Depositional Systems of a Synorogenic Continental Deposit—The Upper Paleocene and Lower Eocene Wasatch Formation of the Powder River Basin, Northeast Wyoming

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Chapter H

Depositional Systems of a Synorogenic Continental Deposit—The Upper Paleocene and Lower Eocene Wasatch Formation of the Powder River Basin, Northeast Wyoming

By DAVID SEELAND

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

U.S. GEOLOGICAL SURVEY BULLETIN 1917

EVOLUTION OF SEDIMENTARY BASINS—POWDER RIVER BASIN

U.S. DEPARTMENT OF THE INTERIOR
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U.S. GEOLOGICAL SURVEY
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Depositional Systems of a Synorogenic Continental Deposit—The Upper Paleocene and Lower Eocene Wasatch Formation of the Powder River Basin, Northeast Wyoming

By David Seeland

Abstract

Fluvial sedimentary rocks of the Wasatch Formation of the Powder River Basin had major sources in the Laramide uplifts that nearly surround the basin on the east, south, and west. Paleocurrent study based on crossbedding in sandstone of stream-channel origin indicates that basin paleoslope directions and the intersecting paleoslopes define two major drainages. The first and largest was an extrabasinal stream that was the major longitudinal river of the upstream Wind River Basin. It flowed across the Casper arch and into the Powder River Basin. This longitudinal basin-axis trunk stream of the Powder River Basin, termed the Wind River of Eocene time, flowed from south to north through the westernmost basin. The other major stream flowed from southeast to northwest and was the major tributary of the Wind River of Eocene time.

Three major alluvial depositional systems can be defined using paleocurrent and facies analysis: (1) a distal mud-rich alluvial plain with a source terrane to the east in the Black Hills, (2) a proximal sand-rich alluvial plain-alluvial fan with a source to the south in the Laramie Mountains, and (3) a stream-dominated proximal to distal alluvial fan with a source to the west in the Bighorn Mountains.

Grain-shape and grain-size studies supplemented the paleocurrent study and corroborated transport directions. An area of large tributaries to the Wind River of Eocene time is indicated by an area of less-regular sand grains in the western basin near Buffalo.

Major coal and uranium deposits are spatially related to the depositional systems of the basin. Known Wasatch Formation uranium deposits are limited to the proximal alluvial plain-distal alluvial fan depositional system of the southern basin. The source of the uranium was probably granitic detritus of the Wasatch sandstone and uraniferous tuff of Oligocene age that overlap permeable Wasatch sandstone units in the southernmost basin. The thickest coal bed known in the United States originated in a peat swamp that paralleled the basin-axis trunk stream. Other coal-forming swamps were more abundant in the vicinity of the basin axis than in areas remote from the axis.

INTRODUCTION

The synorogenic fluvial and paludal rocks of the upper Paleocene and lower Eocene Wasatch Formation in the Powder River Basin contain large deposits of coal and uranium. These rocks also record the culmination of Laramide tectonic events marked by subsidence in the basin and uplift of the bounding structures. This study establishes the early Eocene paleogeography of the basin using a two-part approach consisting of (1) sedimentary particle-shape and -size analysis, and (2) paleocurrent studies.

Because fluvial depositional systems are the key to understanding the origin and localization of large deposits of coal and uranium, many investigators have developed paleogeographic frameworks for all or part of the basin (fig. 1) that attempt to explain the origin of these deposits. Childers (1970) sketched an early Eocene paleogeographic map of Wyoming (which included parts of the Wasatch, Wind River, and Battle Spring Formations) based on regional facies distributions. Galloway (1979) introduced a late Paleocene and early Eocene (Tongue River Member of Fort Union Formation and Wasatch Formation) paleogeographic framework based on a 50-log subsurface study in the southern basin. Galloway's trunk stream was extended northward by Flores and Ethridge (1985) and Flores (1986). Warwick and Flores (1987) postulated a

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north-flowing early Eocene basin-axis trunk stream in the central basin. Seeland (1976) suggested westerly to northwesterly flowing streams in the eastern and central parts of the Wasatch outcrop area (the central part of the topographic basin), with the trunk stream located in the westernmost basin. Because of these conflicting paleogeographic frameworks showing the "western" trunk stream (Seeland, 1976) or the "central" trunk stream (Galloway, 1979; Flores and Ethridge, 1985; Flores, 1986; Warwick and Flores, 1987), the total number of paleocurrent localities in the Wasatch Formation for this study were increased by about 50 percent over the number used in Seeland (1976), with recent supplemental field work concentrated in the eastern part of the Wasatch Formation outcrop (the central part of the topographic basin).

Comparison of the early Eocene paleogeography of the basin (Seeland, 1976) (fig. 1) with the late Paleocene (Tongue River Member of the Fort Union Formation) paleogeography (Seeland, 1988; Seeland and others, 1988) (fig. 2) shows that the two are very different, precluding their combination as suggested by Galloway (1979) and as followed by most of the other proponents of the eastern trunk stream. These differences also preclude making paleogeographic inferences from a sand-percentage map of the combined Wasatch Formation and Tongue River Member of the Fort Union Formation (Flores and Ethridge, 1985).

GEOLOGIC SETTING

The Powder River topographic basin of northeastern Wyoming and southern Montana is defined by the Bighorn Mountains on the west, the Black Hills on the east, and the Laramie Mountains and the Hartville uplift on the south (fig. 1). On the north, the Miles City arch structurally separates the Powder River Basin from the Williston basin of eastern Montana and North Dakota (fig. 3).

Following the eastward retreat of the Western Interior Cretaceous epicontinental sea, thousands of meters of mostly fluvial sediments were deposited, including the Upper Cretaceous Lance and Hell Creek Formations, the Paleocene Fort Union Formation, and the Paleocene (local) and lower Eocene Wasatch Formation (fig. 4). The Wasatch Formation is overlain by remnants of the Oligocene White River Group, which formerly covered most of the basin.

The Wasatch Formation consists of alluvial mudstone and sandstone. In most places mudstone of overbank flood plain origin predominates and makes up about two-thirds of the unit. Crossbedded sandstone that becomes finer grained upwards is interpreted as channel deposits of meandering to anastomosed streams and makes up much of the remainder of the unit. Minor constituents include coarse conglomerate, the Moncrief and Kingsbury Members of the Wasatch Formation, deposited in alluvial fans along the western margin of the basin, and carbonaceous shales and thick coal beds deposited in extensive, long-lived, low-lying swamps.

The maximum preserved thickness of the Wasatch is about 900 m (3,000 ft) along the present structural axis of the basin (fig. 3) about 8 km southeast of Buffalo, Wyo.

GRAIN-SIZE AND GRAIN-SHAPE ANALYSIS

Conglomerate

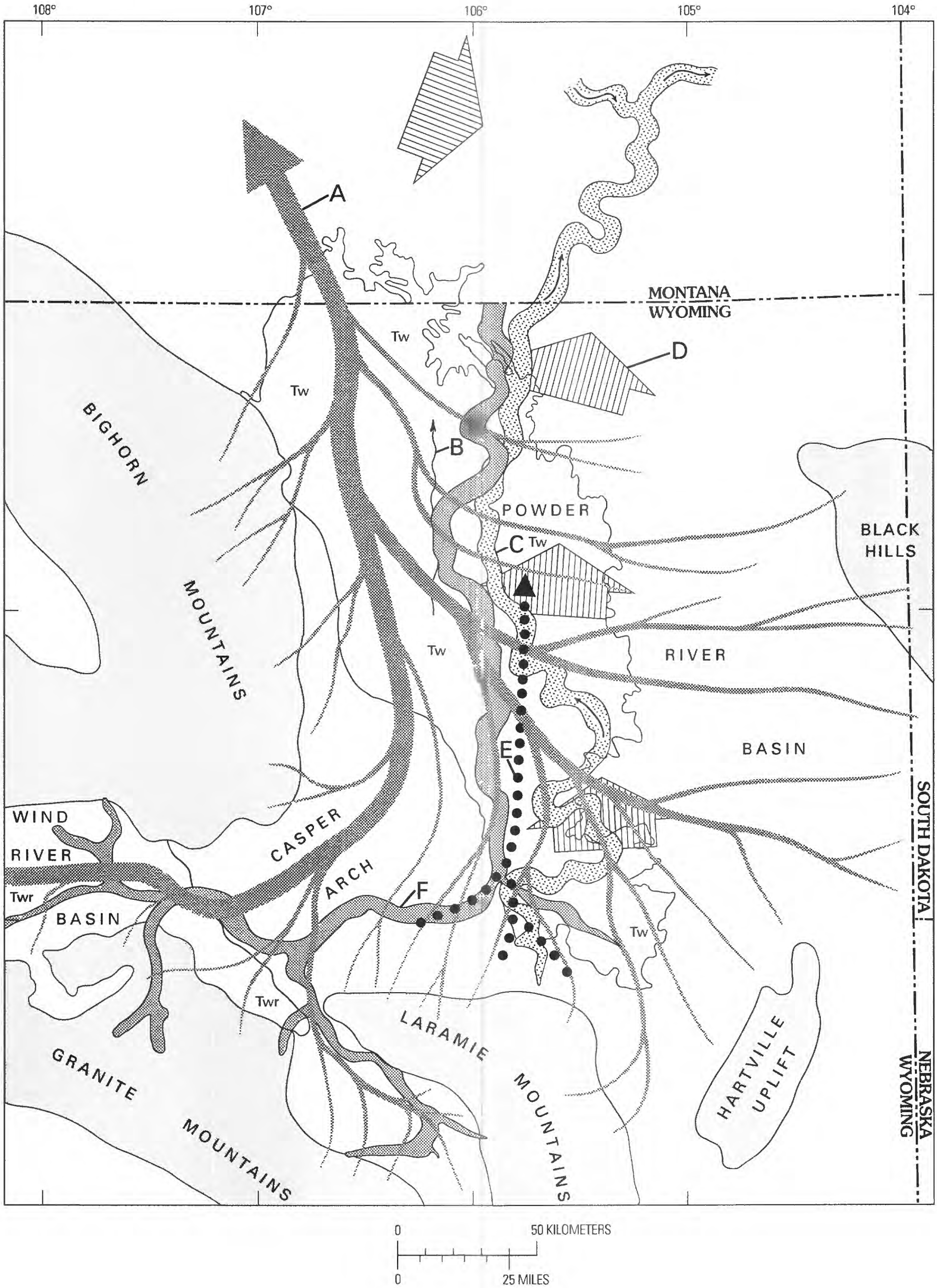
Maximum clast sizes were determined at all field localities where conglomeratic sandstone was present. Clast shape was not studied. The maximum-clast-size map (fig. 5) shows all localities with clasts larger than 3 mm (granules).

Two areas have conglomeratic sandstone: (1) the western part of the basin adjoining the Bighorn Mountains, and (2) the southern part of the basin where the most probable source was the Laramie Mountains, but with the Hartville uplift a second, less likely source. Granules at the three northernmost localities in the southern part of the basin most likely have a southern, rather than a Black Hills, source. This conclusion is based on a lack of conglomerate along the eastern part of the Wasatch Formation outcrop north of these three localities. This eastern nonconglomeratic Wasatch is at least as close to a Black Hills source of conglomerate as are the three granule localities. Probable conglomerate source terranes are discussed in the section on "Paleocurrents and Paleogeographic Synthesis."

The Kingsbury Conglomerate Member and the overlying Moncrief Member of the Wasatch Formation crop out along and on the Bighorn Mountains uplift. They are coarsely conglomeratic and record uplift and progressive unroofing of the Bighorn Mountains. Kingsbury clasts are predominantly carbonate rocks derived from the Ordovician Bighorn Dolomite and the Mississippian Madison Limestone (Nelson, 1968), and the Moncrief clasts are predominantly crystalline rocks (Hoppin and Jennings, 1971; Sharp, 1948). Carbonate boulders as large as 1 m were found at Kingsbury Ridge, 10 km south-southwest of Buffalo. Conglomerate and conglomeratic sandstone are interbedded with sandstone and minor amounts of mudstone at Kingsbury Ridge.

Although Hoppin and Jennings (1971) and Mapel (1959) stated that crystalline-rock fragments are uncommon in the Kingsbury, they are present in fairly large amounts at

Figure 1 (facing page). Map showing five proposed locations for the major basin-axis trunk stream of Wasatch Formation time or Wasatch and late Fort Union Formation time combined, Powder River Basin, Wyoming and Montana. A, Wasatch time only, Seeland (1976); B, Wasatch time only, Warwick and Flores (1987); C, Wasatch and late Fort Union time combined, Flores and Ethridge (1985); D, Wasatch and late Fort Union time, combined, Flores (1986); E, Wasatch time(?) and late Fort Union time combined, Galloway (1979); F, Wasatch time only, Childers (1970). Tw, uppermost Paleocene and lower Eocene Wasatch Formation; Twr, lower Eocene Wind River Formation.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CASPER
ARCH
LARAMIE
MOUNTAINS
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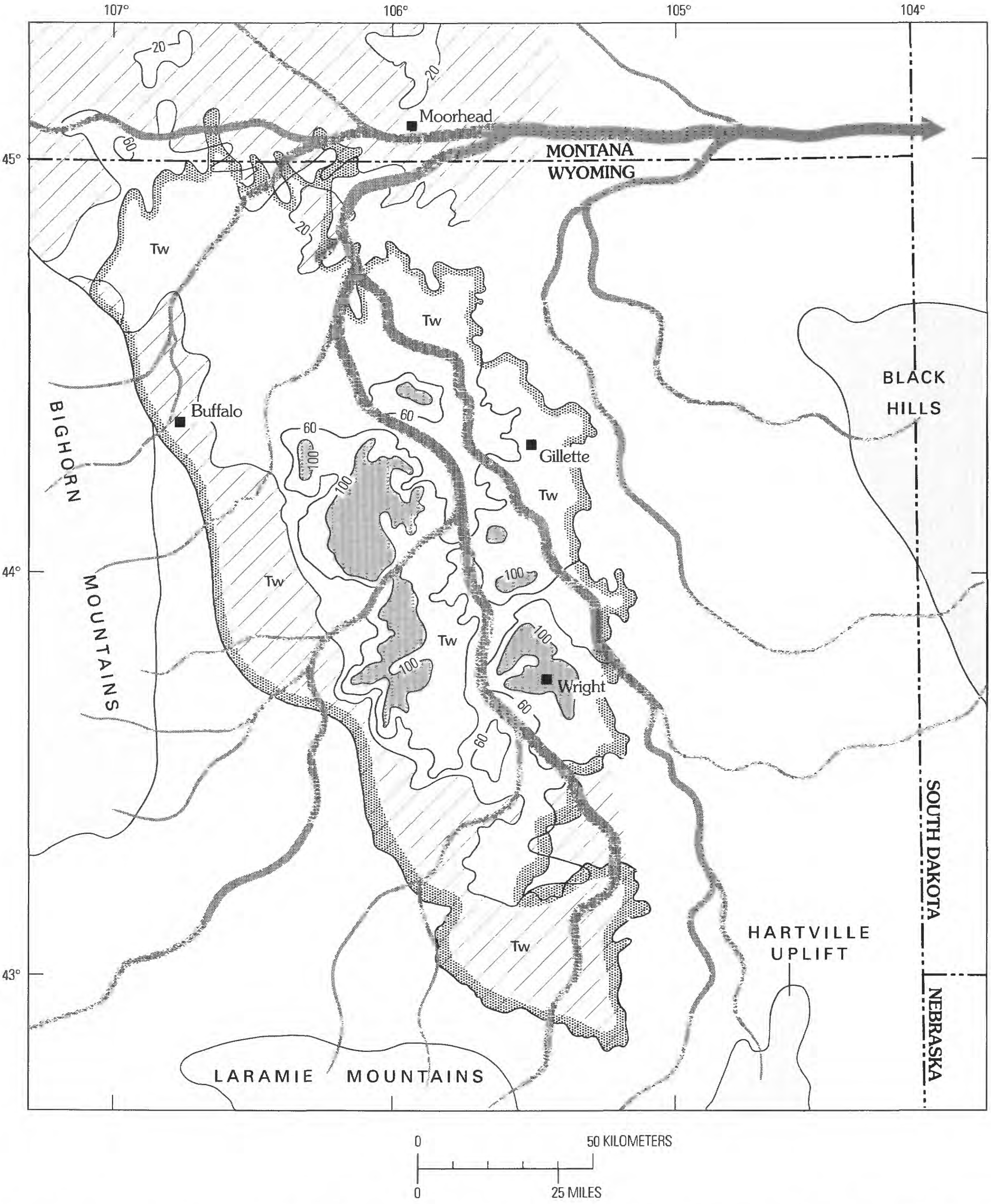

Figure 2. Interpretive stream map for the late Paleocene based on paleocurrent measurements and distribution of thick coal, Powder River Basin, Wyoming and Montana. Paleocurrent measurements from Seeland and others (1988). Coal distribution in the Tongue River Member simplified from Ayers and Kaiser (1984). Contours show thickness of single thickest coal; contour interval 40 feet. Pattern indicates maximum coal thickness is less than 20 feet, and shaded area indicates maximum coal thickness is greater than 100 feet. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

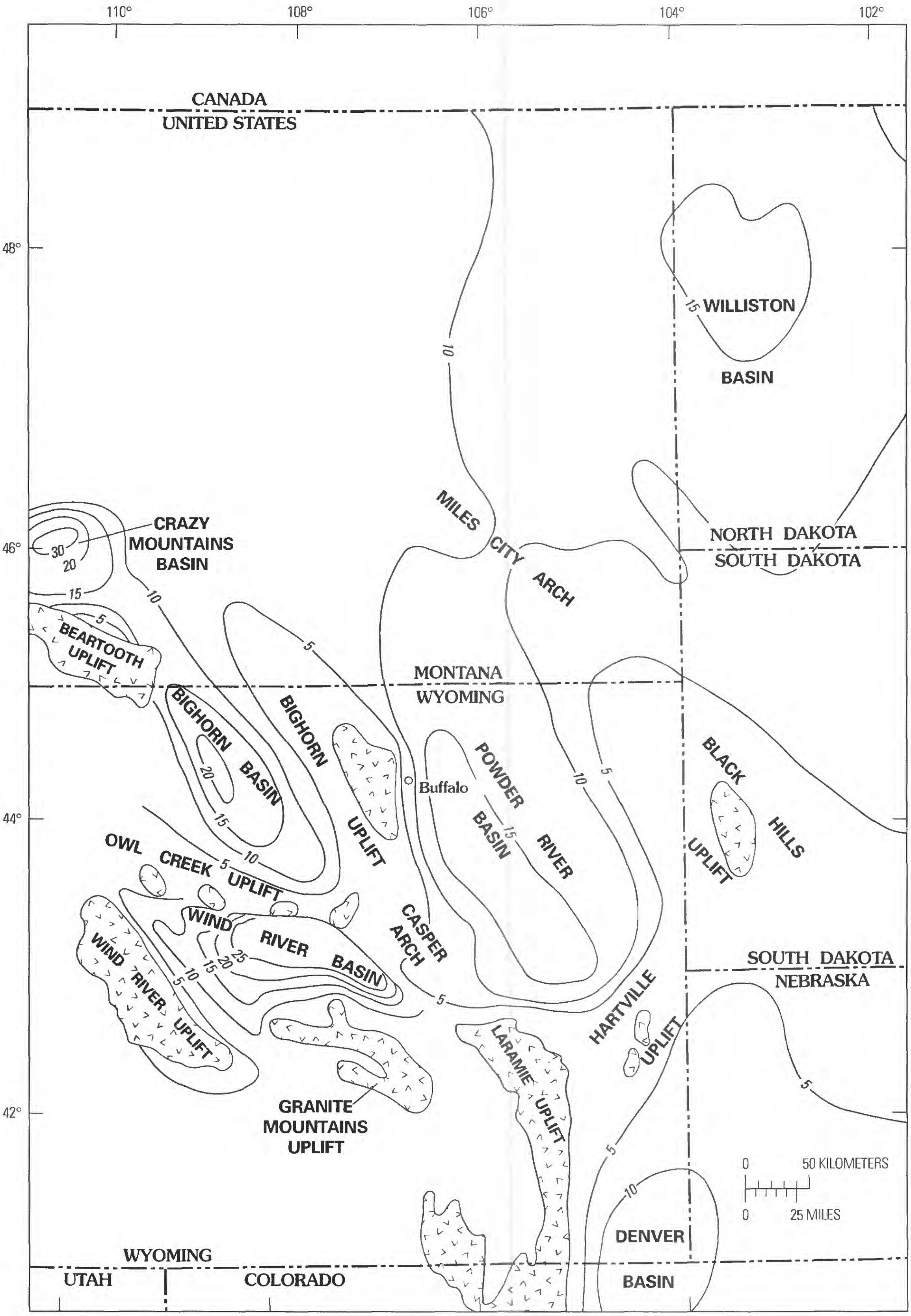

Figure 3. Generalized geologic structures in and near the Powder River Basin, Wyoming and Montana. Structure contours on top of the Precambrian, contour interval 5,000 ft (1,500 m).

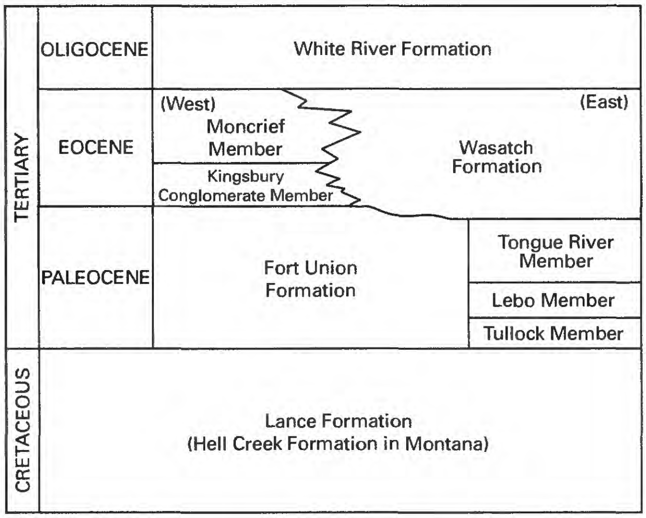

Figure 4. Late Cretaceous through early Tertiary stratigraphic nomenclature for the Powder River Basin, Wyoming and Montana.

Kingsbury Ridge. On the south side of the ridge, an 80-m measured section contains as much as 30 percent granitic-rock clasts. The granitic-rock clasts are smaller than the carbonate clasts and have a maximum diameter of about 100 mm. The presence of granitic clasts throughout the section suggests that the locality represents the distal part of a prograding alluvial fan. Increasingly proximal fan sediments should contain an increasing proportion of Paleozoic carbonate clasts as was seen in the Kingsbury Member northwest of Buffalo, where the clasts are entirely carbonate rocks.

Basin-axis subsidence and a concomitant decrease in paleoslope have been cited as reasons for restriction of conglomerate deposition to the proximal parts of a sedimentary basin (Kraus, 1985; Paola, 1988). In the western part of the basin, subsidence along the basin axis and the development of longitudinal drainage inhibited transport across the axis in a basinward (eastward) direction, as shown by conglomeratic debris extending only about 30 km basinward from the Bighorn uplift. In contrast, in the southern part of the basin, where transport was northward and subparallel to the structural axis of the basin, conglomeratic sandstone is found as far as 100 km north of the Laramie Mountains.

SANDSTONE

Wasatch Formation sandstone samples were collected from crossbed sets at 46 field localities in the basin (fig. 7). The samples were treated with dilute hydrochloric acid to remove carbonate cement, washed, and dried. Grain-size and grain-shape analyses were performed with an electronic image analysis system. Sawyer (1977) described the system, which consists of a microscope; a video scanner; an electronic system that obtains maximum and minimum grain-length, grain-perimeter, and grain-area measurements; and a small computer that records and stores the data and makes statistical calculations. The image analyzer is unique in that it can provide quantitative measures of grain shape that would otherwise be much too time consuming to obtain. The image analyzer requires about 20 minutes per sample to obtain the data used for this investigation.

Parameters that were determined include two measures of grain shape (100 grains per sample) and maximum grain length (250 grains per sample). Grain elongation is the shortest diameter (S) divided by the longest diameter (L), or S/L. As S/L decreases, the grains are more elongated, indicating that the sample locality was closer to the source area. The other shape factor is the area (A) divided by the perimeter squared (P^2), or A/P^2, which is a measure of grain regularity. A circle has an A/P^2 of 0.08; a daisy would have a much lower A/P^2. As A/P^2 decreases, it indicates decreasing regularity of the grain, also suggesting that the source of the grains was closer to the locality where the sample was collected.

The overall mean S/L of 46 samples (4,600 grains) from 46 field localities is 0.746. Figure 6 is a histogram showing the variability of mean S/L. An isopleth map of these values (fig. 7) shows that three areas of the basin have an S/L of less than 0.700 (relatively more elongate); each area is close to one of the major local sediment source areas: the Black Hills, the Laramie Mountains, and the Bighorn Mountains. The areas of relatively less elongate sand grains (S/L near 0.740) in the west-central part of the basin may be due to deposition of far-traveled, less elongate sand grains, whose ultimate source was the uplifts surrounding the Wind River Basin.

A downstream increase in roundness (less elongation) as postulated here is a consequence of selective transport rather than of abrasion during transport. Rounding by abrasion during transport is very slow. Kuenen (1959) found that 20,000 km of simulated transport caused angular, medium-grained sand to lose less than one percent of its weight to abrasion and solution. The rate of rounding must also decrease as the grains become less angular. Only selective transport or source differences can account for the observed abrupt shape changes.

The overall mean sand-grain regularity (A/P^2) of 46 samples is 0.059. The sand-grain regularity map (fig. 8) shows increasing regularity in downstream directions as defined by the paleocurrent analysis. The least regular samples are found in the southern part of the basin. Both the A/P^2 isopleth map (fig. 8) and the paleocurrent maps (figs. 11 and 12) indicate northerly transport in this area; the source of most of these irregular grains must have been the Laramie Mountains, although the Hartville uplift may have been an auxiliary source. The A/P^2 isopleth map also shows a wide area of westward-decreasing regularity in the eastern

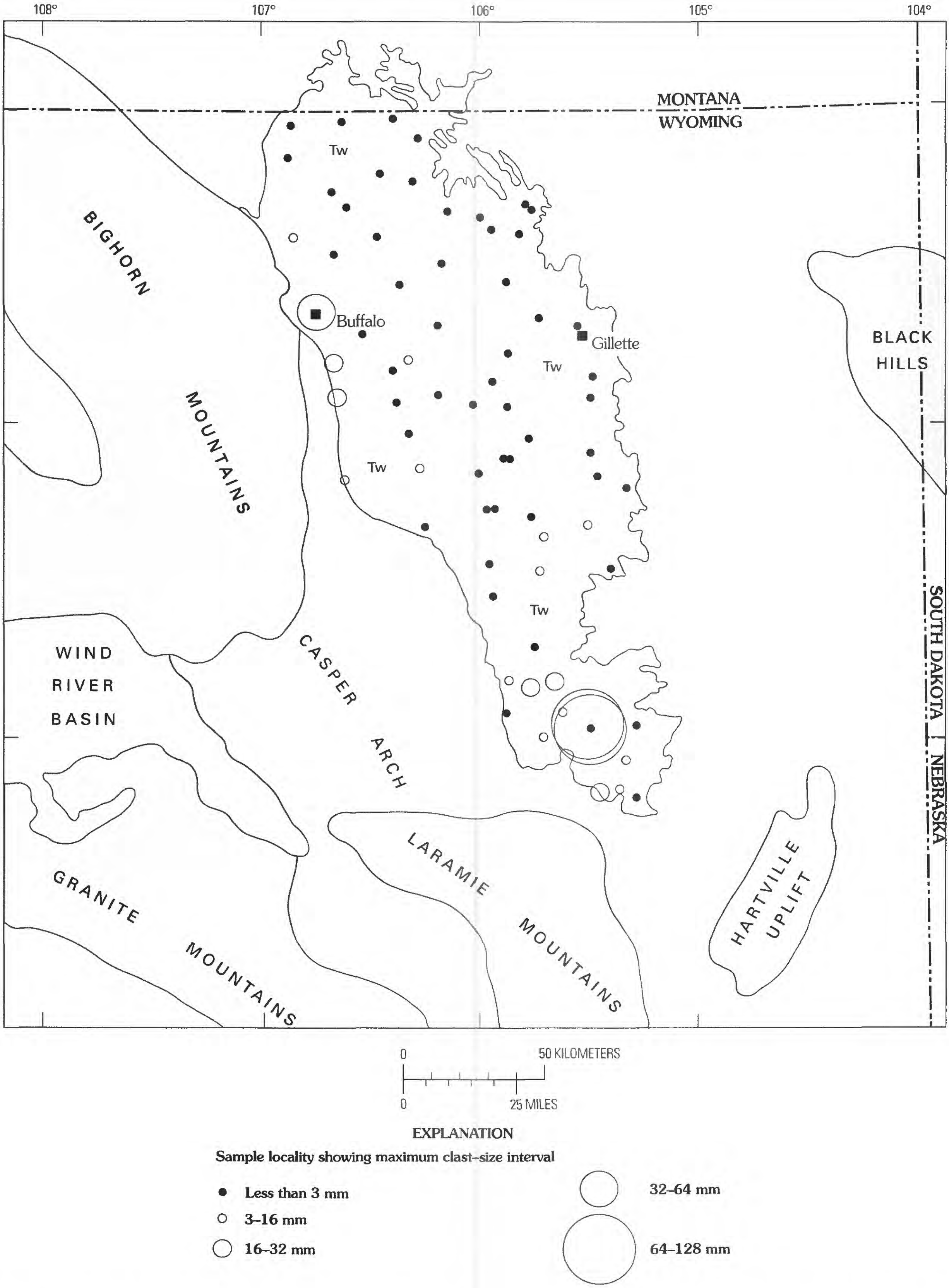

Figure 5. Maximum clast size in the Wasatch Formation at all sample localities having granule-size (3 mm) or larger clasts, Powder River Basin, Wyoming and Montana. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

part of the basin, indicating, as do the paleocurrents, a westward-sloping alluvial plain whose streams carried sediment westward from the Black Hills. The westward decrease in regularity is mostly due to selective transport.

Major basinward inflections of the A/P^2 isopleths allow major tributary streams to be inferred (Seeland, 1978b). Multiple major tributaries entered the Powder River Basin from the Bighorn Mountains in the area near Buffalo as indicated by a strong basinward inflection in the A/P^2 isopleths (fig. 8), which reflects a source of irregular sand grains. This conclusion is supported by the presence of a broad area of coarse lower Eocene conglomerate along the mountain front, the presence of a paleovalley, and the present topography and geology of the Bighorn Mountains. The areal extent of the Kingsbury Conglomerate Member is centered on the basinward A/P^2 inflection near Buffalo (fig. 8). Evidence for an ancestral Clear Creek just west of Buffalo was found by Nelson (1968). He discovered the floor and remnants of the sides of a wide valley filled with Moncrief Member approximately along the present course of Clear Creek and its North Fork.

The north-central part of the Bighorn Mountains is presently the highest part of the range and probably was also the highest part of the range in Eocene time. The range should have received much orographic precipitation during the Eocene. Eocene drainages of the Wind River Range have survived to the present (Seeland, 1978b), indicating that the long-term survival of early Tertiary topography is possible. Thus, present topography suggests that major early Eocene streams flowed out of the north-central Bighorn Mountains. The coarse conglomerates of the Kingsbury Conglomerate and Moncrief Members adjacent to the north-central Bighorn Mountains are additional evidence that the topographic relief was at a maximum in the north-central part of the range in the early Eocene, as it is today.

The grand-mean grain size of 46 sandstone samples is 2.29 phi units (fine sand), based on the measurement of the maximum length of 11,500 grains. A mean-sand-size isopleth map (fig. 9) shows grain-size increases toward the eastern (Black Hills) and southern (Laramie Mountains) margins of the Wasatch Formation outcrop area, reflecting probable sources in or near the Black Hills and Laramie Mountains. The map does not show the Bighorn Mountains source that is obvious from the maximum clast size, elongation, and regularity maps (figs. 5, 7, 8) as well as the paleocurrent maps (figs. 11 and 12) presented in the next section of this report. Low stream gradients and competency along the basin axis may account for this anomaly.

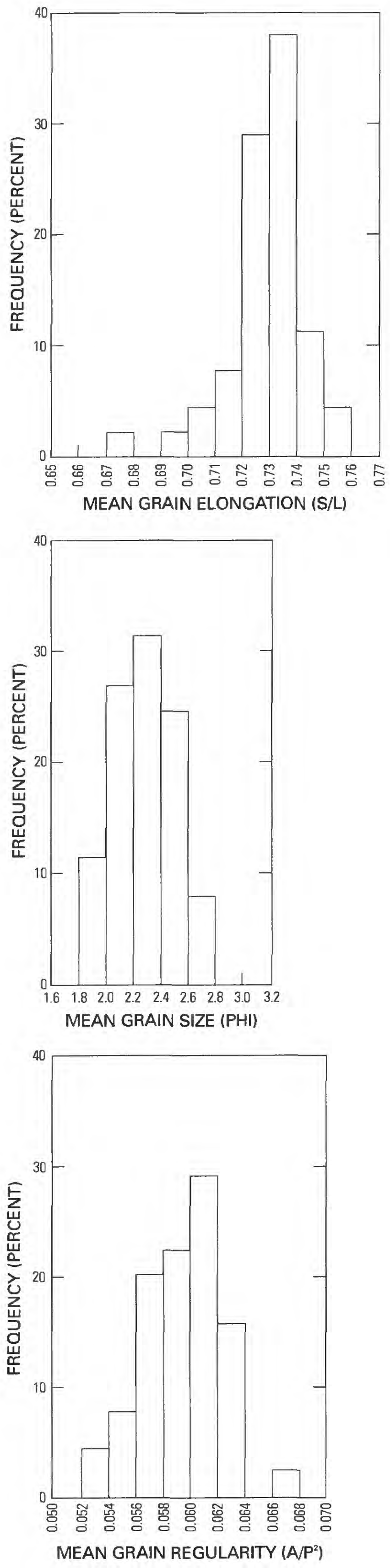

Figure 6 (facing column). Histograms of mean sand-grain regularity, elongation, and size for the Wasatch Formation sandstone at 46 localities, Powder River Basin, Wyoming and Montana.

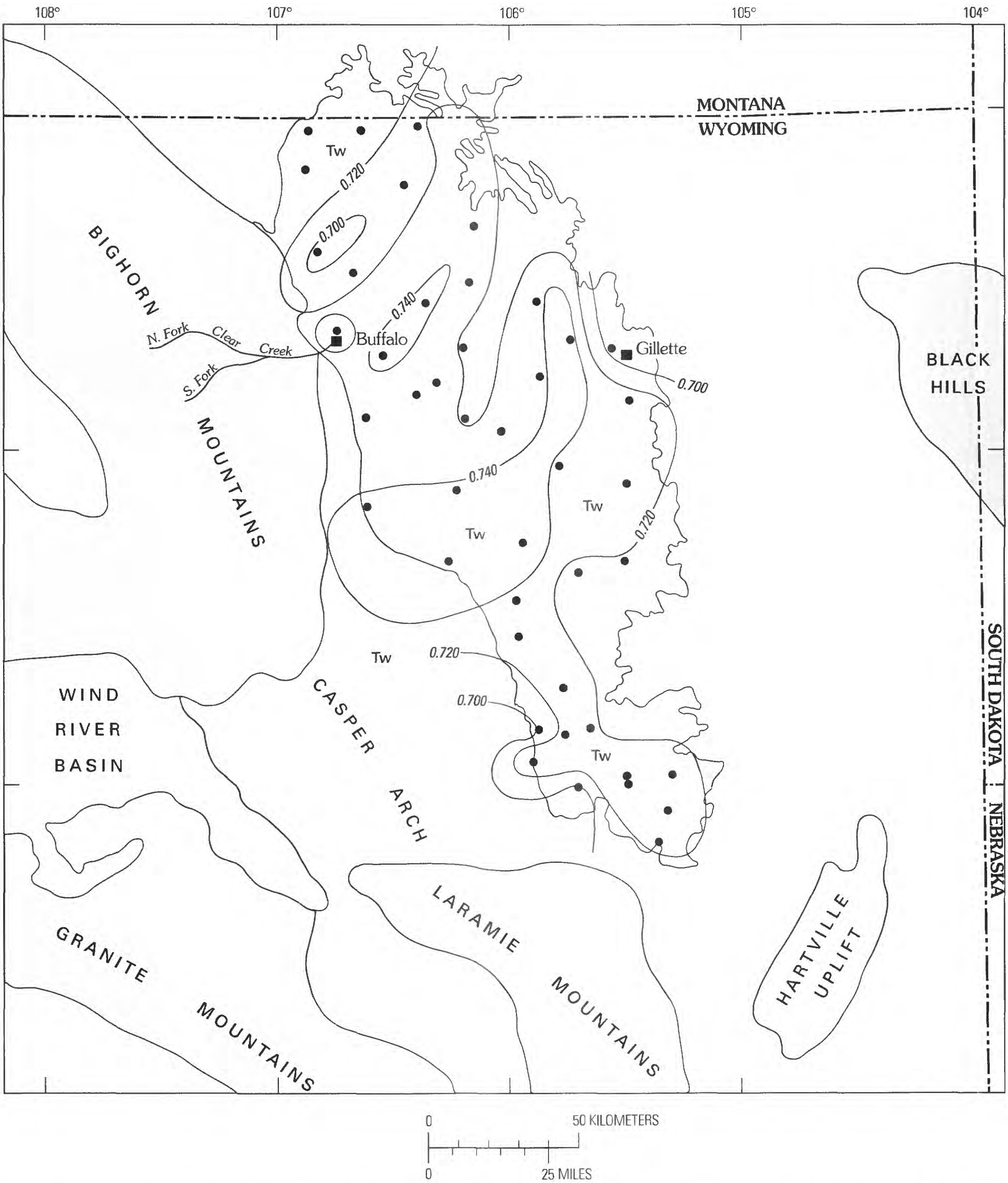

Figure 7. Isopleth map of mean elongation (S/L) of sand grains from Wasatch Formation sandstone, Powder River Basin, Wyoming and Montana. Contour interval is 0.020. Dots are sample localities. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

FACIES STUDIES

Sharp and Gibbons (1964) separated the facies seen at the outcrop of the Wasatch Formation into fine-grained deposits, interbedded sand and fine-grained deposits, medium- to coarse-sand deposits, and conglomerate deposits. The sandier areas as mapped by Sharp and Gibbons (1964) are in the southern and eastern parts of the

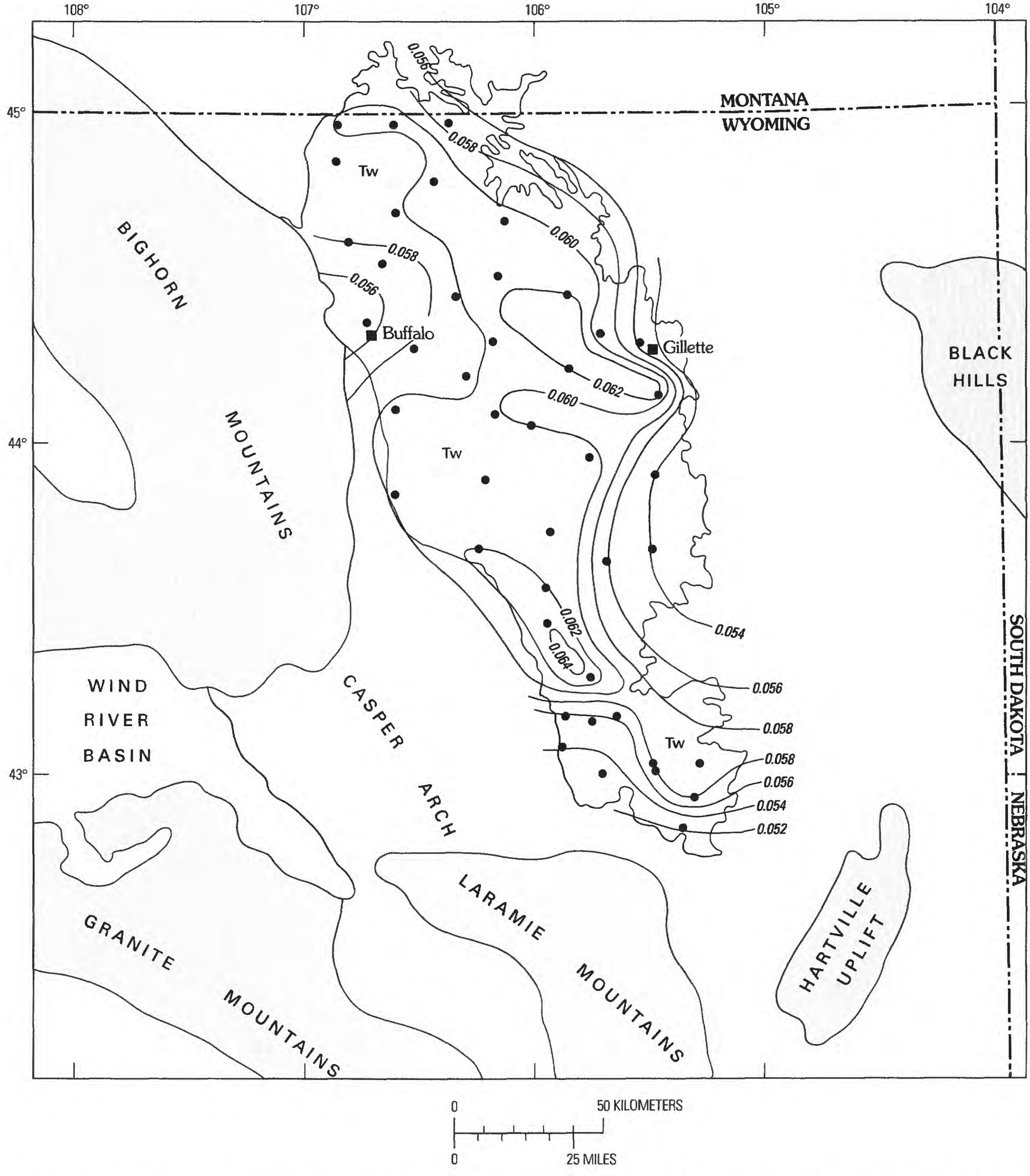

Figure 8. Isopleth map of mean regularity (A/P^2) of sand grains from Wasatch Formation sandstone, Powder River Basin, Wyoming and Montana. Contour interval is 0.002. Dots are sample localities. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

Wasatch outcrop area. Those areas have the Laramie Mountains-Hartville uplift and the Black Hills, respectively, as sources, on the basis of transport directions (fig. 11). The coarser sands of the southern area most likely have a granitic source, and the eastern sand and fine-grained deposits have a source composed of a combination of older sedimentary rock, schist, and minor granite. This conclusion is partly based on the mean sand-grain regularity map (fig.

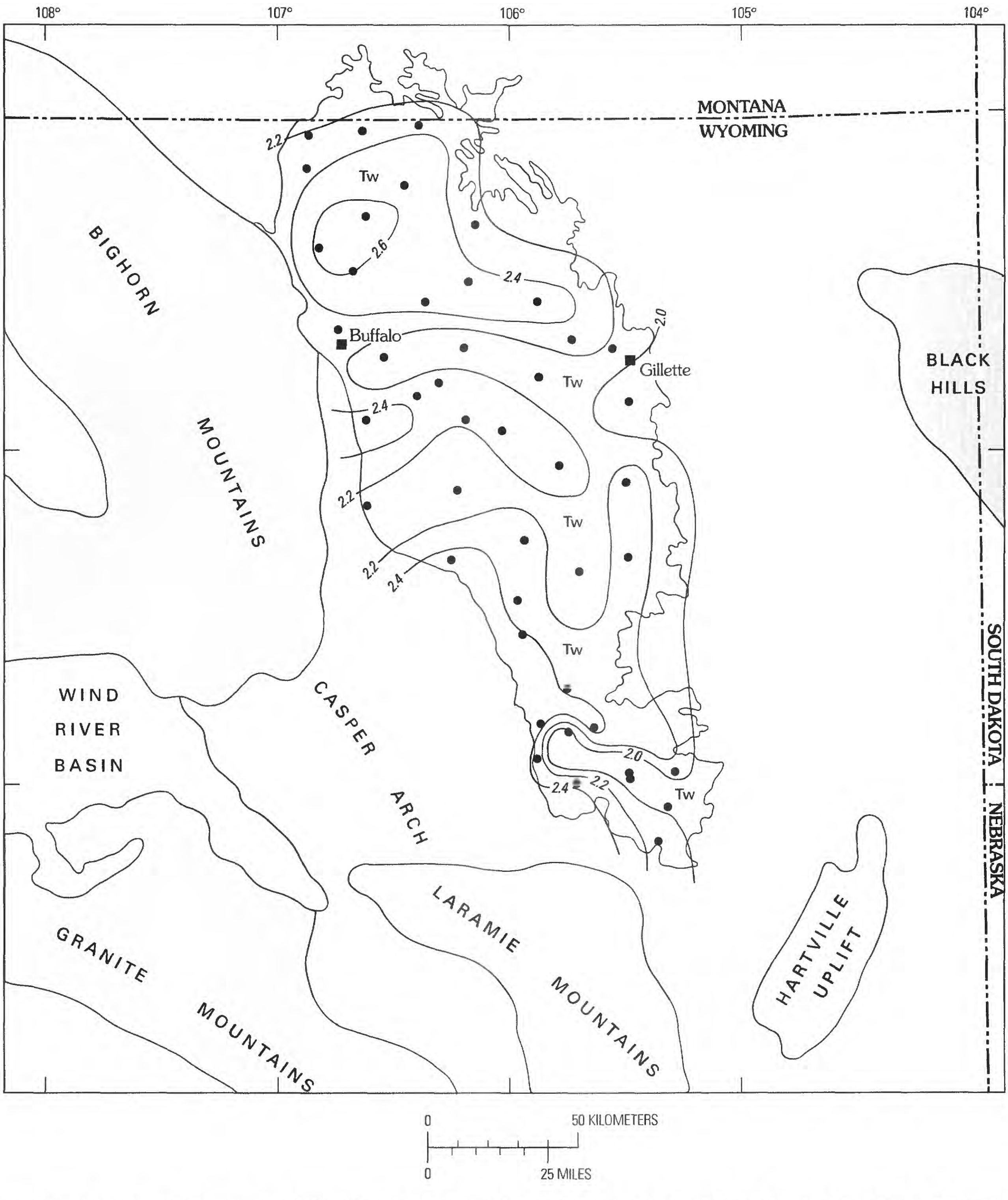

Figure 9. Isopleth map of mean size (phi) of sand grains from Wasatch Formation sandstone, Powder River Basin, Wyoming and Montana. Contour interval is 0.2. Dots are sample localities. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

8), which shows that the most irregular grains are in the southern part of the basin, and substantially more regular grains are in the Gillette area. The finer and more regular grains are thought to be derived from Paleozoic and Mesozoic sandstone and the predominantly schistose Precambrian rocks of the Black Hills. The less regular sand grains in the southern part of the basin were produced by weathering and erosion of the Precambrian granitic rocks of the Laramie Mountains and, to a lesser extent, the granitic rocks of the Hartville uplift.

Bendix Field Engineering Corporation, Geology Division Staff (1976) made sandstone-shale ratio maps for each of seven 150-m (500-ft) thick slices of the Wasatch Formation beginning at the base. An overall sand-percentage map of the Wasatch should provide a reliable representation of sand distribution, because stability over time of lithofacies composition and paleostream directions is indicated by the work of Santos (1981), and stability over time of lithofacies is evident in the slice maps of Bendix Field Engineering Corporation, Geology Division Staff (1976). The sand-percentage map (fig. 10) was prepared from the seven interval maps of Bendix Field Engineering Corporation, Geology Division Staff (1976) for the northern half of the basin. A 16-km (10-mi) grid was superimposed on each slice map, and an interpolated value was recorded for each applicable intersection for each slice. The mean ratio for the entire stack of slices was determined at each grid intersection and the results were contoured (fig. 10).

The overall sand percentage map for the northern half of the Wasatch Formation outcrop area shows two areas with greater than 50 percent sand. The southern of the two areas seems to be the northern extension of the north-south sand trend mapped by Raines and Santos (1980) in the southern Wasatch outcrop area (fig. 10). The northern of the two areas with more than 50 percent sand is centered about 12 km northeast of Buffalo. Although its western part may be related to the early Eocene basin-margin conglomerates and the central part overlies the inferred course of the Wind River of Eocene time, its northeastern extension, lying in the distal part of the area of the basin having a Black Hills source area, is unexplained.

Santos (1981) made a detailed facies study of the Wasatch Formation based on study of 1,050 uranium-exploration geophysical logs in the southern Powder River Basin. He made five separate facies maps for 93-m (300 ft) slices beginning 186 m (600 ft) below the base of the School House coal about at the Wasatch-Fort Union contact and extending 450 m (1,500 ft) upward. He found that the distribution of the sandy facies in all five slices indicates northerly trending paleostreams. The sand trends from Santos' (1981) facies study corroborates the paleostream directions inferred from crossbedding dip directions described later in this report. Furthermore, the relative stability of paleoflow directions through 450 m (1,500 feet) of Wasatch, about 50 percent of the maximum preserved thickness in the basin, supports the validity of this study, which integrates paleocurrent data collected throughout the entire stratigraphic range of the Wasatch Formation.

Raines and others (1978) and Raines and Santos (1980) published lithofacies maps for depths of 0–92 m and 92–183 m below the present land surface for the southern half of the Wasatch outcrop area. Their 0–92-m map was generalized on figure 10. The 0.5 sandstone-mudstone ratio (30 percent sandstone) on both lithofacies maps seems to separate the Black Hills and Laramie Mountains source areas as determined from the following paleocurrent study.

PALEOCURRENTS AND PALEOGEOGRAPHIC SYNTHESIS

Methods

Orientations of 953 crossbeds were determined at 74 localities in the upper Paleocene and lower Eocene Wasatch Formation as mapped on the "Geologic Map of Wyoming" (Love and Christiansen, 1985). At most outcrops the orientation of all exposed and accessible crossbed sets was determined to decrease measurement bias. A compass and levels crossbed-measuring device was used to determine orientations. This device made more crossbeds measureable, regardless of the relationship between orientation and the rock surface, thus decreasing measurement bias introduced by outcrop orientation. The friable nature of many outcrops permitted three-dimensional exposure of almost all crossbeds by grooving the outcrop surface, if corners or natural recesses did not allow determination of crossbed orientation. Orientations of trough-crossbed axes were determined wherever possible. A programmable calculator was used to calculate locality vector mean, crossbedding dip direction, and vector strength at each outcrop following the procedures of Reiche (1938). Each crossbed dip direction at a locality was assigned a unit length, and these vectors were trigonometrically added head to tail. The resultant is the vector mean, and the length of the resultant divided by the number of measurements is the vector strength, a measure of the spread of the dip directions. If all the crossbed dip directions at a locality have the same orientation, the vector strength is one; if the crossbed dip directions have a random orientation, then the vector strength is zero.

Fluvial-transport directions are implied by the vector-mean crossbed dip directions. The vector-mean map (fig. 11) is thus a fluvial-transport-direction (or paleocurrent) map. The vector-mean map was smoothed using the moving average technique (Pelletier, 1958; Potter and Pettijohn, 1977) with an 8-m grid size (fig. 12). The technique may repeat a single divergent vector-mean direction as many as four times, most likely in marginal areas of the map but also in more centrally located areas of sparse data. In order to minimize this problem, the two vector-mean directions outside, but closest to the center, of the block of four squares were used to perform a three-component vector summation. If a four-square block contained two vector-mean localities, then one locality outside but closest to the center of the group was used to perform a three-component vector summation.

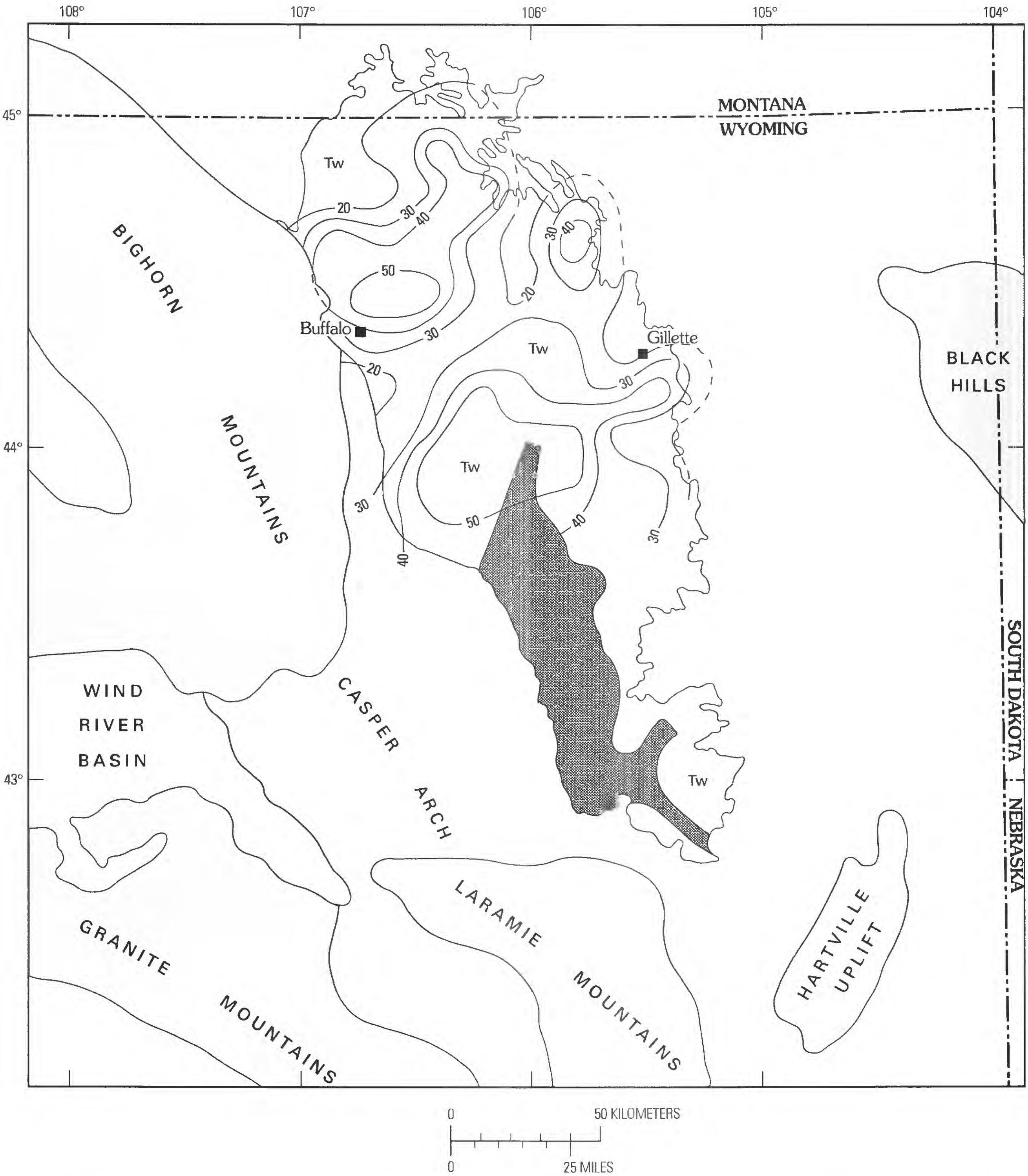

Figure 10. Sandstone-percentage map of the Wasatch Formation, Powder River Basin, Wyoming and Montana. Patterned area has more than 30 percent sandstone from the ground surface to 92-m depth; data modified from Raines and Santos (1980). Contours show percentage of sand in the Wasatch Formation, derived from data of Bendix Field Engineering Corporation, Geology Division Staff (1976); contour interval is 10 percent; contours are dashed where extrapolated outside of the present outcrop of the Wasatch Formation (Tw).

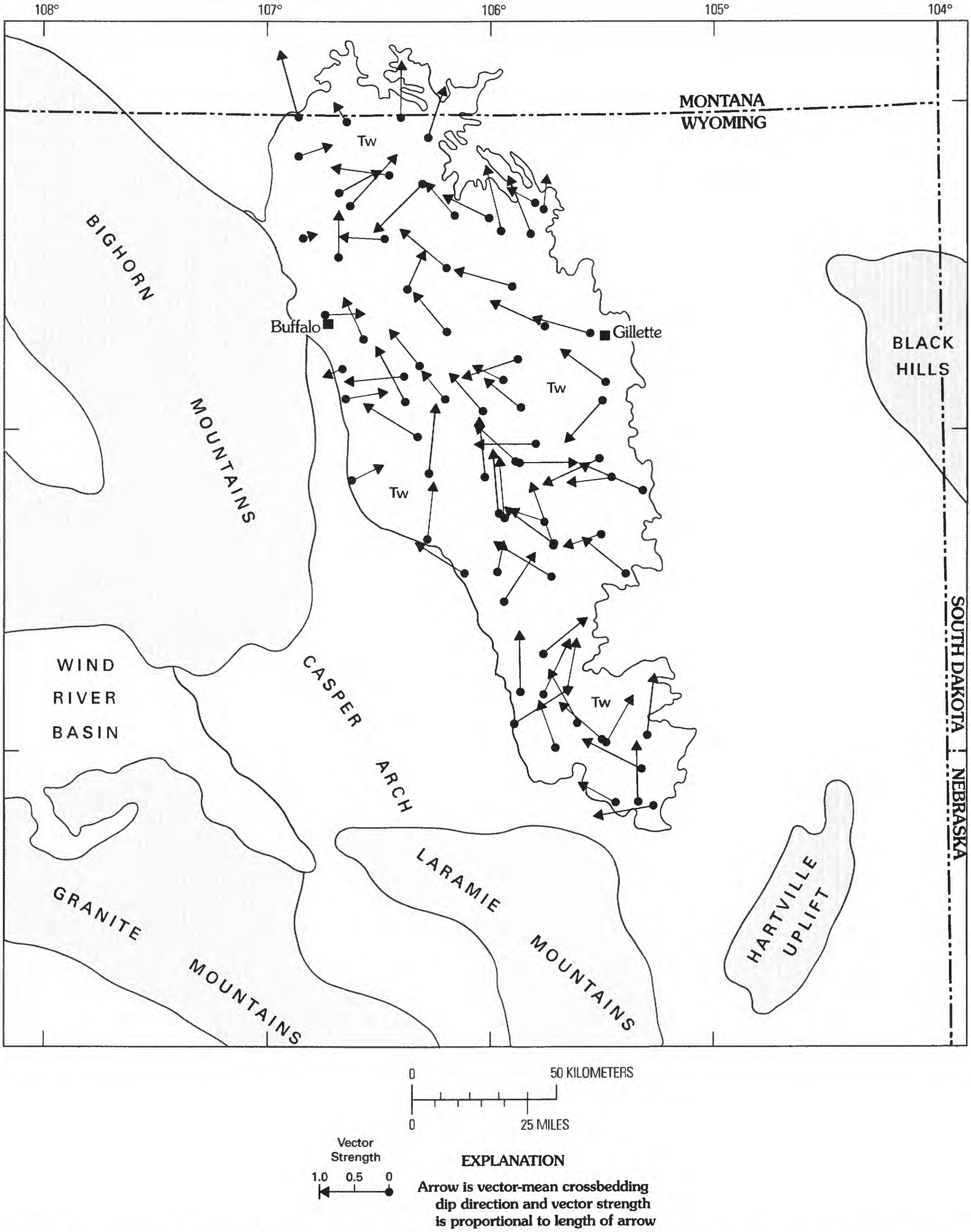

Figure 11. Vector-mean crossbed-dip directions in the Wasatch Formation, Powder River Basin, Wyoming and Montana. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

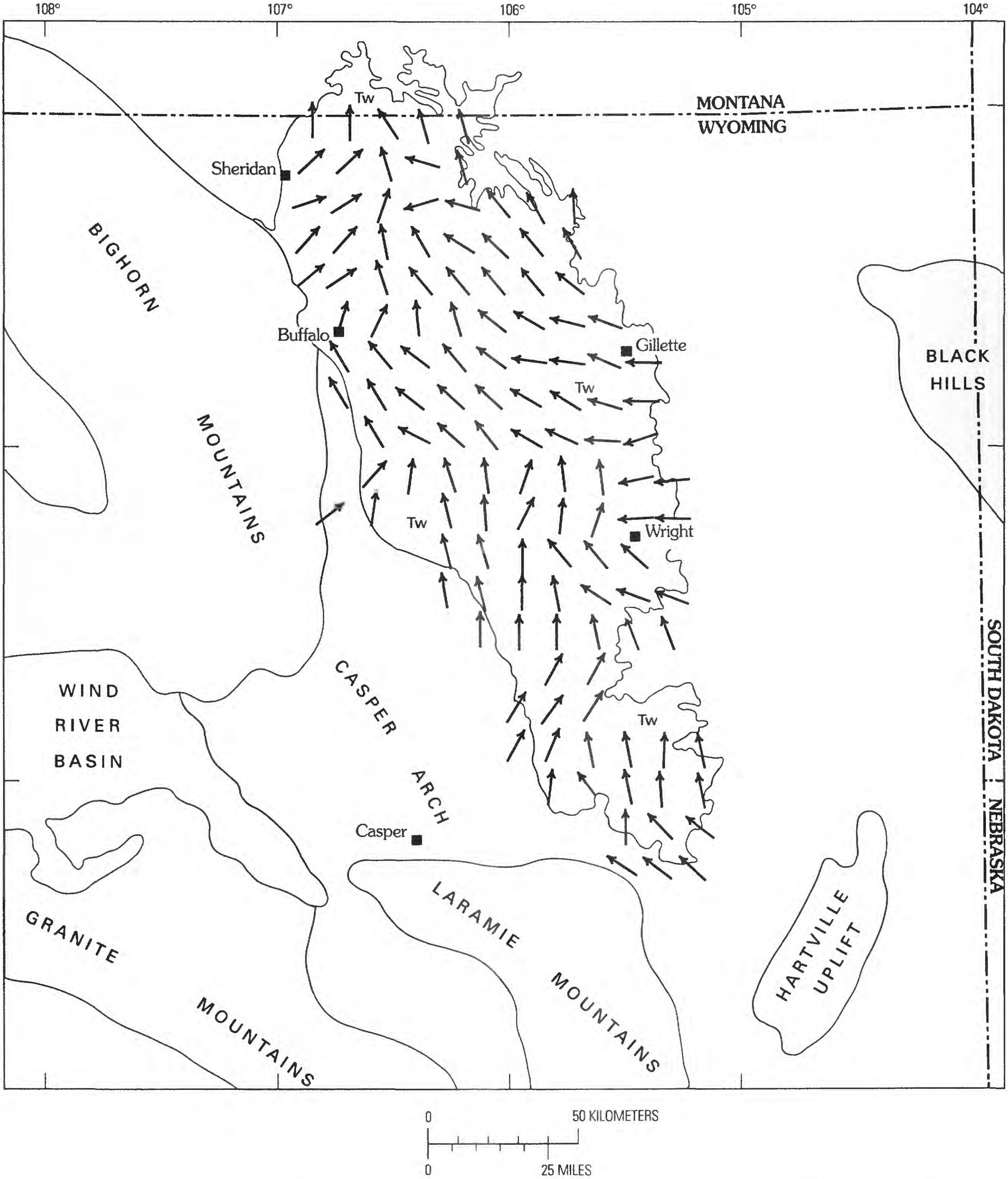

Figure 12. Moving-average crossbed-dip directions in the Wasatch Formation, Powder River Basin, Wyoming and Montana. Grid size is 8 km. Arrows are centered on grid intersections, as explained in text. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

The interpretive map (fig. 13) was constructed using information from both the vector-mean and moving-average maps. In areas of contradictions between the two maps, stream-flow directions from the vector-mean paleocurrent map were given precedence in the construction of the interpretive paleogeographic map.

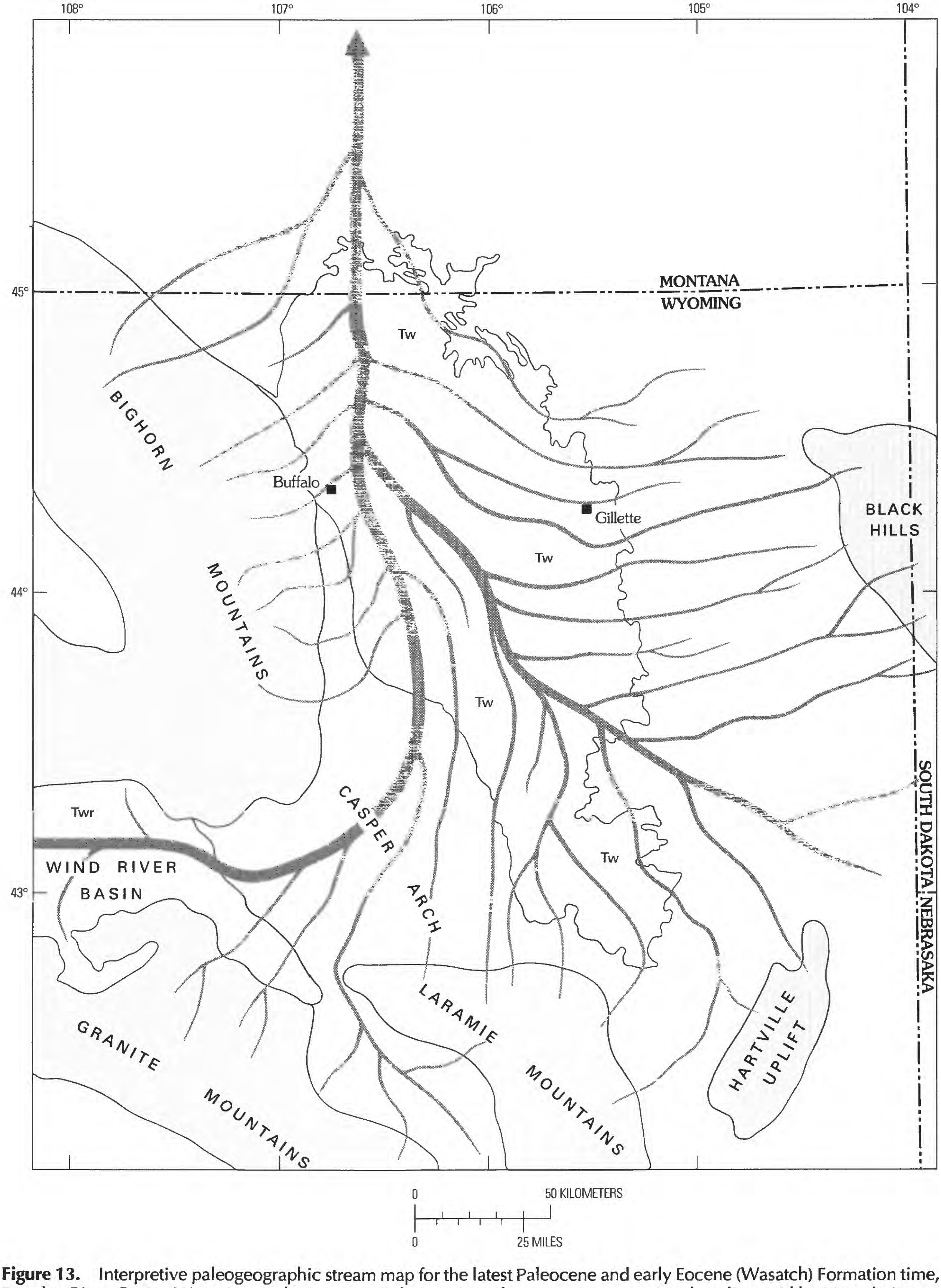

Figure 13. Interpretive paleogeographic stream map for the latest Paleocene and early Eocene (Wasatch) Formation time, Powder River Basin, Wyoming and Montana. Relative size of streams is proportional to line width. Meandering or anastomosed nature of streams not shown. Tw, uppermost Paleocene and lower Eocene Wasatch Formation; Twr, lower Eocene Wind River Formation.

Results

In the broadest sense, drainage was northward out of the Powder River Basin. The latest Paleocene and early Eocene depositional systems of the Powder River Basin are defined by two trunk streams: (1) the south-to-north Wind River of early Eocene time, an extrabasinal stream that followed the primary depositional and structural axis of the basin, and (2) a northwest-flowing intrabasinal stream following a secondary basin axis (fig. 13). These framework streams carried bed loads to mixed loads, and the streams probably meandered, as evidenced by sandy channel deposits that become finer upwards enclosed within extensive fine-grained overbank deposits.

The two streams define three alluvial depositional systems: (1) a distal mud-rich alluvial plain with westward-flowing streams and a Black Hills source area, (2) a proximal sand-rich alluvial plain-distal alluvial fan with northward-flowing streams and a Laramie Mountains source area, and (3) a stream-dominated proximal to distal alluvial fan with eastward-flowing streams and a Bighorn Mountains source area (fig. 13).

The Black Hills provenance area had been much reduced in size by post-Eocene (probably Pliocene to recent) basin excavation. Because of early Eocene basin asymmetry, it is the largest of the three depositional systems. Stream directions in the Black Hills area were relatively constant. The Laramie and Bighorn Mountains depositional systems were smaller, were closer to their respective source terranes, and had more variable stream directions.

Swamps were associated with all three depositional systems. Precipitation was adequate to allow the development of raised swamps anywhere in the basin (Ethridge and others, 1981; Flores, 1981; Warwick, 1985; Pocknall and Flores, 1987). Low-lying swamps were formed mostly in the western part of the basin where coals as much as 80 m thick (Obernyer, 1978) attest to paleogeographic stability and continuous subsidence.

Understanding the regional paleogeography requires an examination of the relationship of the outlet drainage of the Wind River basin to the inlet drainage of the Powder River Basin. Seeland (1978a) postulated that the Wind River of Eocene time, the master stream of the Wind River basin, left the northeastern basin and flowed eastward across the Casper arch into the Powder River Basin (fig. 14). In a preliminary version of this paper, Seeland (1976) concluded, based on the paleocurrents of the Powder River Basin and on the similarity between the textural characteristics of the sandstone of the lower Eocene Wind River Formation in the eastern Wind River basin and the western Powder River Basin, that the Eocene Wind River entered the southwestern Powder River Basin and continued northward along the west side of the basin near the present structural axis (fig. 14). This conclusion is supported by lithofacies interpretations near the present structural axis (Toomey, 1977) and results of paleocurrent studies (Obernyer, 1980).

A Western-Basin Trunk Stream in Wasatch Time?

Paleoslope and stream patterns of the uppermost Paleocene and lower Eocene Wasatch Formation (fig. 14 and Seeland, 1976) and the upper Paleocene Tongue River Member of the Fort Union Formation (Seeland, 1988; Seeland and others, 1988) are similar in the southernmost Powder River Basin but are significantly different to the north. Flores (1986) extended Galloway's (1979) drainage axis for the combined Tongue River and Wasatch northward about to the Montana State line, continuing the assumption that the paleogeography for these two units is the same.

Warwick and Flores (1987) measured 84 crossbed orientations at an unstated number of localities and suggested a north-northwest stream flow in an area of the Wasatch west of Gillette. Their studies locate the north-flowing basin-axis master stream about 50 km east of the position suggested herein and by Seeland (1976) (figs. 1, 13). Positioning the master stream this far east implicitly denies west-flowing drainage in a large area of the basin, as documented in this paper.

In summary, the expanded paleocurrent evidence of this study continues to support a depositional basin axis and associated trunk stream in the westernmost part of the Powder River Basin during latest Paleocene and early Eocene (Wasatch) time (fig. 13). The proponents of a trunk stream in the approximate center of the Wasatch outcrop area (fig. 1) commonly have made regional inferences from local studies and have based Wasatch Formation paleogeography on the assumption that it was nearly identical to the paleogeography of Tongue River Member time (fig. 2). This paper demonstrates that the assumption is untenable on the basis of regionally comprehensive evidence and that the Wasatch-time basin axis was about 75 km west of the Tongue River-time axis.

PALEOGEOGRAPHIC SETTINGS OF COAL AND URANIUM DEPOSITS

Economic deposits of coal and uranium are common in the basin. Most of the uranium deposits are in the Wasatch Formation, and most of the coal deposits are in the Fort Union Formation. The location of the coal and uranium deposits of the Wasatch are directly related to the depositional systems of the Wasatch.

Low-lying peat swamps that formed economic coal beds were most likely to form in the wettest and least-sloping parts of the basin near major streams (Ethridge and

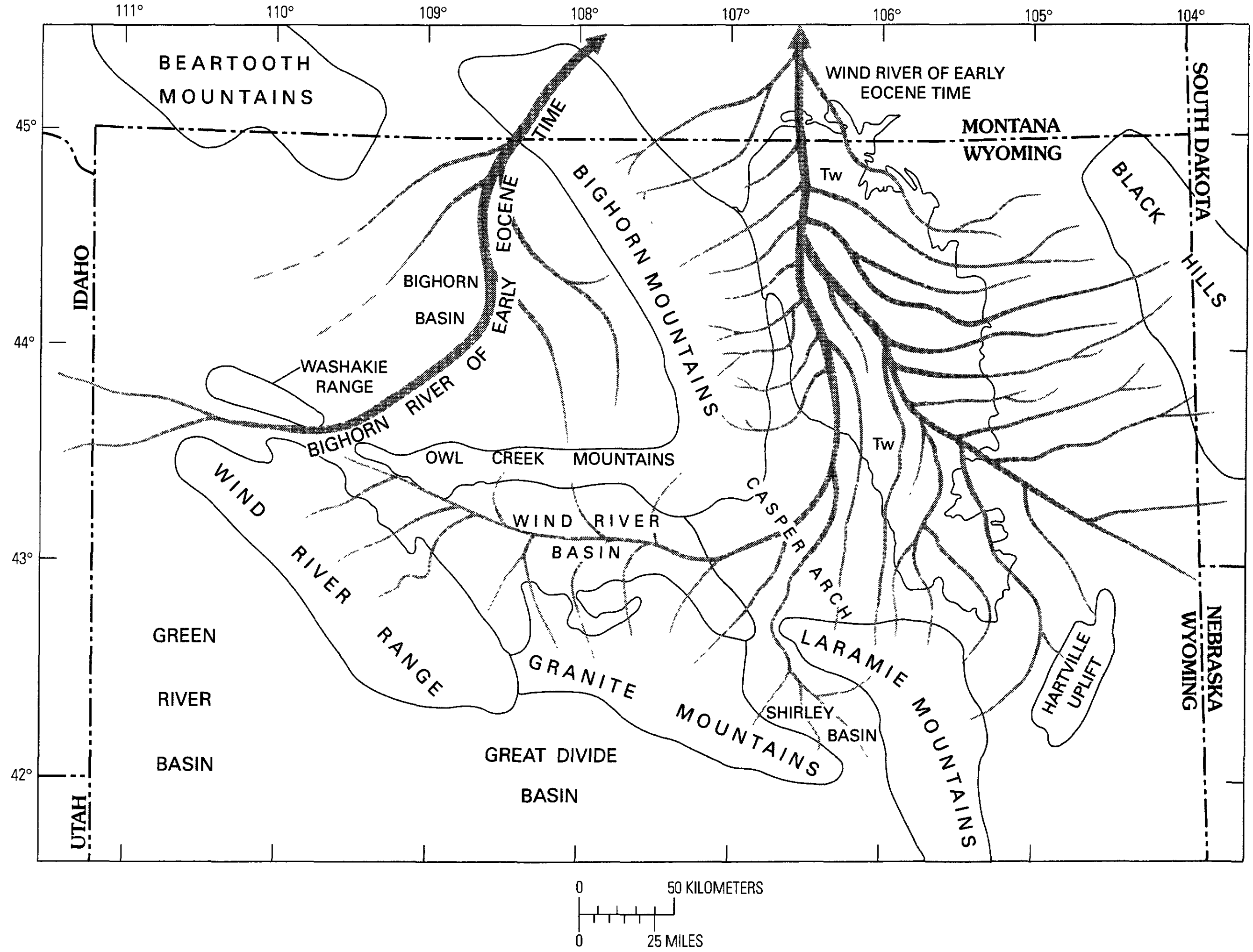

Figure 14. Relationship between early Eocene drainage patterns of the Bighorn, Wind River, Shirley, and Powder River Basins, Wyoming and Montana. Tw, uppermost Paleocene and lower Eocene Wasatch Formation.

others, 1981). As could be predicted from this hypothesis, coal deposits of the Wasatch are thicker and more persistent in the western and central basin (Glass, 1980). The DeSmet (Healy) coal bed locally exceeds 80 m (250 ft) in thickness (Mapel, 1959) and is the thickest known coal in the United States (Glass, 1980). The peat swamp from which it originated was narrow and elongate, and lay just west of and parallel to the basin-axis trunk stream near Buffalo, Wyo. (Obernyer, 1980). It was bordered on the west by coalescing alluvial fans originating in the rapidly rising Bighorn uplift (fig. 3).

The distribution of the uranium deposits of the southern part of the basin is related to the distribution of the sandy facies of the Wasatch Formation, because it acted as a conduit for oxygenated uranium-bearing ground water (Santos, 1981). Seeland (1976) noted that almost all the uranium mines in the basin are in an area shown to have a sediment source in the granite of the Laramie Mountains. Because Wasatch coal beds do not have anomalous uranium, and Szalay (1958) has pointed out that peat adsorbs uranium, Santos (1981) suggested that there was no early influx of uranium in solution or in detrital minerals. J.S. Leventhal (oral commun., 1989) pointed out that the peat-swamp environment has low pH, which would inhibit uranium adsorption even if uranium were present in the water. Galloway (1979) emphasized the importance of the uranium-rich tuff of the White River Group as a uranium source. These tuff units unconformably overlie the coarse-grained sandstone whose sand had a Laramie Mountains source south of the basin. Water percolating downward through the tuffs could have picked up uranium from devitrifying glass shards and carried it northward, forming uranium deposits in the sandy facies of the Wasatch of the southern part of the basin.

CONCLUSIONS

Paleocurrent study defines two major streams in the fluvial rocks of late Paleocene and early Eocene Wasatch Formation in the Powder River Basin. The larger was a north-flowing basin-axis stream in the westernmost Powder River Basin that was also the major longitudinal river of the upstream Wind River basin. The other major stream flowed northwest from the southeastern Powder River Basin.

Three alluvial depositional systems are defined: (1) a distal mud-rich alluvial plain with a source terrane to the east in the Black Hills, (2) a proximal sand-rich alluvial plain-alluvial fan with a source to the south in the Laramie Mountains, and (3) a stream-dominated proximal to distal alluvial fan complex with a source to the west in the Bighorn Mountains.

Grain-shape and grain-size studies corroborate transport directions obtained by the paleocurrent study. In the western part of the basin, an area of large tributaries flowing into the major basin-axis stream from the Bighorn Mountains is indicated by an area of less-regular sand grains near Buffalo.

Major coal and uranium deposits are spatially related to the Wasatch-time depositional systems of the basin. Coal-forming swamps were more abundant in the vicinity of the major basin-axis stream. Uranium deposits in the Wasatch Formation are found only in the proximal alluvial-plain distal-alluvial-fan depositional system of the southern basin.

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