressure shadows (white) around the pyrite grains (black) indicate normal-slip motion along the Ninemile fault.

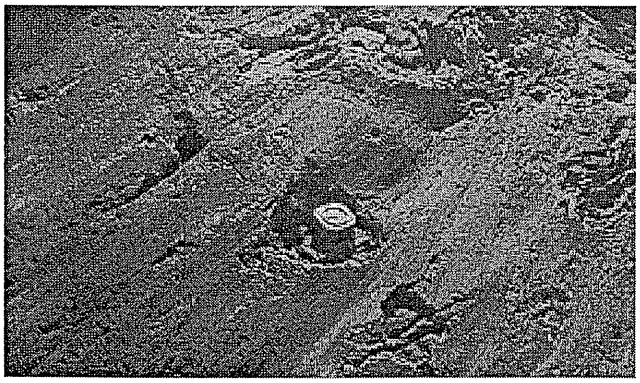

Figure 3c. A minor, normal-fault surface with down-dip striations near the Siegel Pass.

portant to note, however, that the existence of the Thompson Pass fault was originally inferred only from subsurface geology (Hobbs *et al.* 1965). Therefore, its projected surface trace on geologic maps (figure 1a) would depend on how the geometry of the fault was interpreted.

The trace of the St. Mary fault shown on the map of Harrison *et al.* (1986) should be exposed in the northeastern corner of figure 4 near Quinns, Montana. Despite excellent exposure of the Prichard Formation with numerous recognizable marker beds (*e.g.*, mafic sills and quartz arenite beds) along the Clark Fork River that cross the inferred fault trace (Harrison *et al.* 1986), mappable strike-slip faults were not identified. Instead, a few northeast-directed thrusts with slip between 98–30 ft (30–100 m) were mapped along the projected trace of the St. Mary fault. (See northeastern corner of figure 4.)

Discussion

Magmatic-Arc Segmentation and the Original Shape of the Belt Basin

Rehrig *et al.* (1987) considered that the Lewis and Clark line was a Tertiary transfer fault system linking the extensional fault system in the Eocene Priest River crystalline complex to the north with the extensional fault system in the Bitterroot metamorphic core complex to the south. They suggested that the Lewis and Clark line accommodated different amounts of Eocene extension on both sides of the transfer system. The isotopic ages and kinematic data suggest, however, that the western Lewis and Clark line was not a major strike-slip fault system in either the Tertiary or Cretaceous. Movement on the Hope fault and its inferred southeast continuation, the Ninemile fault, is normal slip. The two faults are coeval with extension and detachment faulting in the Priest River and Bitterroot core complexes that lie to the north and south, suggesting a possible common tectonic evolution and kinematic linkage. Because the two faults are normal faults, this invites the question of how the mid-Tertiary core–complex extension in the northeastern Washington and northern Idaho was transferred to western Montana. One hypothesis is that the Hope fault, the Ninemile fault, and other northwest-striking normal faults east of the Purcell-trench detachment fault (Herms and Price 1992) and the Bitterroot core complex (Hyndman *et al.* 1988) have variable normal slip along strike. Such variation of slip along strike led to transfer of extension from the Purcell-trench detachment fault to the Bitterroot detachment.

The result of this study also implies that the Idaho and Kanisku (=Selkirk) batholiths have not shifted in their relative position to one another as suggested previously (Sales 1968). The apparent segmentation of the Mesozoic plutonic belt in the region may have been due to the difference in crustal composition (*e.g.*, continental versus oceanic) that controls the depth of emplacement and thus the surface exposure of the plutons and variations in dip angle of the subducting Farallon plate along its strike during the Late Cretaceous (Yin 1992, figure 6).

In the first model (figure 6a), the segmentation of the Mesozoic plutonic belt in the northern U.S. Cordillera is inferred to be caused by the difference in crustal composition which controls the depth of pluton emplacement. According to the pluton-emplacement model of Mahon *et al.* (1988), the final emplacement depth of a pluton strongly depends on the viscosity of the crust, which in turn depends on the geothermal gradient (*i.e.*, viscosity

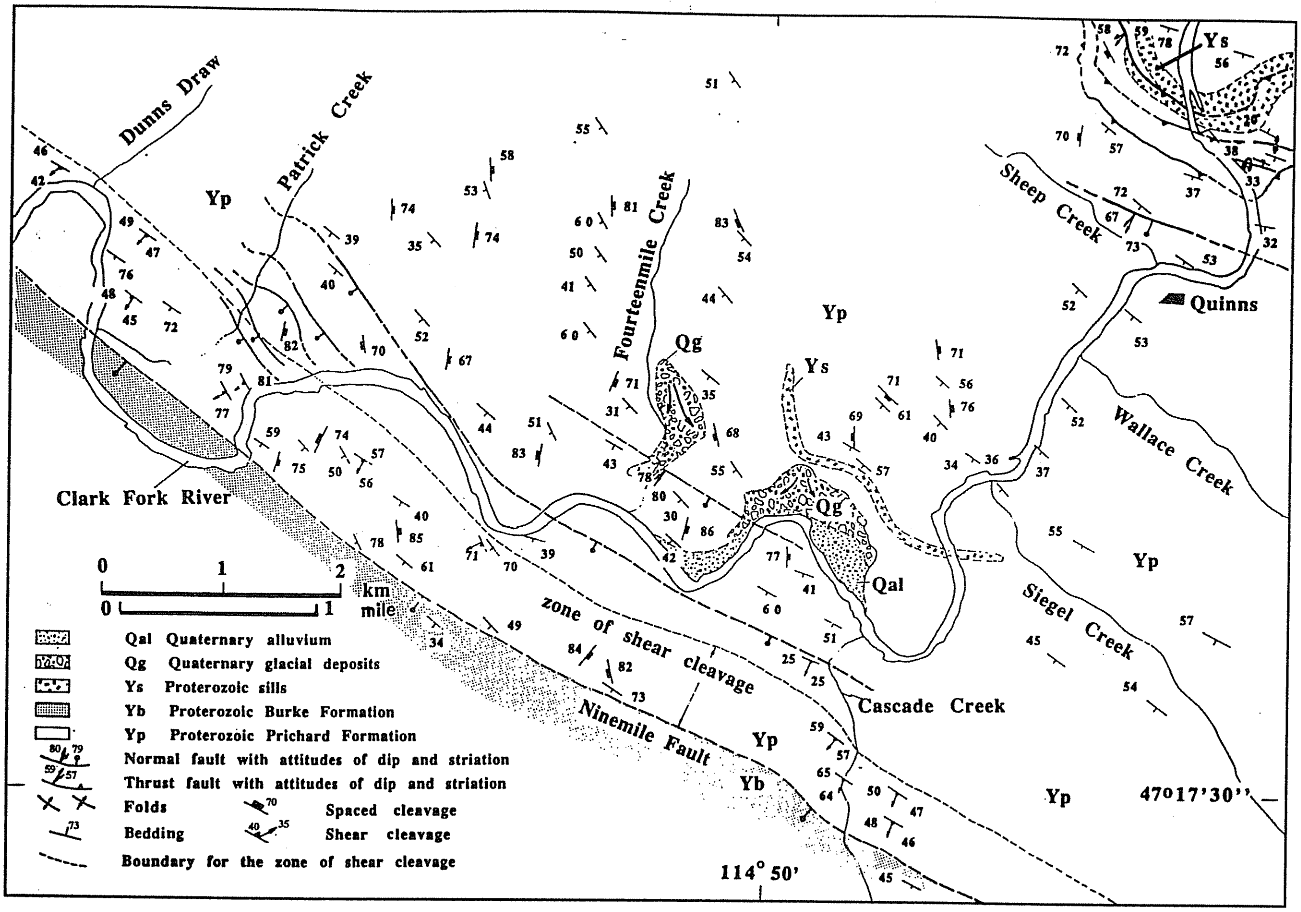

Figure 4. Detailed geologic map of the Ninemile fault zone near Quinns, Montana. Note the trace of the St. Mary fault in the map by Harrison et al. *(1986) should pass through the northeastern corner of the map area. This fault, however, could not be established in the field during mapping because neither beds nor sills in the Prichard Formation are offset along the inferred fault trace.*

decreases exponentially as the temperature increases) and the crustal composition.

Chen and Molnar (1983) pointed out that it is the difference in crustal composition (*i.e.,* quartz-rich continental crust versus olivine-rich oceanic crust) that makes the oceanic lithosphere much stronger and less deformable than the continental lithosphere. The widespread occurrence of mafic sills in the lower Belt strata north of the western Lewis and Clark line (Harrison *et al.* 1986) makes it reasonable to assume that the crust of the Belt basin in northwestern Montana was either oceanic or transitional due to the Middle Proterozoic rifting that initiated the basin. Such crustal composition would have made the basement of the basin much stronger than that of the continental crust to the south where the mafic dikes are either absent or less prominent. Thus, this hypothesis suggests that although the subducting slab might have had uniform dip and magma was transported upward from the subducting slab, the plutons below the northern Belt basin north of the Lewis and Clark line were unable to reach a shallow depth during the Cretaceous. Therefore, few plutonic bodies were exposed north of the Lewis and Clark line. An example of a magmatic event with little surface expression is the mid-Tertiary magmatism across the Colorado Plateau. Although widespread volcanic activity was recognized around the plateau, little trace of this event was detectable within the plateau. However, timing of the magmatism adjacent to the plateau and its systematic correlation with the kinematic history of the Farallon and North American plates suggest that the magmatism indeed affected the Colorado Plateau region during the mid-Tertiary (Dickenson 1981). Although the Colorado Plateau may not be underlain by the oceanic or transitional crust, its absence of mid-Tertiary volcanism implies a difference in either crustal composition or thermal history between the plateau and its neighboring regions. Perhaps the same applies to the northern part of the Belt basin.

An alternative model (figure 6b) for the apparent offset of the Mesozoic plutonic belt in the northern U.S.

Cordillera is that the subducting slab of the Farallon plate was dipping variably along strike, steeper north of the Lewis and Clark line and shallower south of the Lewis and Clark line, when the Late Cretaceous Idaho and Kaniksu batholiths were emplaced. Because subduction-related arc magmatism commonly originated at depths between 50 and 62 mi (80 and 100 km) along the subducting slab (Ringwood 1977), a change in dip of a subducting slab would have caused segmentation of the corresponding magmatic arc at the surface.

The exclusion of major strike-slip faults in the western Lewis and Clark line implies that the shape of the Belt basin has not been modified by a large-scale offsets along strike-slip faults (*c.f.,* Sales 1968). The original geometry of the basin may be constructed by restoring the Mesozoic to early Tertiary shortening and Eocene extension.

Variable Fold Trends and Thrusting Directions in the Lewis and Clark Line

The trend of folds and transport direction of thrusts within the Lewis and Clark line vary from west to east. This may have been caused by multi-phase deformation. However, kinematic indicators observed from the Osburn fault zone show a systematic variation in thrust-transport direction: a north-south direction of shortening to the west, and northeast-southwest shortening to the east (figure 1a). This change in thrust-transport direction along the Osburn fault corresponds with the local trend of fold hinge lines: an east-west trend to the west and an northwest-southeast trend to the east (figure 1a). Consistent with both hypotheses discussed for the curved Mesozoic magmatic belt, it is interpreted that the folds and thrust faults in the western Lewis and Clark line were developed during the emplacement of the Idaho batholith and that the variable trends of folds and thrust-transport directions were caused by the spreading of the Idaho batholith to the east and the north.

Conclusions

Kinematic studies along the major faults in the western Lewis and Clark line suggest that it is a composite tectonic feature that consists of northwest-striking, mid-Tertiary normal-fault systems (Hope and Ninemile faults) and east west-striking, Late Cretaceous thrust system (Osburn fault). Surprisingly, geologic evidence is lacking that would indicate significant strike-slip motion along faults in the western Lewis and Clark line. Because the major faults in the Lewis and Clark line were undeveloped during the same geologic period and thus were not

Figure 5a. Recumbent fold in the Osburn fault zone near St. Regis, Montana.

Figure 5b. Down-dip stretching lineations within the Osburn fault zone, St. Regis, Montana.

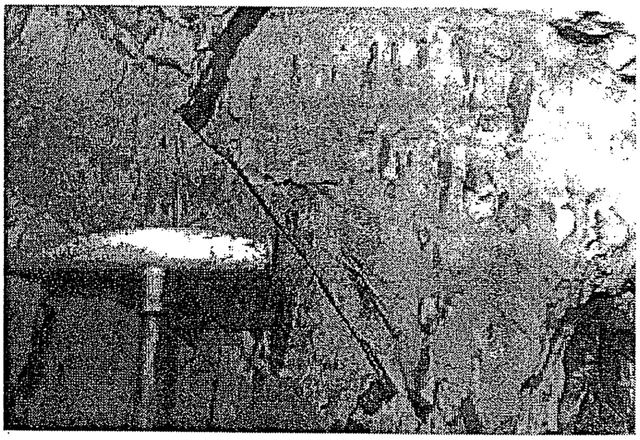

Figure 5c. Highly stretched breccias in the Wallace Formation of the Belt Supergroup. Photo of an overturned fold limb in the Osburn fault zone near St. Regis, Montana.

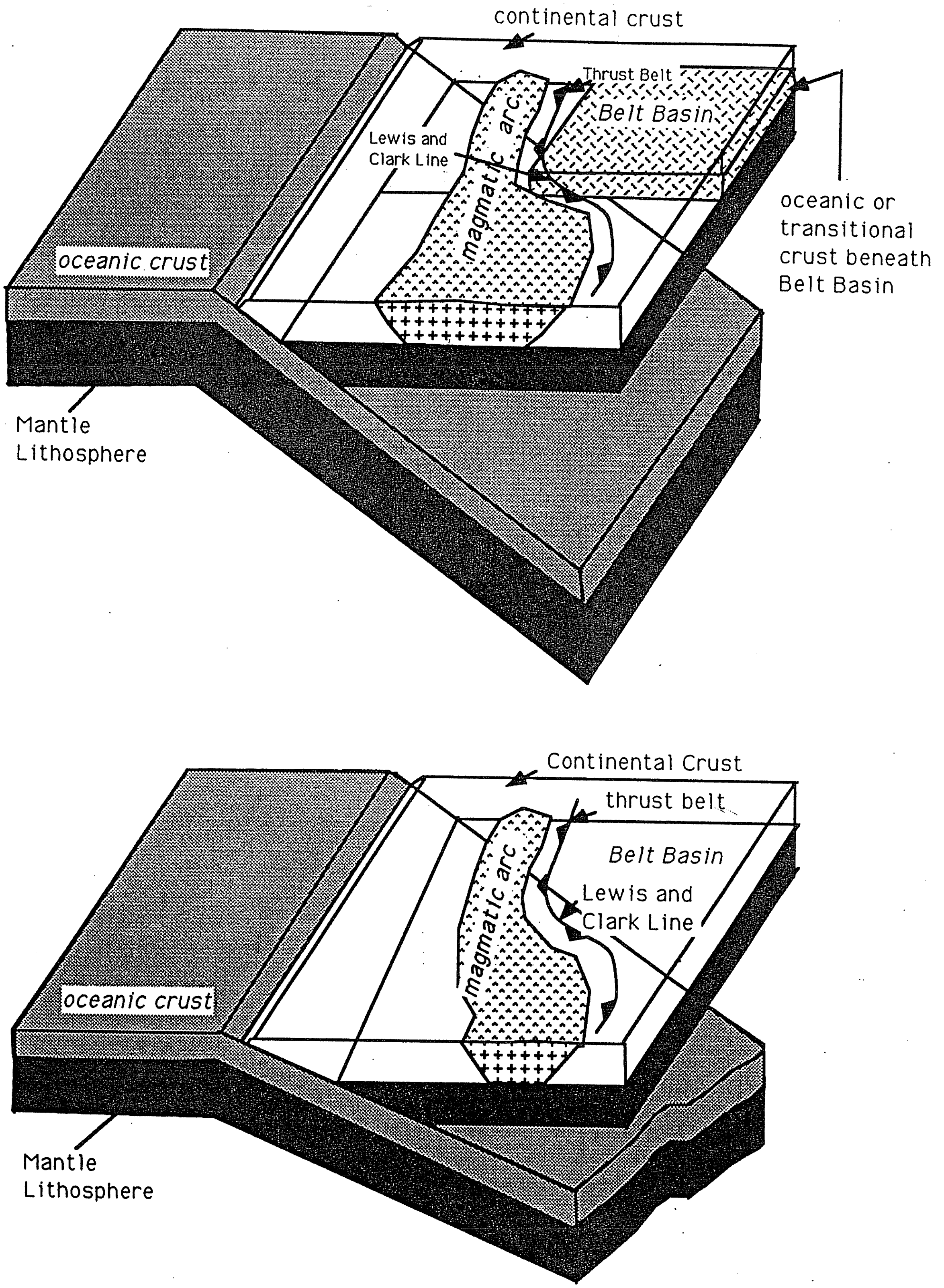

Figure 6. (a) Diagrammatic representation of subducted oceanic crust below Belt basin. (b) An alternative interpretation in which the subducting slab of the Farallon plate has a steeper dip north of the Lewis and Clark line than south of this line.

kinematically related, it is suggested that the phrase "Lewis and Clark fault system" (Lorenz 1984) should not be used.

The apparent offset of the Mesozoic plutonic belt (Kaniksu and Idaho batholiths) in the northern U.S. Cordillera was mostly inherited from the period of their emplacement. This pattern may either have been controlled by the difference in basement composition beneath the Belt sedimentary rocks or by the variation in dip of the subducting Farallon plate along its strike.

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References

Billingsley P., and Locke, A., 1939, Structure of ore districts in the continental framework: American Institute of Mining and Metallurgical Engineers, 51 p.

Chen, W.P., and Molnar, P., 1983, Focal depth of intracontinental and intraplate earthquakes and their implications for the thermal and mechanical properties of the lithosphere: Journal of Geophysical Research, v. 85, p. 4183–4212.

Dickinson, W.R., 1981, Plate tectonic evolution of the southern Cordillera, *in* Relations of Tectonics to Ore Deposits, W.R. Dickinson and W.D. Payne *(eds.)*: Arizona Geological Society Digest, v. 14, p. 113–135.

Fillipone, J.A, 1993, Tectonic and thermochronological evolution of the Cabinet and Selkirk Mountains, northwest Montana and northeast Idaho: [Ph.D. dissertation]: University of California, Los Angeles, California, 341 p.

Fillipone, J.A., Harrison, T.M., Sample, J.C., and Yin`, A., 1992, Thermochronological evolution of the Hope and Moyie fault systems, northwest Montana and northeast Idaho: A progress report: Geological Society of America Abstracts with Programs, v. 24, p. 11.

Fillipone, J.A., and Yin`, A., 1994, Age and regional tectonic implications of Late Cretaceous thrusting and Eocene extension, Cabinet Mountains, northwest Montana and northern Idaho: Geological Society of America Bulletin, v. 106, p. 1017–1032.

Gibson, R., 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geological Survey Bulletin 956, 131 p.

Harms, T.A., and Price, R.A., 1992, The Newport fault: Eocene listric normal faulting, mylonitization, and crustal extension in northeastern Washington and northwestern Idaho: Geological Society of America Bulletin, v. 104, p. 745–761.

Harrison, J.E,. Kleinkopf, M.D., and Obradovich, J.D., 1972, Tectonic events at the intersection between the Hope fault and the Purcell trench, northern Idaho: U.S. Geological Survey Professional Paper 719, 24 p.

Harrison, J.E., and Jobin, D.A., 1963, Geology of the Clark Fork quadrangle, Idaho-Montana: U.S. Geological Survey Bulletin, 1141-K, 38 p.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1986, Geology and structure map of the Wallace 1° x 2° quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-1509. Scale 1:250,000.

Hobbs, S.W., Griggs, A.B., and Campbell, A.B., 1965, Geology of the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geological Survey Bulletin 478, 139 p.

Hyndman, D.W., Alt, D., Sears, J.W., 1988, Post-Archean metamorphic and tectonic evolution of western Montana and northern Idaho, *in* Metamorphic and tectonic evolution of the western Cordillera, conterminous United States, W.G. Ernst *(ed.)*: Rubey Volume 7, p. 332–361.

Lorenz, J.C., 1984, The function of the Lewis-Clark fault system during the Laramide orogeny, *in* Montana Geological Society Guidebook, p. 221–230.

Mahon, K.I., Harrison, T.M., and Drew, D.A., 1988, Ascent of a granitoid diapir in a temperature varying medium: Journal of Geological Research, v. 93, p. 1174–1188.

Parrish, R.R. Haugerud, R.A., and Price, R.A., 1990, The Eocene tectonic transition, Oregon to Alaska: Geological Society of America News and Information, p. 124–125.

Rehrig, W.A., Reynolds, S.J., and Armstrong, R.L., 1987, A tectonic and geochronologic overview of the Priest River Crystalline Complex, northeastern Washington and northern Idaho: Washington Division of Geology and Earth Resources Bulletin 77, p. 1–14.

Reynolds, M.W., 1979 Character and extent of Basin-Range faulting, western Montana and east-central Idaho: Rocky Mountain Association of Geologists—Utah Geological Association 1979 Basin and Range Symposium Guidebook, p. 185–193.

Ringwood, A.E., 1977, Petrogenesis in island arc systems, *in* Island Arcs, Deep Sea Trenches, and Back-Arc Basins, M. Talwani, and W.C. Pitman III *(eds.)*: Maurice Ewing Series 1, American Geophysical Union, Washington, D.C., p. 311–324.

Sales, J.K., 1968, Crustal mechanics of Cordilleran foreland deformation: A regional and scale-model approach: American Association of Petroleum Geologists Bulletin, v. 100, p. 1666–1703.

Sylvester, A.G., 1988, Strike-slip fault systems: Geological Society of America Bulletin, v. 100, p. 1666–1703.

Wallace, J.D., Lidke, D.J., Schmidt, R.G., 1990, Faults of the central part of the Lewis and Clark line and fragmentation of the Late Cretaceous foreland basin in west-central Montana: Geological Society of America Bulletin, v. 102, p. 1021–1037.

Wells, J.D., Lindsey, D.A., Van Loenen, R.E., 1981, Geology of the Cabinet Mountains Wilderness, Lincoln and Sanders counties, Montana: U.S. Geological Survey Bulletin 1501.

Yin`, A., 1991, Kinematics of the Hope-Ninemile fault and its tectonic implications, northern Idaho and northwestern Montana: Geological Society of America Abstracts with Programs, v. 22, p. 96.

———, 1992, Kinematics of the Lewis and Clark fault system in northern U.S. Cordillera: Implications for segmentation mechanisms of Andean-type magmatic arcs: 29th International Geological Congress, v. 2, p. 414.