The Lance Formation—Petrography and Stratigraphy, Powder River Basin and Nearby Basins, Wyoming and Montana

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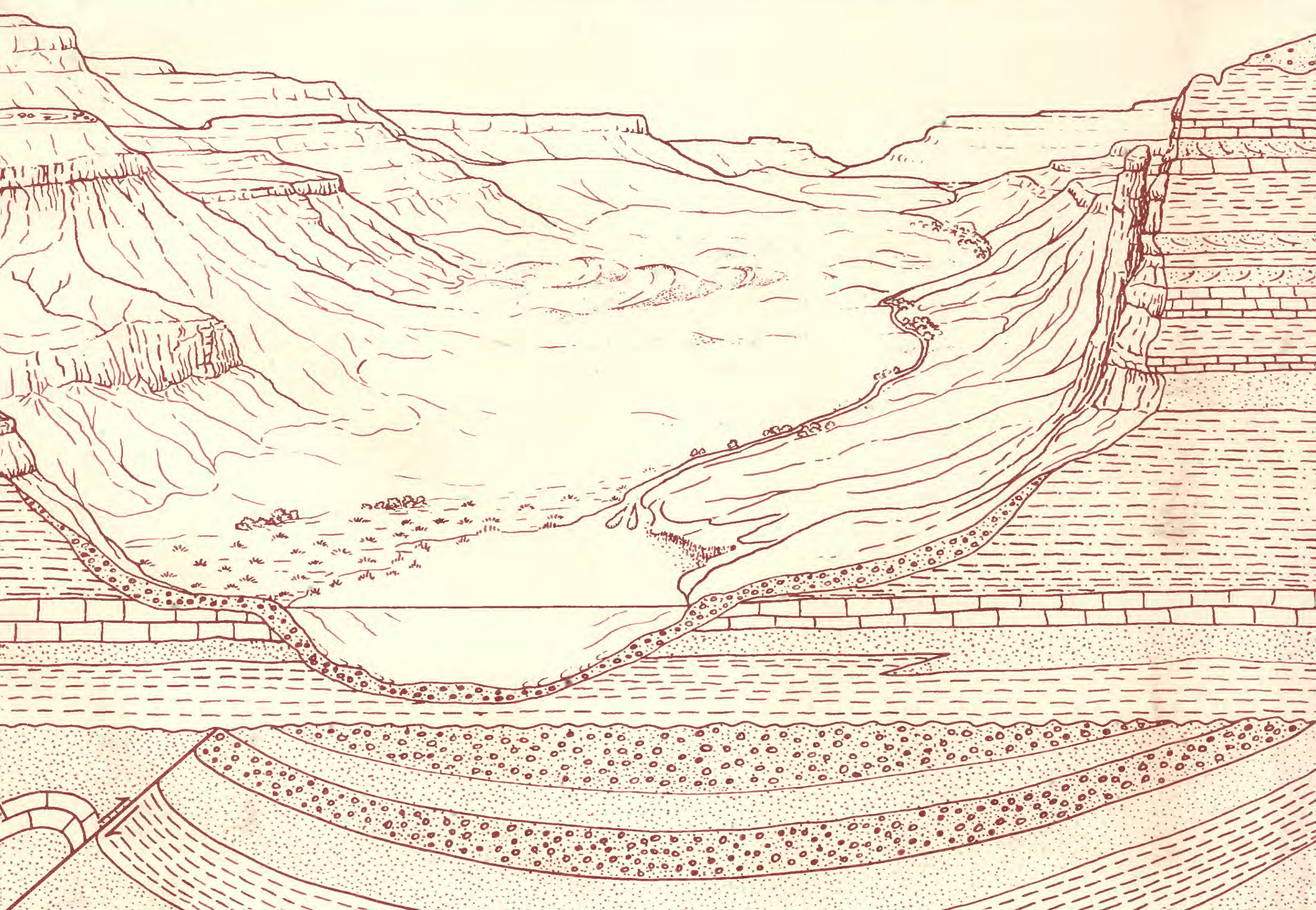

Chapter I

The Lance Formation—Petrography and Stratigraphy, Powder River Basin and Nearby Basins, Wyoming and Montana

By CAROL WAITE CONNOR

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

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The Lance Formation—Petrography and Stratigraphy, Powder River Basin and Nearby Basins, Wyoming and Montana

By Carol Waite Connor

Abstract

The uppermost Cretaceous Lance (Hell Creek) Formation was studied in the Powder River Basin and nearby basins of Wyoming and Montana. The Lance Formation is overlain by the continental Paleocene Fort Union Formation. In the Bighorn and Wind River basins, it is underlain by the continental Meeteetse Formation, and in the Powder River Basin, the Lance is underlain by the marginal marine Fox Hills Sandstone. Channel sandstones make up about one-third of the Lance; the rest of the formation is composed of thinner sandstones and finer grained interfluve sedimentary rocks. The coarsest material within the studied area is along the west side of the Bighorn Basin and in the east end of the Wind River Basin. Within the Powder River Basin, the combined Lance and Fox Hills thicken from less than 700 ft in the north to more than 3,300 ft in the south; there is little change in thickness from east to west. Maximum structural relief of the Lance in the Powder River Basin is more than 6,000 ft.

Petrographic studies of sandstones from the Lance Formation from around the Powder River Basin show that the mineralogy is different in the northern, central, and southern parts of the basin. In the northern part of the basin, the abundance of rock fragments (average 57 percent) exceeds monocrystalline quartz (average 34 percent), and plagioclases exceed potassium feldspars. Many of the rock fragments are volcanic. In the southern part of the basin, the composition is exactly reversed: monocrystalline quartz (average 57 percent) exceeds rock fragments (average 34 percent), and potassium feldspars exceed plagioclases. Many rock fragments in the southern part of the basin are of intrusive origin. Between these areas, the sandstones are more like those in the northern part of the basin but are distinguished by the presence of a green hornblende. No significant vertical changes in mineralogy were noted.

Cross-bed measurements, channel orientations, and orientations of well-cemented sandstones of log-like form were used to determine stream-flow directions. Of particular significance is the evidence of eastward-flowing streams that is found on both sides of the Bighorn Mountains and on the eastern side of the Powder River Basin; this indicates that neither the Bighorn Mountains nor the Black Hills had emerged by Lance time.

Both paleocurrent data and the location of coarse detritus imply sources to the west of the area of study, and petrographic data indicate three source areas in that direction. The very angular volcanic rock fragments in the northern Powder River Basin were probably introduced aerially from the Elkhorn Mountains Volcanics in western Montana. The distinctive green hornblende in the central Powder River Basin might have come from erosion of the Precambrian core of the Beartooth Mountains or from volcanics on the northern side of the Beartooths. Rock fragments of intrusive origin in the southern Powder River Basin probably came from the Granite Mountains, south of the present Wind River Basin.

Deposition of the Cretaceous Lance Formation ended at the time of the Cretaceous-Tertiary boundary event, now thought by many to have been an asteroid impact. Previous studies have indicated that rainfall amounts increased dramatically following this boundary event. This was accompanied initially by a greater influx of sandy sediments and eventually by development of widespread peat-accumulating swamps in the upper part of the Paleocene Fort Union Formation.

Manuscript approved for publication August 5, 1991.

INTRODUCTION

The Lance Formation in Wyoming and the age-equivalent uppermost Cretaceous Hell Creek Formation in Montana have not previously been studied in any detail except in small areas. This study of the Lance and Hell Creek was planned to collect information on stratigraphy, structure, petrography, and provenance throughout the Powder River Basin.

The original research plan for the formation was abandoned during the first field reconnaissance in the Powder River Basin. Exposures were found to be generally poor and widely scattered, and because of the commonly low dip and gentle terrain, "complete" sections covered as many as 20 mi (32 km). The desired detailed measurement of clusters of stratigraphic sections at approximately 50-mile (80-km) intervals was deemed impractical. Instead, field work focused on collection of sandstone samples of the Lance and Hell Creek for subsequent petrographic analysis and on measurement of cross-beds and orientation of channel sandstones. The alternate plan proved fruitful, and some aspects of this study were extended northward into the Williston Basin and westward into the Bull Mountain, Crazy Mountains, Bighorn, and Wind River Basins (fig. 1). The subsurface study was concentrated in the Powder River Basin.

This report is a product of the U.S. Geological Survey Evolution of Sedimentary Basins program.

STRATIGRAPHY

The Lance Formation, Wyoming, and the equivalent Hell Creek Formation in Montana, is the uppermost Cretaceous unit in the Powder River Basin and nearby basins. Henceforth in this report, only the name Lance Formation will be used rather than Lance and Hell Creek Formations. Also, the age of the Lance will be considered as Late Cretaceous, although it has been reported to be locally as young as Paleocene (Bohor and others, 1987).

The beginning of Lance time, estimated at 68 Ma (Gill and Cobban, 1973), marks the end of marine deposition in the areas of the present Powder River Basin, Williston Basin, and Bull Mountain Basin. The formation is made up of sequences of sandy, fluvial channel deposits and finer grained interfluve deposits overlying and intertonguing with the marginal marine Upper Cretaceous Fox Hills Sandstone. In the Bighorn and Wind River Basins, the Lance is transitional to the underlying nonmarine Meeteetse Formation.

The Lance is overlain by the Paleocene Fort Union Formation. The boundary between these nonmarine formations, at approximately 63 Ma (Gill and Cobban, 1973), is marked in places by the thin Cretaceous-Tertiary (K–T) boundary clay that is now widely considered to be an artifact of an asteroid impact (Orth and others, 1981; Bohor and others, 1984; and Tschudy and others, 1984). Three of these K–T boundary clay sites are in the study area: the Dogie Creek site is 21 mi (34 km) north of the community of Lance Creek, Wyoming, in the southeastern part of the Powder River Basin (Bohor and others, 1987); the Hell Creek area localities are about 13 mi (21 km) north of Jordan, Montana, in the western part of the Williston Basin (Bohor and others, 1984); the Teapot Dome site is approximately 30 mi (48 km) north-northeast of Casper, Wyoming (Wolfe and Izett, 1987). The K–T boundary has generally been placed at the base of the lowest persistent lignite or coal bed that overlies the highest occurrence of dinosaur remains; this placement of the K–T boundary was proposed by Calvert (1912).

No original geologic mapping was undertaken for this study because of the size of the study area and because of time constraints. Previously mapped formation boundaries were used as a guide in the field, and where the Lance had been mapped in combination with a unit below, the position of the base of the Lance was roughly estimated based on the thickness of the Lance reported in adjacent areas.

SUBSURFACE DATA

Subsurface work was confined to the Powder River Basin and the Bull Mountain Basin. Two hundred thirty-two boreholes that were fairly evenly scattered throughout the study area were selected for study; these boreholes were, on average, about 10 mi (16 km) apart (pl. 1). The geophysical log picks for the top of the Lance and the base of the Fox Hills were made by the author and were based on results of a study by the Tertiary Subgroup of the Powder River Basin Project of the U.S. Geological Survey (Seeland and others, in press). In that study, a north-to-south line of wells was selected for the basin; formation and member boundaries from the Paleocene and Eocene Wasatch Formation to the Upper Cretaceous Pierre Shale were independently selected by each team member along his or her segment of the line of section; subsequent discussions resulted in agreement on how these boundaries should be determined throughout the basin. This is shown in chart form in figure 2.

The Tullock Member of the Paleocene Fort Union Formation overlies the Lance. The Tullock has a decidedly "hairy" appearance on most geophysical logs—a finely serrate resistivity pattern that practically never reaches the shale baseline of the units above or below. The Tullock appears to be made up of alternating thin sands and shales. The underlying Lance has a "normal" appearance of alternating medium to thick sandstones and shales.

The Lance intertongues with the underlying marginal marine Fox Hills Sandstone. These predominantly delta-front sandstones of the Fox Hills coarsen upward in contrast to the fining-upward fluvial sandstones of the Lance. However, these vertical grain-size trends are clear only on some geophysical logs and are difficult to identify in most others. The transition from marine to nonmarine depositional environments is rarely abrupt, and there is commonly an intertonguing interval that appears to be several hundred ft thick. (See pls. 2, 3, and 4.) The Fox Hills, excluding the intertonguing interval, has generally been considered to be about 100–200 ft (30–60 m) thick. In

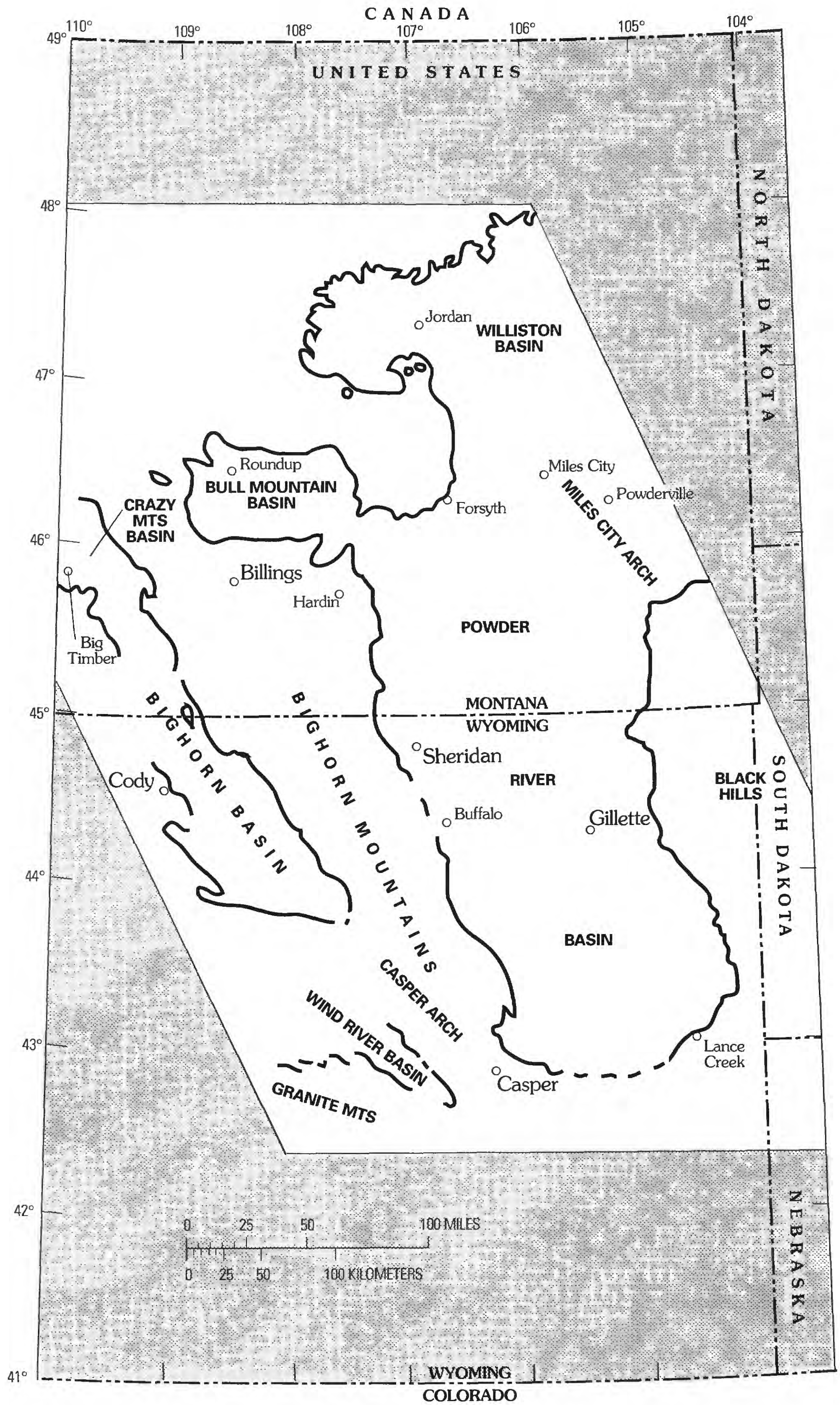

Figure 1. Index map of the study area. Outlines of the Powder River Basin and nearby basins in Wyoming and Montana are drawn at the approximate base of the Lance Formation.

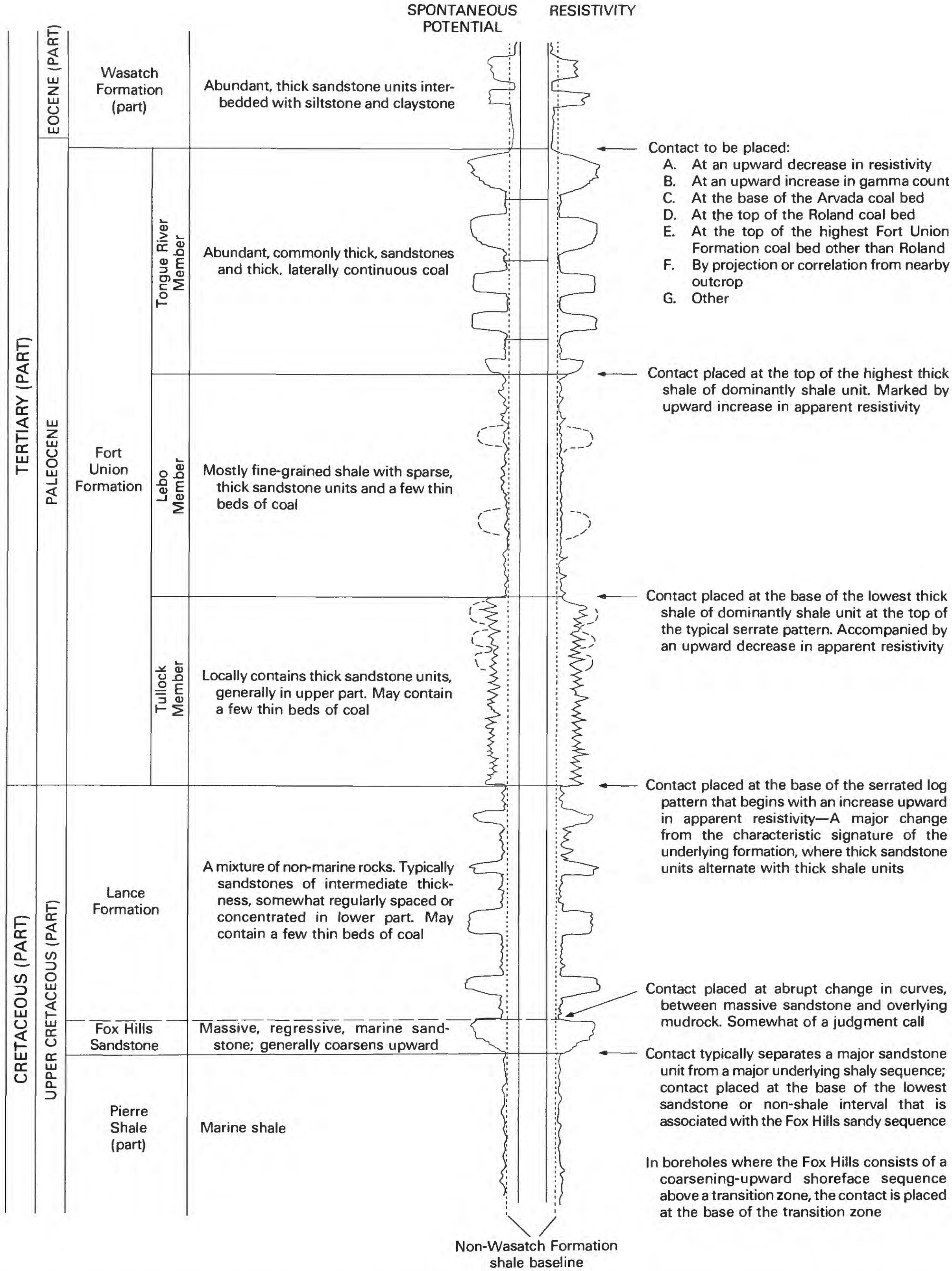

Figure 2. Chart showing the method of picking some Cretaceous and Tertiary stratal boundaries in the subsurface of the Powder River Basin. (Modified from Seeland and others, in press). Not to scale.

a series of Powder River Basin cross sections in Wyoming by Merewether and others (1977a–1977d), the Fox Hills is shown ranging from 20 to 500 ft (6–150 m) thick, with a mean thickness of 190 ft (60 m) and a median thickness of 180 ft (55 m); the thickness increases in a general way to the east and southeast, but with much local variation. The identification of the Lance–Fox Hills boundary was considered "* * *somewhat of a judgment call" (fig. 2) in the study by the Tertiary Subgroup. I felt I could not pick this boundary consistently over the large area of this study, so I combined the Lance and Fox Hills in presenting thickness data.

Thickness

Thickness trends of the combined Lance Formation and Fox Hills Sandstone are very apparent in the cross sections (pls. 2, 3, and 4). The north-south sections, A–A′ and B–B′, show a thickening from less than 700 ft (210 m) in the north to more than 3,300 ft (1,000 m) in the south. There is little east-west change in thickness—this is apparent in cross sections C–C′ to F–F′.

The isopach map (pl. 5), which is remarkably similar to an earlier one of the combined Lance and Fox Hills based on only 36 boreholes (Curry, 1971, fig. 6), also demonstrates the dominant southward thickening and the lack of an east-west change in thickness. The southward increase in thickness suggests that the southern part of what is now the Powder River Basin was either subsiding more rapidly than the northern part or that it was subsiding over a longer period of time.

Structure

The structure contours shown on plate 6 are drawn on top of the Lance (at the K–T contact) and reflect post-Cretaceous deformation in the region. The relief on this surface is more than 6,000 ft (1,830 m). The smoothness of the contours suggests that the precision of the contact picks was good. This same surface was contoured by Lewis and Hotchkiss (1981, sheet 4). The configuration of their map is strikingly similar to that shown on plate 6. Both maps show that the deepest part of the basin is along the west side in the vicinity of Buffalo, Wyoming. The greatest difference between the maps occurs below the sea-level contour line. Plate 6, which has twice as many data points in this area as the map by Lewis and Hotchkiss (1981), shows a single low area, whereas they show two low areas. The other major difference between the two maps is in the northeastern corner of the basin where it should be noted that neither map has many data points—the present study does include a few more data points in this area and also shows additional data points to the east of this area. Lewis and Hotchkiss (1981, sheet 1) say "* * *illustrated is the northwest-trending Miles City arch * * *." Their 2,750-ft contour line does illustrate this, but they have no data points controlling the configuration of that contour line in this area. The data gathered for this report give no indication of a high in this vicinity. There is evidence that the Miles City arch had not yet begun to develop in Lance time: the isopach map (pl. 5) shows no thinning across this area.

LITHOLOGY

Based on geophysical logs, channel sandstones 20 ft (6 m) thick or thicker make up an estimated 30 percent of the Lance. The other 70 percent is composed of thinner sandstones and finer grained interfluve sedimentary rocks. The sandstones are lenticular and range from isolated bodies to stacked sequences as thick as 300 ft (90 m). In outcrop, they are generally friable and are, therefore, poorly exposed. Cement, where present, is calcareous. The sandstones range in grain size from very fine to coarse and typically become finer grained upward within individual channels. Clay pebbles about an inch in diameter, probably derived locally, are not uncommon in the bases of thick sandstone bodies. Chert fragments this large, derived from more distant sources, were observed only along the west side of the Bighorn Basin and along the south side of the Wind River Basin, where small granite pebbles were also found. Very coarse grained sandstones were observed in the Crazy Mountains Basin. Bone fragments up to 1 ft long were seen near the bases of some of the thick sandstones at various locations throughout the study area. Bedding forms in channel sandstone bodies commonly include, from the base upward: large-scale cross-beds, contorted (slumped) beds or structureless intervals, and parallel laminations followed by current ripples in the uppermost 1 to 3 ft (0.3 to 0.9 m).

Peculiar, well-cemented sandstones of log-like form were found at numerous locations in the Lance around the Powder River Basin. They were also seen in the overlying Tullock Member of the Fort Union Formation and in the Lebo Member of the Fort Union Formation. (D.A. Seeland, written commun., 1990, reports occurrences in the Wasatch Formation as well and in lower Eocene sandstones in the Bighorn and Wind River Basins.) They are commonly about 2 ft (0.6 m) in diameter and 10–20 ft (3–6 m) long. One of these sandstone forms measured 130 ft (40 m) long and about 3.5 ft (1.1 m) in diameter. It was found about 30 mi (48 km) north of Lance Creek, Wyoming (fig. 3). These concretions are generally close to channel sandstone exposures and lie on the surface at about the same level as the upper part of the sandstone channels. Small-scale planar cross-beds may be apparent (fig. 4), or the bedding may be contorted (fig. 5). A very useful aspect of these linear bodies is that their orientation lines up closely with that of cross-beds measured in the vicinity. In fact, where cross-beds can be measured on the concretion itself, orientations of the cross-beds and concretions are precisely parallel, as is indicated in figure 4. The earliest mention found of similar concretions is by Love and others (1963, p. 203) who mention " * * *elongate log-like concretions in the Fort Union Formation of the Powder River Basin." Papers by Jacob (1973, 1976) describe "elongate concretions" in the Paleocene Tongue River Member of the Fort Union Formation in North Dakota where they range up to "* * * 5 meters wide and a few hundred meters long." These concretions are interpreted by Jacob to be the cemented, upper parts of transverse bars in nonbraided, low-sinuosity streams of a lower delta plain. They are large enough to be seen and plotted on air photos. The smaller Lance concretions could not be seen on 1:32,000-scale air photos. Schultz (1941) described "pipy concretions" in the lower Miocene Arikaree Formation of Nebraska. These do not look like the Lance concretions because they are composites of long, irregular, cylindrical masses—their overall shape is somewhat sheetlike. However, the origin of the Miocene "pipy concretions," Paleocene "elongate concretions," and the Cretaceous "log-like concretions" is probably the same: calcium carbonate precipitated from ground water flowing through areas of high permeability. The shapes of the concretions are confined by the shapes of the permeable sediments. It is not known why only the upper parts of the channel sandstones were cemented.

Fine-grained intervals are poorly exposed within the study area. In outcrop, they typically exhibit the "popcorn" weathering texture characteristic of montmorillonitic sediments. Based on geophysical logs, these intervals may be as much as 200 ft (60 m) thick. There is more shale in the upper part of the Lance than in the lower part.

Figure 3. Photograph of longest log-like sandstone concretion seen in the Lance Formation, Powder River Basin. Outcrop is 130 ft (40 m) long. Hammer handle is 11 in (28 cm) long. Locality 2–36, plate 8.

PETROGRAPHY

The petrography of the Lance Formation over a large area was first described in a recent abstract (Connor, 1987). This gave the preliminary results of my study that are expanded upon here.

Sandstone samples were collected for thin-section analysis all the way around the Powder River Basin at sites approximately 50 mi (80 km) apart. A few samples were collected in the Bighorn Basin. At each site, channel sandstones were sampled, where available, across the entire outcrop belt to check for stratigraphic as well as geographic changes in mineralogy. Thin-section localities are shown on plate 7. Thirty-one standard thin sections were made from samples from the Powder River Basin and Bighorn Basin and were stained for potassium feldspar.

A pilot study (3 thin sections) to determine the number of measurements necessary to characterize grain size showed that 25 measurements per slide were adequate. Comparison of the first 25 grain measurements on a slide with the next 25 measurements on the same slide showed essentially no difference in the means and very little difference in the variances. The A-axes (long axes) of quartz grains were measured on thin-sections. Although A-axis measurement is an imprecise estimator of grain size (volume), accounting for only about 25 percent of the variation in grain volume, it is not significantly worse than B-axis or area measurement (Connor and Ferm, 1966). Average grain size ranges from very fine sand to the upper half of the medium-sand category. Individual grains range from coarse silt to coarse sand. Sample (within-slide) variance is small.

Approximately 200 framework grains were identified in each slide based on a pilot study that showed that, for these particular rocks, estimates of mineral percentages stabilized when considerably fewer than 200 points per slide were identified. Percentages of the various constituents were calculated for each of five slides after 40, 80, 100, 120 (or 140), 160, and 200 counts of framework grains and matrix or cement (table 1). Many estimates of abundance stabilized by 100 counts, and differences in percentages between the next-to-last and last counts (160 and 200

Figure 4. Photograph of log-like concretion with planar cross-bedding, Lance Formation, Powder River Basin. The concretion was moved during road construction. Under ordinary field conditions, only the top portion would be exposed. Hammer handle is 11 in (28 cm) long. Locality 2/3–11, plate 8.

counts) were no more than two percentage points, with a mean difference of only half a percentage point. Since 200 points per slide (framework grains and matrix or cement) were found to be adequate to estimate mineral percentages in the pilot study, 200 points of framework grains alone were deemed more than adequate for the final study.

Framework grains were categorized according to the system of Dickinson (1970), Dickinson and Suczek (1979), and Graham and others (1976): Qm (monocrystalline quartz) and Qp (polycrystalline quartz, including chert), which combine as Q (total quartz); K (potassium feldspar) and P (plagioclase), which combine as F (total feldspar); Lv (volcanic lithic fragments) and Ls and Lm (sedimentary and metamorphic lithic fragments), which combine as L (unstable polycrystalline lithic fragments); and L and Qp, which further combine as Lt (total lithic fragments); "others" were also noted. The results of thin-section analysis are summarized on plate 7 and figure 6 and are given in detail in table 2.

Because there are so many sandstone nomenclature schemes, to avoid confusion, no names will be used in categorizing the Lance rocks. The suggestion of Dickinson (1970) is followed: subscripts indicating percentages are simply attached to Q, F, and L and subsidiary categories. Average composition of the sandstone samples of the Lance is Q_{65} F_9 L_{26} or Qm_{49} F_9 Lt_{42}.

Mineral composition of the sandstones changes from north to south within the Lance in the Powder River Basin. Stratigraphic trends are not evident. Three geographic mineralogical groupings have been identified (pl. 7). The northern group extends southward to an approximately east-west line about 20 mi south of Hardin, Montana. Here, rock fragments, commonly angular pieces of volcanic origin and chert, commonly exceed monocrystalline quartz grains in abundance (Qm_{34} F_9 Lt_{57}), and plagioclases exceed potassium feldspars (fig. 7). In the southern part of the basin, south of an approximately east-west line a few miles north of Buffalo and Gillette, Wyoming, the composition is exactly reversed: monocrystalline quartz exceeds rock fragments (Qm_{57} F_9 Lt_{34}), which here are commonly of intrusive origin, and potassium feldspars exceed plagioclases (fig. 8). The sandstones in the central part of the basin (Qm_{39} F_{12} Lt_{49}) are distinguished by the presence of a green hornblende that is extremely rare to the north or south (fig. 9). The last four columns of table 2 illustrate the three mineralogical groupings. The northern and central regions

Figure 5. Photograph of log-like concretion with typical contorted cross-bedding, Lance Formation, Powder River Basin. Hammer handle is 11 in (28 cm) long. Locality 1–2, plate 8.

combined are further differentiated from the southern region by the amounts of polycrystalline quartz, not including chert, which average 17 and 11 percent, respectively. A Student's t test of the data indicate this difference is significant at the 99.9 percent confidence level, (t=3.14 compared with a critical t of 3.12). A ternary plot (fig. 6) of monocrystalline quartz, total feldspar, and total rock fragments (including chert) reveals that there is no overlap in the gross composition of sandstones in the northern part of the basin and the southern part of the basin.

Accessory minerals and rock fragments that occur in thin sections from all parts of the Powder River and Bighorn Basins are muscovite, brown biotite, tourmaline, sphene, glauconite, metamorphic quartz, and chert (up to 22 percent; see fig. 10); this indicates a wide range of source rocks. Minerals that occur only in the north include zoned potassium feldspar and zoned plagioclase, indicative of a volcanic source. A mineral occurring in the central part of the region, but rarely elsewhere, is green hornblende that

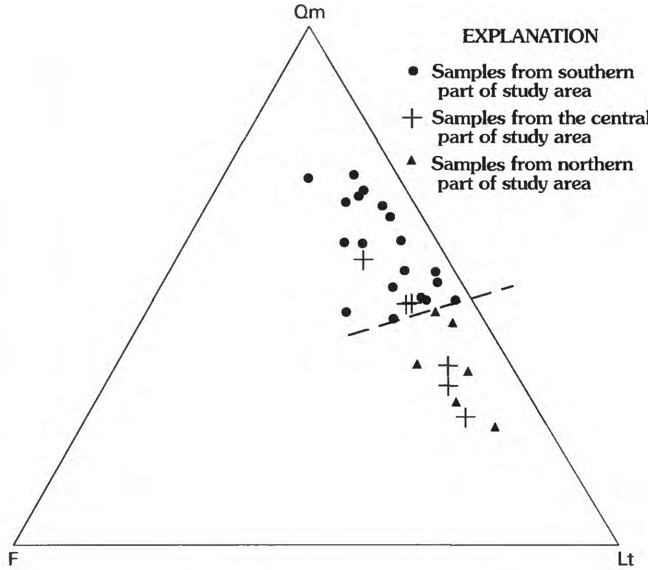

Figure 6. Ternary diagram showing relative amounts of monocrystalline quartz (Qm), total feldspar (F), and total rock fragments (Lt) in sandstones of the Lance Formation, Powder River Basin and Bighorn Basin.

may come from a high-rank metamorphic source. Minerals and rock fragments occurring only in the south are graphic granite, reticulated quartz, chalcedony, microcline, perthite, green biotite, chlorite, and olivine; many of these indicate an acidic igneous source. Epidote and brown hornblende, indicative of high-rank metamorphic to acidic igneous sources, occur only in the middle and south parts of the area of study.

The amount of matrix originally occurring in the rocks sampled is not known. Secondary sparry or micritic calcite cement now makes up 21 to 62 percent of the rocks and can be seen to have encroached upon or destroyed framework grains as well.

No mineralogical comparison with units immediately above or below the Lance is possible because no published basin-wide data exist.

PALEOCURRENT DATA

Results of a paleocurrent study are displayed on plate 8. Cross-bed measurements and channel, splay, and log-like-concretion orientations were recorded wherever they were clearly evident. This part of the Lance study, which involves the kind of data that are quick and easy to both obtain and analyze, was extended north and west well beyond the Powder River Basin into the Williston Basin, Bull Mountain Basin, Crazy Mountains Basin, Bighorn Basin, and Wind River Basin (fig. 1 and pl. 8).

Channel and splay orientations were recorded in the few places where a three-dimensional view of the channel

Table 1. Estimates of constituent abundance in sandstones from the Lance Formation, Powder River Basin, according to the number of points identified on a thin section

[Locality numbers are shown on plate 7. If percentages of all constituents at a locality do not equal 100 percent, the apparent error is either due to rounding (>100 percent) or to rounding and (or) to "others" not reported here (<100 percent)]

Locality no.	40	80	100	120	160	200
	Constituent abundance (percent)					
	Monocrystalline quartz (Qm)					
1–2	48	49	43	44*	43	42
1–10	52	59	57	60	60	58
1–17	70	68	67	66	67	67
10–4	52	49	48	47	48	47
3–1	13	19	18	18	21	23
	Polycrystalline quartz (Qp)					
1–2	17	16	17	21*	22	24
1–10	19	13	15	12	10	10
1–17	10	11	11	10	9	9
10–4	13	15	14	14	17	17
3–1	13	18	19	16	15	15
	Sedimentary and metamorphic lithic fragments (Ls, Lm)					
1–2	31	30	32	29*	29	28
1–10	13	16	17	16	15	14
1–17	7	11	11	12	14	14
10–4	29	33	33	33	31	31
3–1	0	0	0	0	0	0
	Potassium feldspar (K)					
1–2	0	3	2	2*	2	1
1–10	13	8	8	9	9	9
1–17	7	5	4	5	4	3
10–4	6	4	5	4	4	3
3–1	0	0	3	3	3	3
	Plagioclase feldspar (P)					
1–2	0	0	1	1*	1	1
1–10	3	3	3	2	3	3
1–17	3	4	3	5	4	3
10–4	0	0	0	0	0	1
3–1	10	6	6	6	5	5
	Volcanic lithic fragments (Lv)					
3–1	65	58	54	56	56	55

* Percentage based on 140 point counts

was possible, generally where a cut at a high angle to its trend exposed the sandstone on both sides of a road. The actual direction of flow, as opposed to the orientation of the sandstone body, was determined by observing general cross-bed dip directions in the vicinity.

Log-like concretions were described in the "Lithology" section of this report and illustrated in figures 3–5. Their orientation is extremely easy to measure, and the flow direction can generally be determined by observation of cross-beds in the area. Where cross-beds were actually measured in the vicinity of these log-like concretions, their flow directions proved to be essentially parallel to the orientation of the log-like concretions. Work by Jacob (1973, 1976) on similar concretions indicates that the variation in orientation of elongate concretions is considerably less than that of cross-beds. In the few areas where multiple log-like concretions were found during this study, this proved to be true.

Cross-beds were the most common paleocurrent indicator measured. Measurements were mostly restricted to large-scale trough cross-beds in the bases of channels but also included were smaller scale, planar cross-beds in the

Table 2. Constituent abundance (in percent) in sandstones from the Lance Formation, Powder River Basin and Bighorn Basin

[Locality numbers are shown on plate 7. Brackets along left margin indicate stratigraphic sequence within small area. Figures are rounded to nearest integer except where exactly one-half. Position indicates stratigraphic position within the Lance Formation: L, lower; LM, lower middle; M, middle; UM, upper middle; U, upper. Numbers appearing between columns indicate the sum of those two columns. N, number of points counted; n–(oth+cmt), total number of points counted minus the sum of cement point counts and point counts that did not fit into any other category ("others"); % frame, percent framework grains; % cmt, percent cement; n.c., not counted; Qm, monocrystalline quartz; Qp, polycrystalline quartz and chert; K, potassium feldspar; P, plagioclase; Lv, volcanic lithic fragments; Ls, Lm, sedimentary or metamorphic lithic fragments; Q, monocrystalline quartz plus polycrystalline quartz and chert; F, potassium feldspar plus plagioclase; L, volcanic, sedimentary, and metamorphic lithic fragments; Lt, polycrystalline quartz plus volcanic, sedimentary, and metamorphic lithic fragments; 0*, constituent present but did not occur in point-count data. Group characteristics is a summary of characteristics that differentiate the mineralogic groups: Grn hbl, green hornlende; Y, yes; N, no; —, unknown; =, equal]

						Framework percent												Group characteristics			
Locality no.	Position	n	n–(oth+cmt)	% frame	% cmt	Qm	Qp	K	P	Lv	Ls, Lm	Q	F	L	Qm	F	Lt	Qm>Lt	K>P	Lv present	Grn hbl present
						Northern mineralogic group															
3-1	L	200	200	100	n.c.	23	15	2	5		55	38	7	55	23	7	70	N	N	Y	N
3-6	L	318	212	72	28	33	32	3	4	6	22	65.5	6.5	28	33	7	60	N	N	Y	N
3-3-1	M	314	194	64	36	27	23	3	9	8	30	50	12	38	27	12	61	N	N	Y	N
3-3-2	M	200	200	100	n.c.	42	12	4	1		41	54	5	41	42	5	53	N	Y	—	N
3-3-4	M	369	204	58	42	34	19	7	8	9	23	53	15	32	34	15	51	N	N	Y	N
7-1	L	403	202	52	48	44	16	5	2	0*	33	60	7	33	44	7	49	N	Y	Y	N
						Central mineralogic group															
8-1	LM	425	209	50	50	46.5	14	7	4	0.5	28	60	11	29	46	11	43	Y	Y	Y	Y
2/3-2B	M	465	203	48	52	33	16	4.5	6	0.5	40	49	10	41	34	10	56	N	N	Y	Y
2-9	L	430	201	50	50	24	22	6	6	4	38	46	12	42	24	12	64	N	=	Y	Y
2-8	M	582	204	38	62	54	11	5	9	0*	21	65	14	21	54.5	14	31.5	Y	N	Y	Y
2-4	UM	353	211	62	38	30.5	25	2.5	10	6	26	56	12	32	30	12	58	N	N	Y	Y
2-5	U	539	211	43	57	46	17	5	5	0	27	63	10	27	46	10	44	Y	=	N	Y
						Southern mineralogic group															
2-11	L	508	200	42	58	58	9.5	11	1	0	20.5	67.5	12	20.5	58	12	30	Y	Y	N	Y
2-12	UM	385	199	55	45	65	9	4.5	1	0	20.5	74	5.5	20.5	65	5.5	29.5	Y	Y	N	—
2-13	U	516	210	46	54	68	11.5	7	0.5	0	13	80	7	13	68	7	25	Y	Y	N	N
9-3	M	286	208	74	26	58	15	4	2	2	19	73	6	21	58	6	36	Y	Y	Y	N
2-27	M	378	198	53	47	58	7	13	2	0	20	65	15	20	58	15	27	Y	Y	N	—
10-11	L	275	203	76	24	52	18	2	1	0	27	70	3	27	52	3	45	Y	Y	N	N
10-7	M	361	217	63	37	63	15	3	1	0	18	78	5	17	63	5	32	Y	Y	N	N
10-4	U	354	223	64	36	47	17	6	2	0	28	64	8	28	46.5	7.5	46	Y	Y	N	N
1-10	L	291	195	70	30	66	10	8	3	0	13	76	11	13	66	11	23	Y	Y	N	N
1-13	M	295	207	73	27	42.5	10	11	4	4	28.5	52	15	33	42.5	15	42.5	=	Y	N	N
1-17	U	355	221	65	35	71	10	4	3	0	12	81	7	12	71	7	22	Y	Y	N	N
1-2	LM	209	203	100	n.c.	46	23	2	1	0	28	69	3	28	46	3	51	N	Y	N	N
12-9	U	200	200	100	n.c.	67	12	7.5	0	0.5	13	79	8	13	67	8	25	Y	Y	Y	N
11-7	L	302	202	70	30	47	20	8	0	0	27	67	8	25	47	8	45	Y	Y	N	N
11-4	M	600	376	65	35	49	17	10	2	0	22	66	12	22	49	12	39	Y	Y	N	N
12-22	U	263	200	79	21	44	13.5	21	1	0	20.5	57.5	22	20.5	44	22	34	Y	Y	N	N
13-3B	M	300	202	69	31	51	27	4	0	0	18	78	4	18	50	4	46	Y	Y	N	N
13-12	U	353	199	62	38	52	27	7	0	0	14	79	7	14	52	8	40	Y	Y	N	N
13-8	U	315	194	63	37	71	5	14	1	0	9	76	15	9	71	15	14	Y	Y	N	N

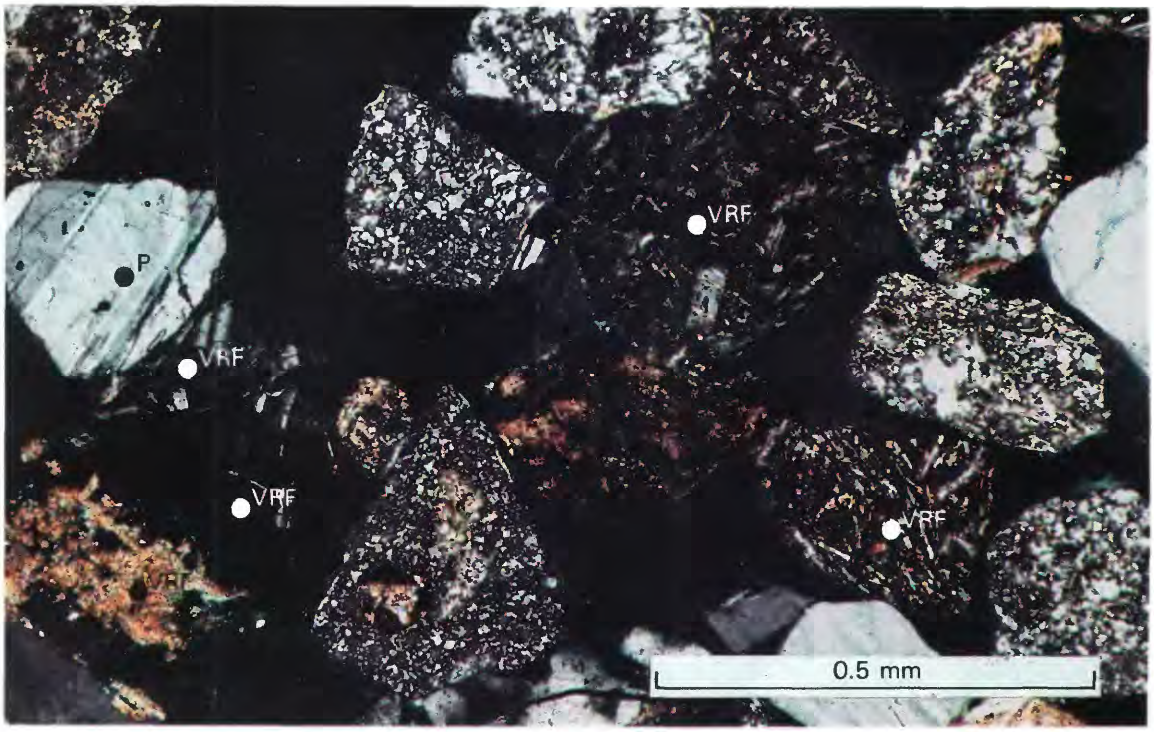

Figure 7. Photomicrograph of sandstone from the Lance Formation from the northern part of the Powder River Basin. Note volcanic rock fragments (VRF) and plagioclase (P). Polarized light.

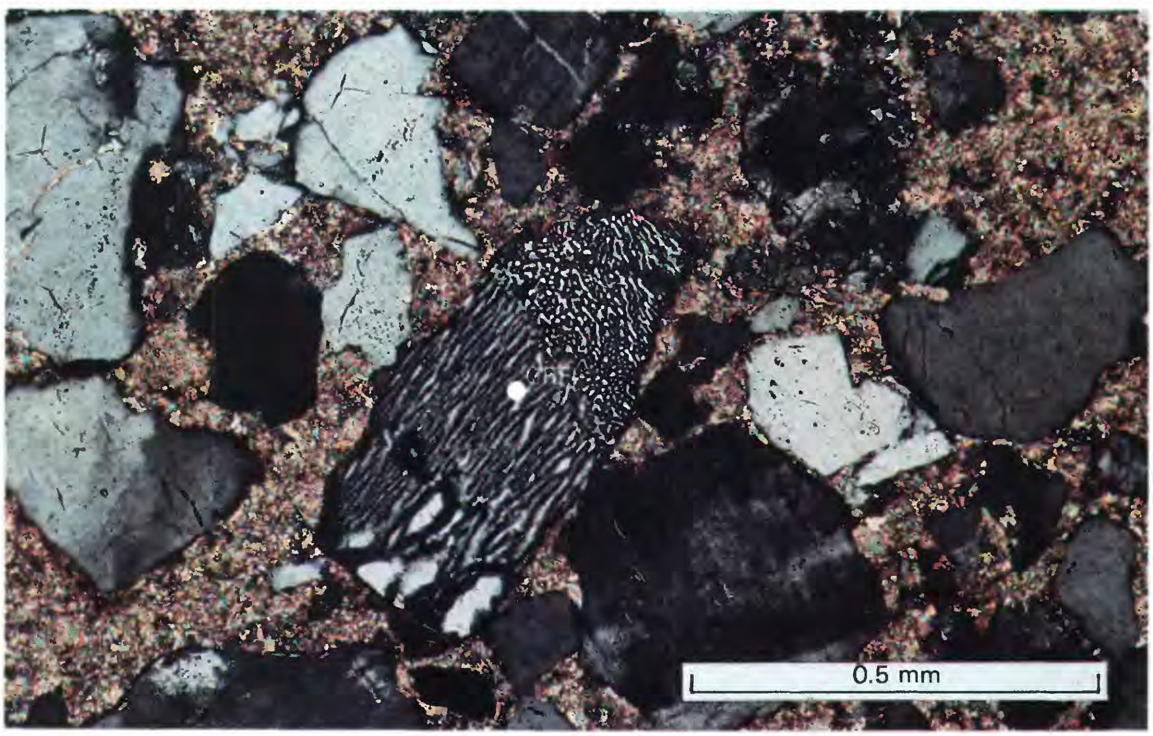

Figure 8. Photomicrograph of sandstone from the Lance Formation from the southern part of the Powder River Basin. Note granitic rock fragment (GRF). Polarized light.

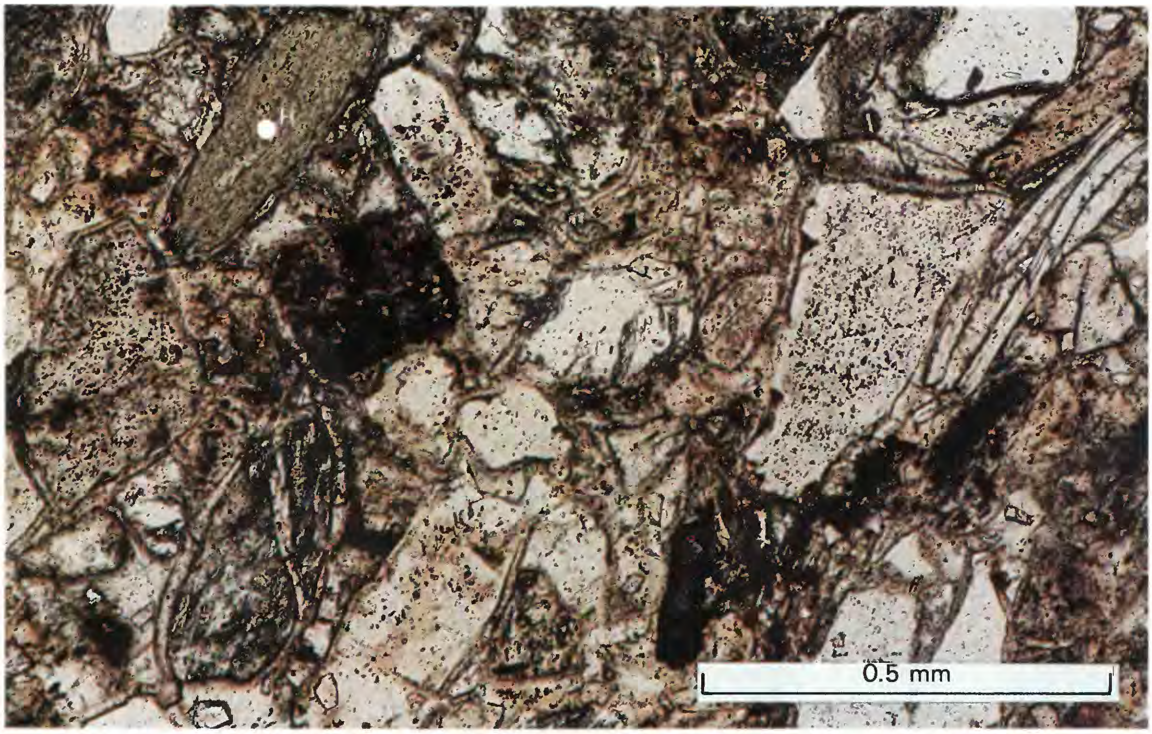

Figure 9. Photomicrograph of sandstone from the Lance Formation from the central part of the Powder River Basin. Note green hornblende (H). Plain light.

upper parts of channels. Very low angle cross-beds were ignored. Where regional dip exceeded 10 degrees, the measurements were corrected for rotation, as suggested by Miall (1984, p. 258). Some cross-bed measurements posted on plate 8 were taken from the literature and have a separate symbol to differentiate them from measurements made during the course of this study. Additional measurements along the east side of the basin by Seeland (1988, fig. 1) were not incorporated here because so many are near the locations selected for this study and show the same general trends.

It is apparent from plate 8 that latest Cretaceous stream flow for this large region, indicative of regional paleoslope, was from west to east. In the northern part of the area, the flows are from slightly north of west, and in the southern part of the area, they are from slightly south of west.

SUMMARY AND INTERPRETATION

During Lance time, the area of study was 5 to 10 degrees of latitude farther north, as interpolated from 60-Ma and 80-Ma maps in Smith and others (1981). According to J.A. Wolfe (oral commun., 1986, 1989) and Wolfe and Upchurch (1986), the climate was warm—the temperature was 77–99 °F (25–37 °C), and rainfall is estimated to have been 31–35 inches (80–90 cm) per year. Warm temperatures are indicated by the prevalance of small, thick leaves with mostly entire (smooth) margins. Low precipitation is indicated by the paucity of leaf drip tips. There was little seasonal climatic variation: deciduous trees were absent, broadleaf evergreens dominant.

It is probable that this subhumid, warm area had little topographic relief because Lance sediments were deposited on relatively level marine and marginal marine plains. The area also was probably at low elevation because the sea was not far to the east (Cherven and Jacob, 1985, fig. 25), and the closest uplift to the west would have been west of the present Bighorn Basin. Rivers and streams traversed this coastal plain from west to east, and sands and shales were deposited as fluvial channel and overbank sediments.

A slight eastward convergence of paleocurrents suggests that the surface was slightly lower in the central part of the study area, resulting in a concave westerly curve to the Lance shoreline. This fluvial depositional surface extended at least as far west as the western side of the present Bighorn Basin; it extended to the east beyond the present Black Hills. It extended at least as far northwest as the western edge of the present Williston and Bull Mountain basins and as far southwest as the northern edge of the present Granite Mountains. None of the present structural or topographic highs and lows within the study area were present, or incipient, during Lance time. There were no Bighorn Mountains, no Casper arch, no Miles City arch, no Black Hills. There was no Williston Basin, no Bull Mountain Basin, no Bighorn Basin, no Wind River Basin, and no Powder River Basin. This is clearly shown by the

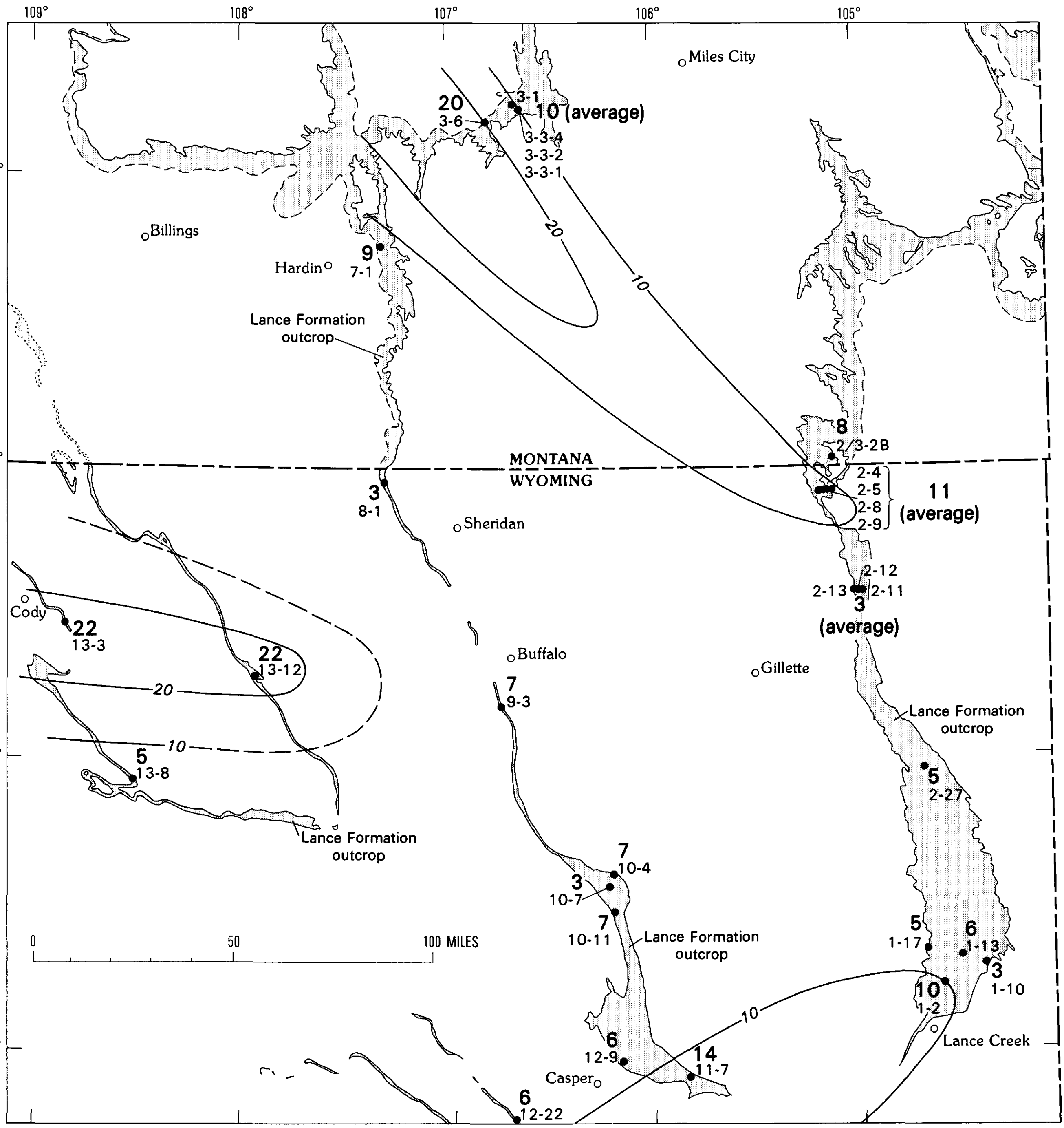

Figure 10. Isopleth map showing percent chert in thin sections, Lance Formation, Powder River Basin and Bighorn Basin. Locality numbers shown on plate 7.

paleocurrent data, which indicate stream-flow directions that trend uninterruptibly eastward.

The much greater thickness of sediments in the southern part of the Powder River Basin suggests that either the depositional rate (and subsidence rate) was greater in that area, or that deposition (and subsidence) proceeded over a longer interval of time there than in the north. The former suggestion appears to be the case. Robinson and others (1959, fig. 2) show that, based on ammonite zones, the base of the Fox Hills Sandstone is progressively younger southward along the eastern side of the Powder River Basin; the scattered occurrences of the K–T boundary clay at the top of the Lance suggest that the top of the Lance may everywhere be synchronous. Therefore, the Lance-plus-Fox Hills interval, though thicker in the south, had less time to accumulate there. Apparently, deposition kept up with greater subsidence in that area. Estimated sedimentation rates for the Lance and Fox Hills combined, based on

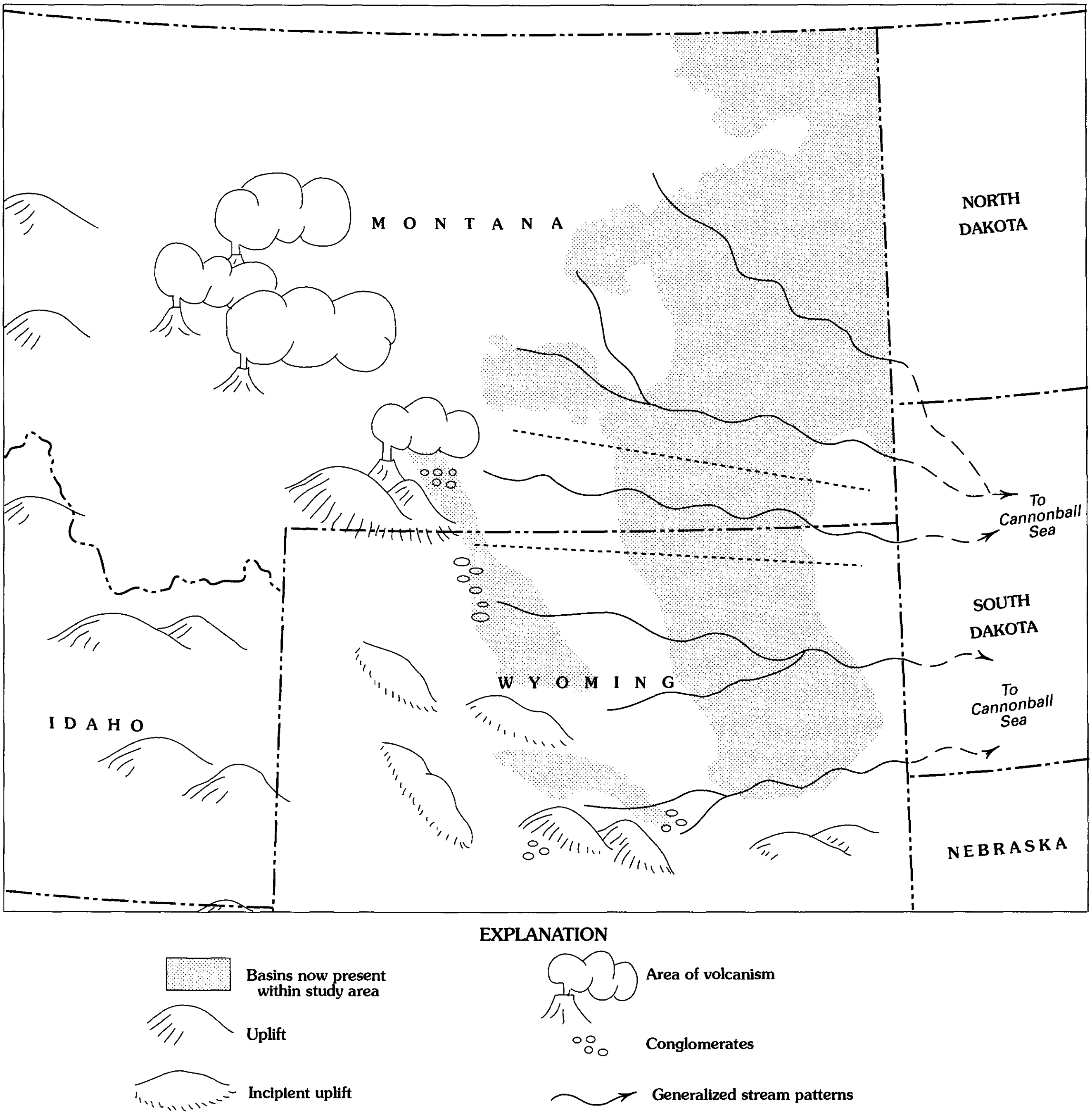

Figure 11. Paleogeographic map of the region surrounding the present-day Powder River Basin during Lance time. Short dashed lines separate the three petrographic groupings described in the text and shown on plate 7. Map based on this report, Love and others (1963), American Association of Petroleum Geologists (1972), McGookey (1972), Reynolds (1976), and Cherven and Jacob (1985).

thicknesses reported here and assuming 5 million years for the duration of the Lance plus 1 million years for the Fox Hills, range from about 120 ft (35 m) per million years in the north to 550 ft (170 m) per million years in the south. These estimates are somewhat greater than, but fairly comparable to, those reported by Gill and Cobban (1973, fig. 21) for the Late Cretaceous (late Santonian to early Maastrichtian) in this area.

Both the paleocurrent data and the location of the coarsest material imply source areas to the west. Petrographic data indicate three different sources:

1. Sediments in the northern part of the Powder River Basin, coming from the west-northwest, are rich in volcanic rock fragments. Volcanic rocks of Late Cretaceous age, reported in western Montana, were probably the source; there was major activity in the Elkhorn Mountains

volcanic arc in southwestern Montana (Cherven and Jacob, 1985, p. 162). The angular nature of the fragments indicates they were either deposited directly as ash falls or were water transported only a short distance. If these were air falls, the volcanic source could have been as far as 150–200 mi (240–310 km) away, based on data from the 1980 Mount St. Helens, Washington, eruptions where particles of fine-sand size were found that far away. (Sarna-Wojcicki and others, 1981, fig. 342*A*).

2. Sediments in the central segment of the Powder River Basin (studied in thin sections) and in the Crazy Mountains Basin (studied in hand specimens), coming from the west, are characterized by the presence of green hornblende. This green mineral is very rare to absent elsewhere in the study area. There was uplift, volcanism, and erosion along the northeastern border of the Beartooth Range in southwestern Montana and northwestern Wyoming in the Late Cretaceous (Foose, 1958), and the Precambrian core was exposed (Roberts, 1972, p. C10). The core of the Beartooths is granite and amphibolite. Either the Beartooth amphibolite or volcanics (andesite breccia is well exposed at Greycliff, 10 mi east of Big Timber, Montana) could have been the source of the green hornblende.

3. Sediments in the southern part of the study area—in the Bighorn Basin, in the eastern end of the Wind River Basin, and in the southern Powder River Basin—are quartz rich. They also contain potassium feldspar, which predominates over plagioclase, and some intrusive rock fragments. Thus, the implied provenance would be acidic igneous rocks. Further evidence of such a source is that there is only 11 percent polycrystalline quartz on the average in the southern part of the study area. Polycrystalline quartz of 13 percent or less is considered indicative of a plutonic source (Basu and others, 1975). The Washakie, Owl Creek, and Wind River Mountains were present only in juvenile form by the end of the Cretaceous (Love and others, 1963); probably only their sedimentary cover provided detritus for the Lance. The greater amounts of quartz in the southern part of the study area might be due to input of these reworked sediments. Uplift in the ancestral Granite Mountains (Love and others, 1963) likely provided the granite pebbles seen in the Lance in the eastern end of the Wind River Basin and the granitic rock fragments found in thin sections from the southernmost Powder River Basin. There is also evidence farther south that the Granite Mountains were uplifted by Lance time. Reynolds (1976, p. 23–24) found granule-size fragments of sedimentary rocks in the middle part of the Lance and rare cobbles and small boulders of Paleozoic sedimentary rocks and Precambrian granitic rocks in the basal unit of the Fort Union along the southern flank of the Granite Mountains. He concluded that, as early as latest Cretaceous or earliest Paleocene time, the crystalline basement was exposed. He also estimated the amount of uplift in latest Cretaceous time to have been about 1,500–2,000 ft (460–610 m) (Reynolds, 1976, p. 29 and fig. 11). This amount of uplift might well have contributed, by sedimentary loading, to the greater amount of subsidence in the southern part of what is now the Powder River Basin.

The conclusions reached here about the Lance Formation in the Powder River Basin have been supported by several lines of evidence (lithology, depositional setting, paleocurrents, petrography, and subsurface data). Figure 11 summarizes these conclusions. Deposition of the Upper Cretaceous Lance Formation ended at the time of the K–T boundary event. The climate very briefly became cooler, but soon it was warmer and markedly wetter. Rainfall increased from 31–35 inches (80–90 cm) per year prior to the boundary event to more than 118 inches (300 cm) per year (J.A. Wolfe, oral commun., 1989), thus setting the stage for greater influx of coarser grained sediments (the sandier Tullock) and the widespread peat-accumulating swamps of the Paleocene.

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