

MONTANA THRUST BELT PROVINCE (027)

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INTRODUCTION

The Montana Thrust Belt Province lies in the generally mountainous terrain of western Montana, bordering Canada and Idaho. It includes that part of the Cordilleran Thrust Belt which occurs within the State of Montana. The basic setting of the Province consists of numerous thrust sheets and intrusive bodies. Thrusting took place generally from west to east during Late Cretaceous and Paleocene time. The overall structure of much of the province is complex, and many structural and stratigraphic relationships remain obscure or are the subject of controversy. The pre-Jurassic stratigraphic sequence varies markedly from south to north as shown in figure 2.

The area of the province is approximately 41,400 sq mi. Approximately 20 percent of the province consists of Federal lands withdrawn from oil and gas exploration because of inclusion within Glacier National Park, 10 wilderness areas, and various proposed additions to wilderness. Unlike the adjacent and contiguous Alberta Foothills Belt to the north, the Montana Thrust Belt has failed to yield appreciable hydrocarbons in spite of more than 80 years of exploration and wildcat drilling, favorable source rocks in the eastern part of the province, and hydrocarbon seeps in the northern part. Only one producing gas field is present in the province; the two-well Knowlton field, in T. 26 N., R. 8 W., has produced about 6 BCFG and 33,000 barrels of condensate. Federal lands withdrawn from exploration are generally west of the mountain front in areas analogous to those in Alberta that have not yielded hydrocarbons.

Five conventional hydrocarbon plays were individually assessed, the confirmed Imbricate Thrust Gas (2701) and the hypothetical Imbricate Thrust Oil (2707) Plays north of the Lewis and Clark Lane; the hypothetical Helena Salient Gas Play (2704) east of the Boulder batholith; the hypothetical Blacktail Salient Oil Play (2705) in the Lima area of southwestern Montana; and the hypothetical Tertiary Basins Oil and Gas Play (2706) in relatively small basins scattered throughout the province. The province includes two unconventional continuous-type plays, the Cone Member, Marias Shale Play (2703) and the Bakken Shale Fracture Systems Play (2804) described in Province 28, North Central Montana. I particularly acknowledge data provided by Joe Piombino, AMOCO; Joe Curial, UNOCAL; Dave Lopez and Karen Porter, Montana Bureau of Mines and Geology; Melody Holm, U.S. Forest Service; Jim Halvorson, Montana Board of Oil and Gas Conservation; and Debra Hanneman and Jack Warne, Consultants.

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CONVENTIONAL PLAYS

2701. IMBRICATE THRUST GAS PLAY

Undiscovered gas-bearing imbricate thrust zones and related anticlines likely occur in the footwall of the Eldorado-Lewis Thrust system, including the frontal Montana Disturbed Belt in a 9,600 sq mi area designated the Imbricate Thrust Gas Play. The play area is approximately 185 mi long (NW-SE) and 30 to 60 mi wide (E-W) and extends southeastward from the United States-Canada boundary to the Lewis and Clark Fault Zone (Lane). The western edge of this play is the Rocky Mountain Trench. The eastern edge is the front of the Montana Thrust Belt. The central part of the play area contains about 7,100 ft of Middle Proterozoic sedimentary rocks unconformably overlain by about 4,350 ft of Paleozoic rocks, primarily carbonates, more than 800 ft of Jurassic and 4,800 ft of Cretaceous chiefly siliciclastic rocks (Mudge, 1972).

Reservoirs: Potential reservoir rocks are primarily dolomitized limestone in the upper part of the Mississippian Madison Group (Castle Reef Formation). Where drilled or exposed in the east-central part of the play area, this reservoir section ranges from less than 200 to more than 500 feet thick and exhibits both vuggy and intercrystalline porosity (4-12 percent) but low permeability (6-12 mD) and provides a demonstrated reservoir for the relatively small structurally trapped gas accumulations so far discovered. Where drilled in the southwestern part of the play area, the Madison had very little matrix porosity; "production tests of three of the most highly fractured intervals recovered only 141 to 288 bbl of fresh water with R_w values ranging from 2.55 to 3.75" (Peterson and Nims, 1992). Underlying Lower Mississippian cherty limestone and Devonian dolostones may be sufficiently fractured locally to be reservoirs in zones several hundred feet thick. Thin Jurassic and Cretaceous sandstone may also provide fracture-enhanced reservoirs for hydrocarbons in structural traps.

Source rocks, timing, and migration: Source rocks include the following, from Clayton and others (1983): Of the Marias River Formation, the oil-prone Cone Member, 18-38 ft thick, averages 2.4 percent TOC (eight samples); the Kevin Member, 229-274 ft thick, averages 1.14 percent TOC (range 0.43-2.64 percent, 58 samples). The Flood Member of the Blackleaf Formation, 43-168 ft thick, averages 1.1 percent TOC (range 0.1-2.81 percent, seven samples). The shale member of the Jurassic Swift Formation, Ellis Group, 6-32 ft thick, averages 1.09 percent TOC (range 0.75-1.77 percent, nine samples); other Jurassic and Cretaceous units are generally lean, as are the Mississippian limestones. The only older source rock, the oil-prone Bakken-equivalent Exshaw Formation, 10-40 ft thick, averages 0.97 percent TOC (range 0.11-2.81, eight outcrop samples). However, Dolson and others (1993, fig. 8) reported a range of 2.5-8.7 percent TOC from wells penetrating this unit farther east. Vitrinite, RockEval, and CAI (conodont alteration index) measurements show that thermal maturity generally increases westward in this play, but is lower in structurally higher thrust sheets, indicating heating during thrust burial. In the

northwestern part of the play, CO₂ may be a serious contaminant, based on wells drilled on the western margin of the Lewis Thrust Plate in adjacent British Columbia (table 1).

Table 1. Gas analyses from northernmost duplex zone of Fritts and Klipping (1987a, b) beneath western edge of Lewis Thrust Plate, northeastern margin of Kishenehn Basin (Boberg, 1984, fig. 1)

GAS ANALYSES FROM NORTHERN PART OF LIVINGSTONE DUPLEX				
Shell-Honolulu Flathead D-22-A				
DEPTHS	% CO₂	C1	C2	H₂S
6,528-7,085	43.87	45.02	3.01	0.36
7,208-7,665	84.92	11.06	0.35	0.95
10,144-10,606	99.99	Tr	Tr	Tr
11,175-11,581	97.68	Nil	Nil	0.11
Average	81.62	28.04	1.68	0.47
Shell #2 Flathead D-12-A				
DEPTHS	% CO₂	C1	C2	H₂S
2,350-3,300	86.65	6.58	0.13	1.55
	90.45	5.41	0.09	1.40
Depth Unlisted	93.91	4.05	0.02	1.05
3,372-3,385	67.79	29.73	0.05	1.04
	83.14	14.77	0.02	1.00
3,454-3,524	93.77	4.02	0.03	1.10
Depth Unlisted	93.82	3.99	0.01	1.10
Average	87.08	9.79	0.05	1.18

Data from Montana Oil and Gas Conservation Division

The sequence of thrusting presented by Fritts and Klipping (1987a, b) indicates thrust burial, (by thrust loading) through the critical temperature-depth for oil generation, and the sequence proceeded from west to east against the long-active Sweetgrass Arch (Lorenz, 1983). Therefore, hydrocarbons generated beneath the Lewis and Eldorado Thrusts may have migrated updip into the Cutbank and associated oil and gas fields to the east on the Sweetgrass Arch.

Traps: The trap types are imbricate thrusts, which are inferred to form large duplex culminations in the western part of this play (Fritts and Klipping, 1987a, b) similar to major oil- and gas-productive structures in the Canadian Foothills Belt in front of the Lewis and other major thrusts. The analogous region of this play contains relatively small buried imbricate thrust closures (for example, Blackleaf Canyon and Knowlton gas fields), which occur along the eastern edge of and east of the large areas of Federal lands withdrawn from leasing. The depth distribution for undiscovered accumulations is expected to range from more than 19,000 ft in the west to 3,000 ft in the eastern part of the play.

Exploration status: These two small gas accumulations have produced a total of 7 BCFG and 0.03 million barrels condensate (J.W. Halvorson, written commun., 1993), and gas analyses from these yield more than 11 percent CO₂ (Johnson, 1984). The smaller Two Medicine gas field produced 0.27 BCFG and 0.01 MMB

condensate prior to being shut in more than 20 years ago. Altogether fewer than 80 wildcat wells have resulted in the discovery of three relatively minor gas fields.

Resource potential: Four very large duplex zones, antiformal imbricate stacks of inferred Mississippian carbonate rocks, remain to be drilled in the western part of this play in the United States (Fritts and Klipping, 1987a, b). The northeasternmost contains abundant CO₂ in Mississippian carbonate reservoirs in adjacent Canada (table 1). The southern extent of this contaminant is unknown. Large Tertiary normal faults, present in the western part of the play, may have breached older seals and traps, resulting in the fresh water recovered from the Madison in the southwestern part of the play. If one of the large duplex zones is natural gas productive, it could contain as much as 2,000 BCFG, based on inferred closure volume.

UNCONVENTIONAL PLAY

Continuous-Type

2703. CONE MEMBER, MARIAS RIVER SHALE PLAY (HYPOTHETICAL)

This is an unconventional, continuous-type oil play. The calcareous Cone Member of the Cretaceous Marias River Shale in the Montana Disturbed Belt "is considered to be a good potential source rock for oil because of the relatively high hydrogen index values and above average organic carbon values" (Clayton and others, 1983). These authors reported a thickness range of 18 to 38 ft with an average TOC of 2.4 percent (eight samples), and briefly described the Cone as a gray calcareous marine siltstone. Rice (1976) correlated this unit with the Cenomanian to Turonian Greenhorn Formation of the northern Great Plains. The entire Marias River Shale is from 1,200 to 1,300 ft thick in the disturbed belt (Mudge, 1972). Oil-stained fractures are common in the Cone Member where it is exposed in the disturbed belt. Marine shales assigned to the Marias River extend southeastward into the Lewis and Clark Fault Zone in the footwall of the Eldorado Thrust System (Tysdal and others, 1991). Anticipated depths to the Cone range from less than 2,500 ft at the eastern edge of the play to more than 13,000 ft beneath the front of the Lewis Thrust.

The play area comprises 3408 sq mi in the northeastern part of the Montana Thrust Belt. The eastern and western limits are respectively the inferred $R_o = 0.6$ and $R_o = 1.5$ contours from a great deal of published (Clayton and others, 1982) as well as unpublished data. The Cone is considered to represent a continuous-type oil deposit based on oil production from a relatively low structural position lateral to anticlinal and thrust-imbricate closures in the top of the Madison in the East Glacier field and the apparent lack of a documented oil-water contact. The oil has not been expelled from its source, and conventional oil-water contacts are not anticipated.

Exploration status and resource potential: About 70 wildcat wells have drilled through the Cone Member of the Marias River within the play area. Many have reported good oil shows. Production (cumulative through 1992) from the two-well East Glacier field is given as 22,620 BO (barrels of oil) (Jacobson and others, 1993, p. 13). The first oil discovery well in Montana, completed in 1905 in the eastern part of what is now Glacier Park, probably produced from fractured Cone (Boberg, 1984). Between 1905 and 1907 one other oil well with initial capacity of 20 BO/day and two dry holes were completed; however, very little oil was produced, according to Boberg (1984).

I consider that an excellent chance exists for considerable oil production from fractured Cone within the play area, particularly if wells are drilled so as to encounter the maximum number of fractures.

2704. HELENA SALIENT GAS PLAY (HYPOTHETICAL)

The Helena Salient of the Montana Thrust Belt lies east of the Boulder Batholith. Anticlinal and thrust imbricate closures within the salient define the Helena Salient Gas Play, a hypothetical structural play slightly more than 3,600 sq mi in area. The central part of the play area contains 12,000-25,000 ft of Middle Proterozoic sedimentary rocks, unconformably overlain by about 9,000 ft of Phanerozoic sedimentary rocks nearly half of which are Cretaceous. These latter are chiefly Upper Cretaceous siliciclastic and volcanic rocks. The salient forms a portion of the Belt Embayment, an inferred aulacogen during Middle Proterozoic time, and a region of locally intense igneous activity during Late Cretaceous and early Tertiary time.

Reservoirs: Anticipated reservoir rocks include Pennsylvanian and Permian sandstones, Devonian and Mississippian carbonates, and Cretaceous sandstones with fracture-enhanced porosity. On outcrop, these rocks appear to have very little primary porosity. Karstic porosity may be present near the top of the Mississippian Madison Group, and Waulsortian mounds are present near the base of the Madison in the play area (Precht and Shepard, 1989).

Source rocks: Recently acquired Middle Proterozoic samples from the play area contain minimal organic matter and show evidence of a regional Precambrian thermal event which heated the rocks to temperatures of greater than 200^o C (Pawlewicz, 1994; T.A Daws, G.A. Desborough, and M.J. Pawlewicz, written commun., 1993). Surface samples of Cretaceous rocks in the western part of the play are supermature with respect to liquid hydrocarbons, mature in the central part of the play, footwall to the Lombard Thrust, and immature to the east. Three samples of Late Mississippian Heath-equivalent Lombard black shale from the immediate footwall of the Lombard Thrust contain 2.7-2.89 percent TOC and are gas-prone (HI range 30-54, OI range 28-68, and S2 range 0.85-1.47, T.A. Daws, written commun., 1983; see Tissot and Welte, 1978, p. 443-447). Devonian Bakken-equivalent and Permian Phosphoria oil-prone source rocks appear to be thin to absent in the play. Timing of hydrocarbon generation probably coincided with thrusting: Late Cretaceous to Paleocene. Intrusive activity in the northern part of the play area and along the western margin of the play appears to be dominantly Late Cretaceous.

Traps and resource potential: Hypothetical traps are thrust-cored anticlines and thrust-imbricate culminations in the footwall and east of the Lombard Thrust. The depth range expected for natural gas in the play is from 500 to 20,000 ft. None of the source rocks sampled in the play east of the Lombard Thrust were oil-prone, even though these rocks were in the oil window. Therefore the chance of finding significant oil in this play is remote.

2705. BLACKTAIL SALIENT OIL PLAY (HYPOTHETICAL)

The play involves inferred anticlines and imbricate thrust slices of Paleozoic rocks in the footwall and east of the McKenzie Thrust System. The play area is ovate, covering approximately 21 mi north-south and 19

mi east-west. The play extends westward from the front of the Blacktail Mountains Salient to a major down-to-west normal fault system suspected to mark the position of a footwall ramp, the estimated western limit of significant source-rock and reservoir section, beneath the McKenzie Thrust.

Reservoirs: Potential reservoir rocks include (1) the Pennsylvanian Quadrant Sandstone, which thickens southward, (2) underlying Lower Pennsylvanian and Upper Mississippian sandstones and carbonate rocks, and (3) limestones of the lower Mississippian Madison Group with possible karstic porosity and secondary dolomitization near the top of the Mission Canyon Limestone.

Source rocks: Probable oil-prone source rocks in the play include the Permian Phosphoria Formation (Retort Shale Member) and the Devonian Three Forks Formation (Sappington Member--Bakken equivalents). The presence of clinker beds within the Sappington, exposed in the McKenzie Thrust System, suggests a high original TOC content, in excess of the 7 percent TOC reported in previous studies. The type area of the Retort Shale lies within the Blacktail Mountains Salient, where it is a demonstrated oil shale. Gas-prone source rocks may be present in the Mississippian to Pennsylvanian Snowcrest Range Group (formerly Amsden and Big Snowy Groups); recent analyses show mainly woody to herbaceous kerogen in the Big Snowy where it was sampled farther south, in the Lima, Montana, area. Generation and migration of hydrocarbons from beneath the McKenzie Thrust System probably occurred during emplacement of this system. Rocks at the surface in the northeastern part of the play are submature with respect to oil generation. Those of the McKenzie Thrust System are late mature to supermature.

Traps: Possible structural traps in anticlines and imbricate thrusts in rocks of favorable thermal maturity are anticipated to underlie the frontal part of the McKenzie Thrust System, beneath Cretaceous through Quaternary cover. Drilling depths should range from 2,000 to 10,000 ft.

Exploration status and resource potential: Only one well has been drilled within the play, a 4,351-ft Devonian test (A, fig. 3) drilled in 1977 by American Quasar in the northeastern part of the area, from which shows of gas were reported in Madison rocks. However, recent examination of drill cuttings from the well revealed that the shows actually occurred in Pennsylvanian rocks of the upper Snowcrest Range Group, and the test bottomed in Upper Mississippian Lombard (formerly Big Snowy) limestones. Numerous black shale stringers were encountered in both the upper Snowcrest Range Group and underlying Lombard Limestone of the lower Snowcrest Range Group as well as slight oil cuts in samples in the deeper section. The apparent dip of the section drilled is very steep, and the well appears to be located near the leading edge of a thrust that does not reach the surface. The Amoco No. 1 McKnight Canyon Unit, 16,000 ft Quadrant test (Tensleep Sandstone equivalent), drilled just south of the play area (B, fig. 4), encountered complexly faulted Cretaceous and older rocks. The test was drilled, in part, on the basis of oil saturation in Upper Cretaceous rocks at the surface, oil that was generated from Cretaceous or

older rocks beneath the Salient. This well suggests that undiscovered hydrocarbons may be trapped farther north, within the play area. Future potential for small-size gas fields is low.

2706. TERTIARY BASINS OIL AND GAS PLAY (HYPOTHETICAL)

A number of relatively small Tertiary basins occur in the Montana Thrust Belt Province, of which, from north to south, the Kishenehn (343 sq mi), Flathead (133 sq mi), Ninemile (145 sq mi), Bitterroot (329 sq mi), Deer Lodge (257 sq mi), and Big Hole (438 sq mi), are among the largest and deepest. These are outlined as part of the Tertiary Basins Oil and Gas Play. Three basins, the Kishenehn, Big Hole, and Deer Lodge, are more than 11,000 ft deep. Most of the basins are normal fault bounded on at least one side and are the result of basin-and-range extension. The southwestern basins are floored by middle Eocene volcanic rocks emplaced between about 49 and 46 Ma (M'Gonigle and Dalrymple, 1993). These and the Paleozoic-Proterozoic basement rocks to the north are unconformably overlain by late Eocene to early Miocene devitrified volcanoclastic and lacustrine rocks associated with locally derived coarse clastic rocks (Fields and others, 1985). The lacustrine rocks include identified oil shales in the Kishenehn Basin, and associated paludal rocks contain locally abundant coals. This 40-29 Ma sequence is as much as 8,000 ft thick in the Big Hole Basin and 4,000 ft in the Deer Lodge Basin. In a number of Basins, this sequence is overlain by Miocene and younger predominantly coarse siliciclastic sediments, as much as 7,000 ft thick in the Big Hole Basin and 4,000 ft thick in the Deer Lodge Basin.

Reservoirs: Anticipated reservoir rocks are sandstones of Oligocene to Miocene age, generally poorly sorted, tuffaceous, and zeolite cemented. These sandstones are generally younger than the lacustrine rocks, but some are older as well. Thickness of individual sandstone bodies is generally less than 200 ft.

Source rocks: Source rocks are late Eocene to Oligocene in age. In the Kishenehn Basin, Curiale and others (1988) obtained a mean TOC of 6.89 percent based on 70 oil-shale samples and hydrocarbon indices of greater than 500 mg/g, and "all samples studied are thermally immature to marginally mature, having vitrinite reflectance values of 0.28 to 0.51 percent R_o ". Constenius and Dyni (1983) reported 40 m (131 ft) of oil shale in the lower sequence and 40 m (131 ft) in the middle sequence of the 1,150 m (3,773 ft) thick Coal Creek Member, the lower member of the Kishenehn Formation. These yielded 34 to 155 L/ton (8.1-37.2 gal/ton) liquid hydrocarbons (Constenius and Dyni, 1983). Lacustrine rocks are reported from a number of other Tertiary basins within the play (Fields and others, 1985), but no other oil shales are described. Timing and migration are unknown factors. Shows of oil and gas have been reported from wildcat wells drilled in the Kishenehn, Deer Lodge, and Big Hole Basins, so hydrocarbon generation has taken place in at least three of the basins.

Resource potential: Our records show that 17 exploratory tests have been drilled in the play. No accumulations have been discovered, although oil and gas was tested in the Deer Lodge and Big Hole

Basins. I consider that a 30 percent chance exists that a hydrocarbon accumulation of 1 MMBO or 6 BCFG will be discovered in this play.

2707. IMBRICATE THRUST OIL PLAY (HYPOTHETICAL)

Based on surface Cretaceous samples from the immediate footwall of the Eldorado Thrust near the southern end of play 2701, a small subset of that play is deemed to have oil potential and therefore is treated separately from play 2701 (Imbricate Thrust Gas) as a hypothetical structural oil play.

Reservoirs: Reservoir rocks are primarily dolomitized limestone with possible karstic (vuggy) porosity, as in play 2701. Thin Jurassic and Cretaceous sands may provide fracture-enhanced reservoirs for hydrocarbons in structural traps. A more extensive discussion of the regional geology is given under play 2701.

Source rocks: Source rocks are primarily the Upper Cretaceous Marias River Shale, which had a mean R_o value of 0.88 and TOC of 1.38 percent, and secondarily the Lower Cretaceous Blackleaf Formation, with an R_o of 1.20 and TOC of 1.44 percent (Tysdal and others, 1991). The Devonian Bakken-equivalent rocks are inferred to be supermature with respect to oil generation in this play.

Traps: The inferred trap types are imbricate thrust slices considerably smaller in area than the large duplex culminations shown by Fritts and Klipping (1987a, b) farther west. Jurassic and Cretaceous shales should provide adequate seals. Inferred minimum and maximum depths for expected undiscovered oil accumulations are 3,000 and 16,000 ft, with a median of about 8,000 ft.

Exploration status and resource potential: The play is essentially unexplored. I infer a 0.25 probability of an oil occurrence of 1 MMBO or larger in the play.

REFERENCES

- Boberg, W. W., 1984, Flathead region, Montana, Alberta, and British Columbia, petroleum exploration, an historical review, *in* McBane, J.D., and Garrison, P.B., eds., Northwest Montana and adjacent Canada: Montana Geological Society 1984 Field Conference and Symposium Guidebook, p. 1-25.
- Clayton, J., Mudge, M.R., Lubeck, Sr. C., and Daws, T.A., 1983, Hydrocarbon source rock evaluation of the disturbed belt, northwestern Montana, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt - 1982: Rocky Mountain Association of Geologists, v. 2, p. 817-830.
- Constenius, K., 1988, Structural configuration of the Kishenehn Basin delineated by geophysical methods, northwestern Montana and southeastern British Columbia: *The Mountain Geologist*, v. 25, no. 1, p. 13-28.
- Constenius, K., and Dyni, J.R., 1983, Lacustrine oil shales and stratigraphy of part of the Kishenehn Basin, northwestern Montana: Mineral and Energy Resources, Colorado School of Mines Press, v. 26, no. 4, p. 1-16.
- Curiale, J.A., Sperry, S.A., and Senftle, J.T., 1988, Regional source rock potential of lacustrine Oligocene Kishenehn Formation, northwestern Montana: *American Association of Petroleum Geologists Bulletin*, v. 72, no. 12, p. 1437-1449.
- Dolson, J., Piombino, J., Franklin, M., and Harwood, R., 1993, Devonian oil in Mississippian and Mesozoic reservoirs--Unconformity controls on migration and accumulation, Sweetgrass arch, Montana: *The Mountain Geologist*, v. 30, no. 4, p. 125-146.
- Fields, R.W., Rasmussen, D.L., Tabrum, A.R., and Nichols, R., 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho, *in* Flores, R.M., and Kaplan, S.S., Cenozoic paleogeography of west-central United States: Rocky Mountain section Society of, p. 9-36.
- Fritts, S.G., and Klipping, R.S., 1987a, Structural interpretation of northeastern Belt Basin; implications for hydrocarbon prospects; Belt Basin--1: *Oil and Gas Journal*, v. 85, no. 39, p. 75-79.
- Fritts, S.G., and Klipping, R.S., 1987b, Belt Basin needs further exploration; Belt Basin--2: *Oil and Gas Journal*, v. 85, no. 40, p.93-95.
- Jacobson, R., Syth, L., and Elwell, B., 1993, Montana oil and gas annual review 1992: Department of Natural Resources and Conservation of the State of Montana, Oil and Gas Conservation Division, v. 36, 57 p.

- Johnson, E.H., 1984, Blackleaf Canyon field and Knowlton field, Teton County, Montana, *in* McBane, J.D., and Garrison, P.B., eds., Northwest Montana and adjacent Canada: Montana Geological Society 1984 Field Conference and Symposium Guidebook, p. 1-25.
- Lorenz, J. C., 1983, Lithospheric flexure and history of the Sweetgrass arch, northwestern Montana, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt - 1982: Rocky Mountain Association of Geologists, v. 1, p. 77-89.
- Lorenz, J.C., 1984, The function of the Lewis and Clark fault system during the Laramide orogeny, *in* McBane, J.D., and Garrison, P.B., eds., Northwest Montana and adjacent Canada: Montana Geological Society 1984 Field Conference and Symposium Guidebook, p. 221-230.
- M'Gonigle, J.W., and Dalrymple, G.B., 1993, $^{40}\text{AR}/^{39}\text{AR}$ ages of Challis volcanic rocks and the initiation of Tertiary sedimentary basins in southwestern Montana: *The Mountain Geologist*, v. 30, no. 4, p. 112-118.
- Mudge, M. R., 1972, Pre-Quaternary rocks in the Sun River Canyon area, northwestern Montana: U.S. Geological Survey Professional Paper 663-A, 142 p.
- Mudge, M. R., 1983, A resume of the structural geology of the northern disturbed belt, northwestern Montana, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt - 1982: Rocky Mountain Association of Geologists, v. 1, p. 91-122.
- Pawlewicz, M.J., 1994, Organic petrographic and Rock-Eval pyrolysis analyses of Proterozoic Belt Supergroup rocks, west-central Montana: U.S. Geological Survey Open-File Report 94-155, 8 p.
- Peterson, C.H., and Nims, R.C., 1992, How Montana's deepest hole cut Mississippian carbonates underneath Precambrian Belt: *Oil and Gas Journal*, v. 90, no. 31, p. 67-70.
- Precht, W.F., and Shepard, Warren, 1989, Waulsortian carbonate buildups of Mississippian age from Montana and relations to rifting, *in* French, D.E., and Grabb, R.F., Geologic resources of Montana: Montana Geological Society, 1989 Field Conference Guidebook, v. 1, p. 65-68.
- Rice, D.D., 1976, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, Montana: U.S. Geological Survey Oil and Gas Investigations Chart OC-71, 3 sheets.
- Tissot, B.P., and Welte, D.H., 1978, Petroleum formation and occurrence, A new approach to oil and gas exploration: Berlin, Springer-Verlag, 538 p.
- Tysdal, R.G., Reynolds, M.W., Carlson, R.R., Kleinkopf, M.D., Rowan, L.C., and Peters, T.J., 1991, Mineral resources of the Sleeping Giant Wilderness Study Area, Lewis and Clark County, Montana: U.S. Geological Survey Bulletin 1724, 31 p.

