Origin and Distribution of Six Heavy-Mineral Placer Deposits in Coastal-Marine Sandstones in the Upper Cretaceous McCourt Sandstone Tongue of the Rock Springs Formation, Southwest Wyoming

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By HENRY W. ROEHLER

Heavy-mineral placers are investigated along 40 miles of a wave-dominated strand-plain shoreline of the interior Cretaceous sea of North America

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Origin and Distribution of Six Heavy-Mineral Placer Deposits in Coastal-Marine Sandstones in the Upper Cretaceous McCourt Sandstone Tongue of the Rock Springs Formation, Southwest Wyoming

By Henry W. Roehler

Abstract

The geology of six geographically separated but genetically related heavy-mineral placer deposits are investigated along 40 miles of coastal-marine sandstone outcrops comprising the McCourt Sandstone Tongue. The heavy-mineral placer deposits consist of dark-brown to black, fine- to medium-grained, ferruginous sandstones that occur in elongated lenses that are as much as 6.6 ft thick and 2,000 ft long. The placer deposits are mostly intercalated with light-gray or tan quartzose shoreline sandstones that offlapped southeastward across the study area and formed a strand plain during a regression of the interior Cretaceous sea. The placers were deposited along a single shoreline during one stage of the regression.

The heavy-mineral placer deposits are composed of about 85 percent opaque iron minerals, mostly magnetite, hematite, and ilmenite, and about 15 percent nonopaque minerals, mostly zircon, with minor amounts of tourmaline, rutile, garnet, sphene, hornblende, apatite, and traces of other minerals. The depositional settings are river mouth, berm, forebeach, surf, and middle shoreface, where the segregation of light and heavy minerals took place by fluvial, marine, and eolian processes. A plutonic source for most of the heavy minerals was probably the Sevier orogenic belt located 150–250 miles west of the study area. The heavy-mineral deposits in the McCourt Tongue are analogous in origin to that of heavy-mineral deposits that are presently forming along the southeast Atlantic and gulf coasts of the United States.

INTRODUCTION

Purpose of Investigation and Previous Work

This report describes the geographic location, stratigraphic position, lithology, depositional setting, paleogeographic distribution, and provenance of six heavy-mineral placer deposits in the Upper Cretaceous McCourt Sandstone Tongue of the Rock Springs Formation in the Rock Springs uplift area of southwest Wyoming. The petrology and economics of the deposits were investigated previously by Houston and Murphy (1962), and are presently being reinvestigated by G.B. Schneider of the U.S. Geological Survey.

Stratigraphic study of the Rock Springs Formation was completed by the author between 1970 and 1977 while mapping 7½-minute geologic quadrangles for the U.S. Geological Survey in the southeast part of the Rock Springs uplift (Roehler, 1973, 1977a, 1977b, 1978, 1979). The mapping was followed by investigations of the depositional environments of sandstones in the McCourt Tongue (Roehler, 1980) and of coal beds in the overlying Gottsche Tongue of the Rock Springs Formation (Roehler and Phillips, 1980). The strand plain origin of the McCourt Tongue was first discussed by Roehler (1984) at a Geological Society of America coal symposium in Reno, Nevada. The symposium proceedings appear in Special Paper No. 210 (Roehler, 1986).

Heavy-mineral placer deposits in the Rock Springs uplift area were identified and described by Dow and Batty (1961) in a report covering a reconnaissance of titanium- and zirconium-bearing heavy-mineral sandstone deposits in Utah, Wyoming, New Mexico, and Colorado. Three of the deposits described by Dow and Batty (1961), at Richards Gap, Titsworth Gap, and near Black Butte, were included by Houston and Murphy (1962, 1970, 1977; Murphy and Houston, 1955) in investigations into the occurrence and distribution of black sandstones in Cretaceous rocks of the Rocky Mountain states. This report provides important stratigraphic, paleogeographic, and sedimentologic details, not previously published.

The heavy-mineral placer deposits in the Rock Springs uplift area are analogous to those that are currently forming in coastal-marine sands along the southeast Atlantic and gulf coasts of the United States. Similar deposits are abundant in Holocene coastal-marine settings worldwide (Zenkovich, 1967). They are also common in older geologic formations (Mackie, 1923; Hutton, 1950; Zimmerle, 1973). The physical factors involved in the formation and distribution of heavy-mineral placer deposits have been described by Rubey (1933), Rittenhouse (1943), Foxworth and others (1962), Tikhomirov (1975), and Force (1976). The economics of the deposits have been discussed by Houston and Murphy (1962), Force (1976), and Fantel and others (1986).

Location of the Study Area

The six heavy-mineral placer deposits that were studied are aligned north-northeast along a 40-mi belt of discontinuous outcrops of the McCourt Sandstone Tongue. The first of the deposits is located 42 mi south of the city of Rock Springs, Wyo. (fig. 1), on the south limb of Red Creek syncline, on the north flank of the Uinta Mountains, near the Wyoming-Utah State line. The remaining deposits are located along the southeast flank of the Rock Springs uplift, 20–28 mi southeast of the city of Rock Springs. The names and locations of the heavy-mineral placer deposits are listed in table 1. Cross sections of the deposits constructed from measured sections are illustrated on plate 1.

Geologic Setting

The Rock Springs uplift is a large north-south-trending upwarp that occupies the geographic center of the greater Green River basin north of the common boundary of Wyoming, Colorado, and Utah (fig. 1). The uplift, about 70 mi long and 50 mi wide, is an asymmetric Laramide structure with a gentle east limb where the strata dip from 3° to 6° and a steep west limb where the strata dip from 5° to 35°. The crest of the uplift has been deeply eroded to expose sedimentary rocks of mostly Late Cretaceous, Paleocene, and Eocene ages. Sandstones in these exposures resist weathering and form infacing escarpments that encircle the uplift and rise irregularly from 150 to 2,500 ft above a central valley composed of Upper Cretaceous marine shale that forms the core of the uplift. The McCourt Tongue is a bench-forming sandstone that crops out in steep slopes above the central shale valley around the southern part of the uplift.

Red Creek syncline (fig. 1) forms an east-west trending structural depression that separates the Rock Springs uplift to the north from the Uinta Mountains to the south. Cretaceous rocks exposed in the study area along the south limb of the syncline dip 15° to 45° northward and weather to hogback ridges. Outcrops of the McCourt Tongue form ledges and cliffs within these hogback ridges.

Mean annual precipitation in the Rock Springs uplift area ranges from 7 to 11 in. (Root and others, 1973). The precipitation is seasonal and occurs mostly as snow in winter months and as rain during spring thunderstorms. The arid climate is windy and allows only sparse vegetation characterized by thin desert grasses, patches of sage brush, and small groves of cedar trees. Topographic elevations range from 6,000 to 9,000 ft. Bedrock is exposed over most of the uplift area, but drainages are filled with alluvium, and thin soils cover valley floors.

STRATIGRAPHY

Nomenclature, Lithology, and Age

The term "Rock Springs coal group" was first used by Schultz (1909). Schultz (1920, p. 32) continued this usage; the Rock Springs coal group being the basal economic designation in the Mesaverde Formation.

Table 1. Heavy-mineral placer deposits in the McCourt Sandstone Tongue of the Rock Springs Formation in the Rock Springs uplift area of southwest Wyoming

Heavy-mineral placer deposits	Location
1. Richards Gap	SE ¼ sec. 22, T. 12 N., R. 105 W.
2. Titsworth Gap	SE ¼ sec. 7, T. 14 N., R. 103 W.
3. Camel Rock	S ½ sec. 8, T. 16 N., R. 102 W.
4. Brady Road	SW ¼ sec. 11, T. 17 N., R. 102 W.
5. Cooper Ridge	SE ¼ sec. 1, T. 17 N., R. 102 W.
6. Black Butte	SE ¼ sec. 30, T. 18 N., R. 101 W.

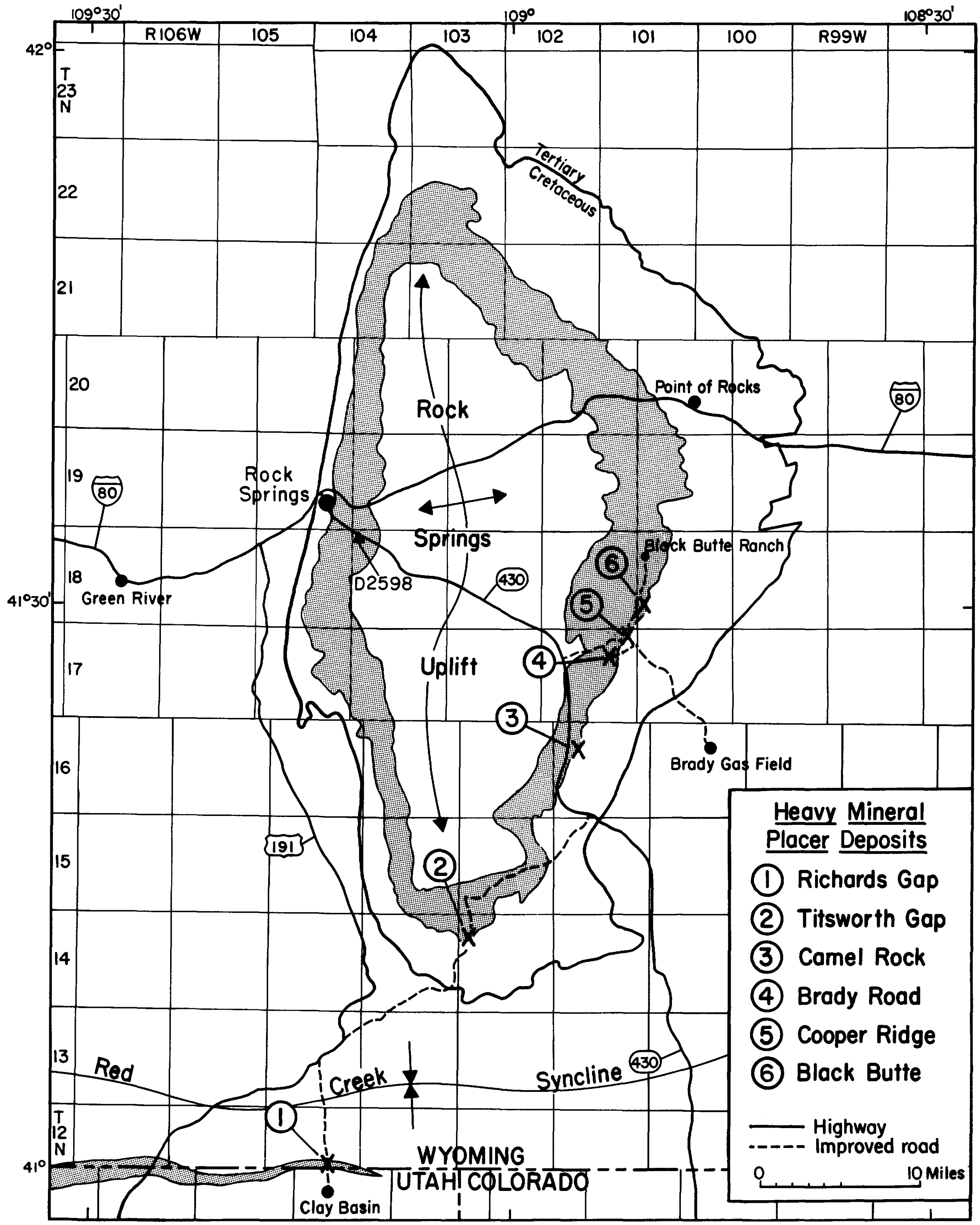


Figure 1. Location of heavy-mineral placer deposits in the McCourt Sandstone Tongue of the Rock Springs Formation in the Rock Springs uplift area of southwest Wyoming. Outcrops of the Rock Springs Formation are shaded.

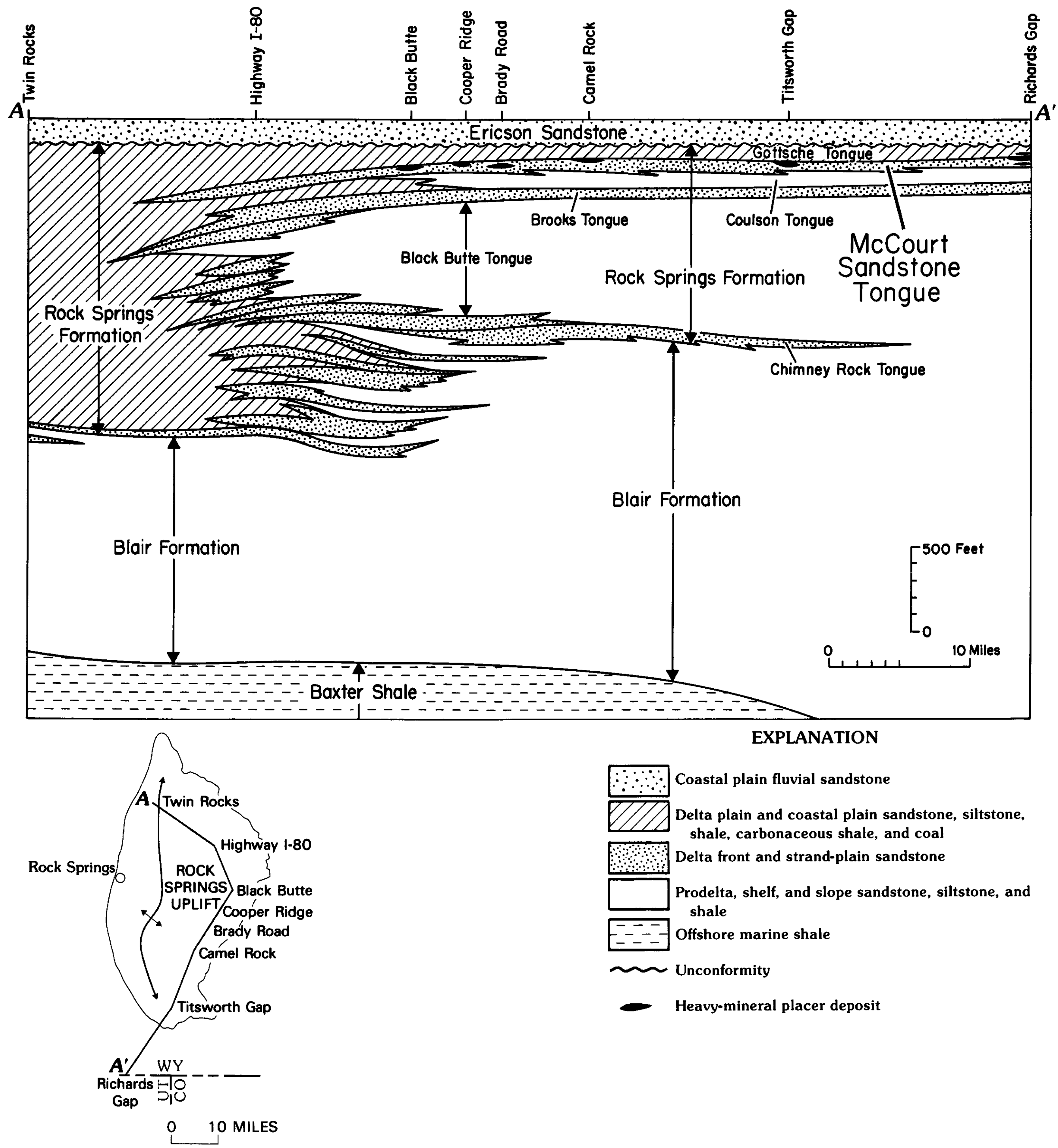


Figure 2. North-south cross section *A-A′* of the Rock Springs and associated formations in the Rock Springs uplift area of southwest Wyoming.

Sears (1926) changed the usage to Rock Springs Formation of the Mesaverde Group. The formation is 1,600 ft thick at Twin Rocks (fig. 2) in the northern part of the Rock Springs uplift (Roehler, 1983), where it consists of interbedded shale, carbonaceous shale, coal, siltstone, and sandstone of mostly delta-plain origin. It thins to the southeast across the uplift as it intertongues with marine shale, sandstone, and siltstone comprising the upper part of the Upper Cretaceous Blair Formation (fig. 2). The intertonguing relationship was first described by Hale (1950) who named the Chimney Rock and Black Butte Tongues of the Rock Springs Formation in the southern part of the uplift. The Chimney Rock Tongue wedges out in a southward direction south of Titsworth Gap (fig. 2). At Richards Gap the base of the Rock Springs Formation rises stratigraphically to the base of a persistent sandstone bench called the Brooks Tongue by Smith (1961). The Rock Springs Formation at Richards Gap, which is less than 300 ft thick, is mostly interbedded sandstone and shale with minor thin beds of carbonaceous shale and coal (Roehler and Phillips, 1980). The lithologies that characterize the Rock Springs Formation in the southern part of the uplift are illustrated in a stratigraphic section measured near the Camel Rock heavy-mineral placer deposit (fig. 3).

The McCourt Tongue crops out as a tan and gray bench-forming sandstone unit that is laterally persistent and forms a stratigraphic marker bed in the upper part of the Rock Springs Formation in the southern part of the Rock Springs uplift (fig. 4). The tongue is also recognizable in the subsurface on electric logs of oil and gas test holes drilled east of the uplift. The name "McCourt Sandstone" was first applied by Smith (1961) to 105 ft of sandstone that crops out near the abandoned McCourt Ranch at Titsworth Gap in sec. 7, T. 14 N., R. 103 W., near the southern end of the Rock Springs uplift. The McCourt Tongue is overlain by the Gottsche Tongue and underlain by the Coulson Tongue of Smith (1961) (figs. 2 and 4). The Gottsche Tongue is composed of carbonaceous and coal-bearing beds of continental origin, and the Coulson Tongue is composed of gray and black shales of marine origin. The McCourt Tongue is composed of shoreline sandstones that comprise the coastal-marine transition between the Gottsche and Coulson Tongues.

The Rock Springs Formation is Campanian in age based on diagnostic ammonite fossils that have been collected from the Rock Springs uplift and other areas in southwest Wyoming. Smith (1961) collected *Scaphites hippocrepis* at USGS Locality D2598, which is located about 200 ft below the base of the Chimney Rock Tongue in NW¼ sec. 6, T. 18 N., R. 104 W., about 3 mi southeast of the city of Rock Springs. *Scaphites hippocrepis* has been considered to be early Campanian by Gill and others (1970). The upper part of the Rock Springs Formation, above the Chimney Rock Tongue, remains undated in the Rock Springs uplift area. However, regional stratigraphic relationships provide indirect evidence for its age. Persistent lithostratigraphic units in the Rock Springs Formation have been correlated regionally using measured surface sections and geophysical logs from oil and gas drill holes (Roehler, 1989). These correlations indicate that the McCourt Tongue in the Rock Springs uplift is the chronostratigraphic equivalent of beds that are situated about 300 ft above the Hatfield Sandstone Member of the Mesaverde Formation of Hale (1961, p. 134) at Atlantic Rim. Atlantic Rim is located 10 mi southwest of Rawlins, Wyo., 90 mi east

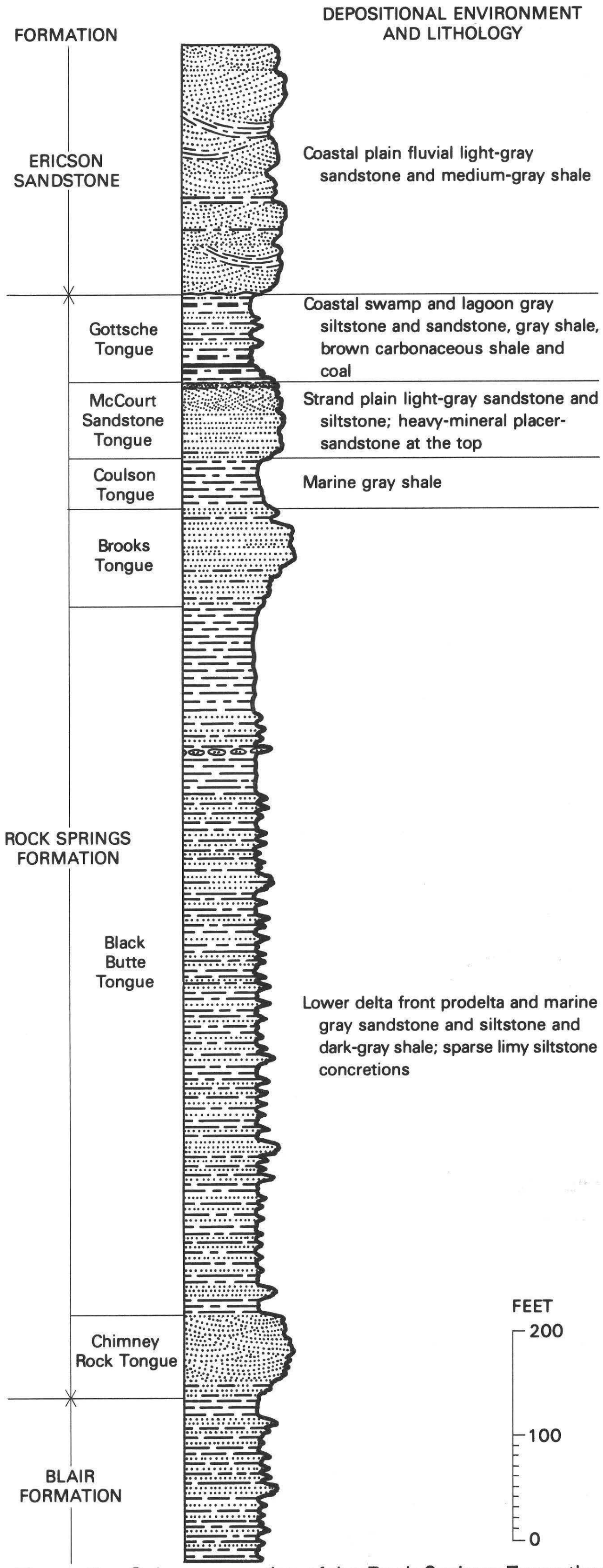


Figure 3. Columnar section of the Rock Springs Formation in secs. 7 and 8, T. 17 N., R. 102 W., near the Camel Rock heavy-mineral placer deposit.

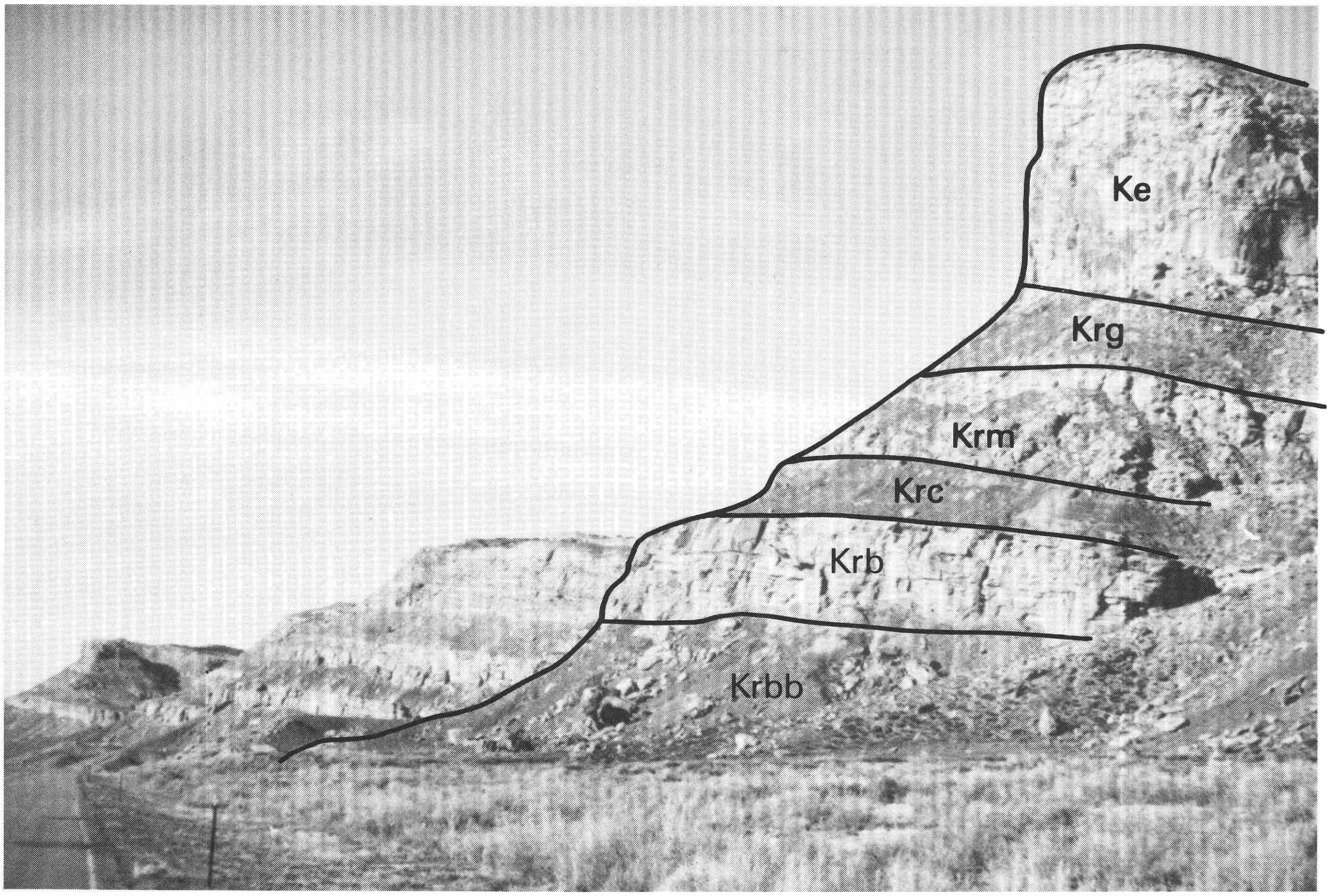


Figure 4. Outcrops of the McCourt Sandstone Tongue and adjacent stratigraphic units east of Wyoming Highway 430 on the southeast flank of the Rock Springs uplift. View is to the north in T. 16 N., R. 102 W. The stratigraphic units shown in the right foreground are repeated in the distance. Subdivisions of the Rock Springs Formation include: Krbb, Black Butte Tongue; Krb, Brooks Tongue; Krc, Coulson Tongue; Krm, McCourt Tongue; and Krg, Gottsche Tongue. Ke, Ericson Sandstone.

of the city of Rock Springs, at the east edge of the greater Green River basin. A specimen of *Baculites perplexus* was collected by Gill (1974) from a stratigraphic interval 250 ft above the Hatfield Member. *Baculites perplexus* has been dated late Campanian (Gill and others, 1970), so the McCourt Tongue may also be late Campanian, probably early late Campanian (≈75 Ma).

Paleogeography and Depositional Environments

The geometry of beds comprising the McCourt Tongue indicates that the tongue was deposited during a slow southeastward regression of part of the western shoreline of the interior Cretaceous sea of North America (fig. 5). Offlapping shoreline sandstone beds were deposited during this regression in a pattern similar to that described by Pirkle and others (1974) for the Green Cove Springs and Boulougne heavy-mineral sand deposits of Florida. The marine regression produced a strand-plain depositional environment in the study area (fig. 6) at the seaward edge of a foreland located east of the Sevier orogenic belt (fig. 5). The heavy-mineral concentrations in the McCourt Tongue appear to have been deposited along a single wave-dominated shoreline representing one stage of this regression. The shoreline strikes N. 30° E. and crosses part of what are now the southeast flank of the Rock Springs uplift and the north flank of the Uinta Mountains. Lagoons formed inland parallel to the beach (fig. 7).

The strand-plain shorelines of the McCourt Tongue subsided during the regression of the interior Cretaceous seaway. This is evident by the offlapping of the shoreline sandstones that were stacked in imbricate fashion during successive stages of the regression. Subsidence of the shoreline areas was necessary for the rapid burial and preservation of the heavy-mineral deposits.

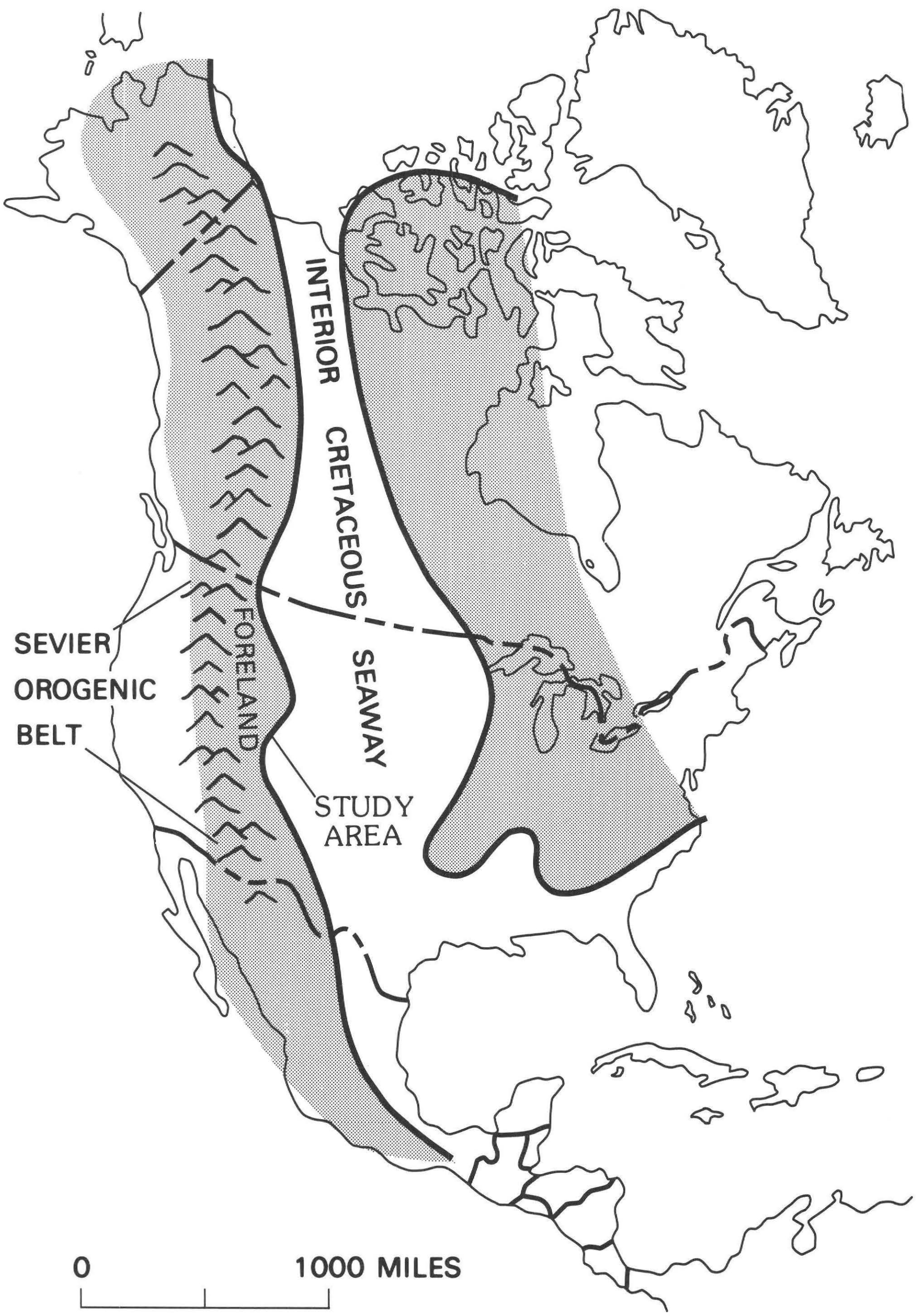


Figure 5. Paleogeographic map of North America during late Campanian. Land areas are shaded. (Modified from Gill and Cobban, 1966).

Strand-plain and Associated Lithofacies

The offlapping strand-plain sandstone beds that compose the McCourt Tongue are narrow and lenticular in cross section but are linear in plan view (figs. 6 and 7). Each bed is tens of miles long, from 2 to 5 mi wide, and as much as 117 ft thick. Within each offlapping bed are vertical successions of lithofacies that usually have well defined upper and lower contacts and exhibit progradation. The lithofacies, in ascending order, consist of lower shoreface, middle shoreface, surf (upper shoreface), forebeach (foreshore), berm, and dune (fig. 6). The lithofacies are easily identified in outcrops by their sedimentary structures, fossils, and stratigraphic positions. Progradation is apparent as the vertical succession of lithofacies within each offlapping bed in the McCourt

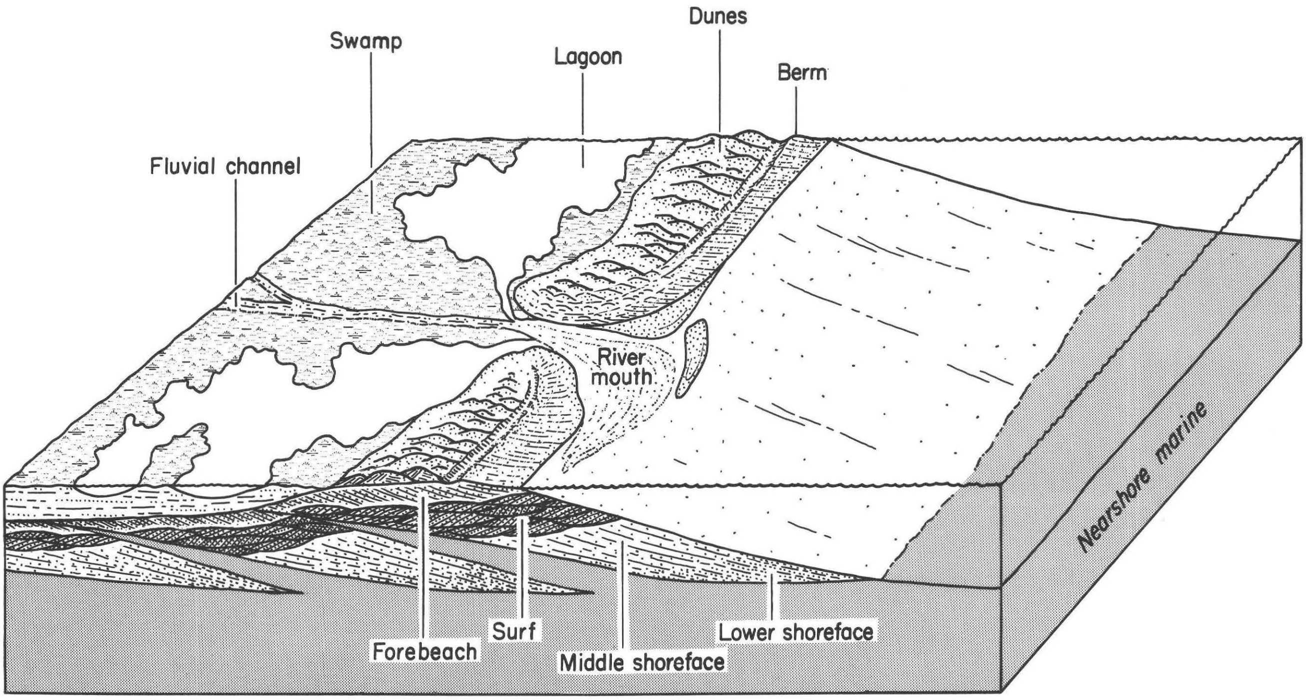


Figure 6. Strand-plain depositional model postulated for the McCourt Sandstone Tongue of the Rock Springs Formation.

Tongue is duplicated horizontally through the bed in landward-seaward directions following Walther's Law (Walther, 1893). Figure 8 illustrates the typical lithofacies present in the McCourt Tongue and in adjacent parts of the underlying Coulson Tongue and the overlying Gottsche Tongue in the study area.

Nearshore Marine Lithofacies

The nearshore marine lithofacies is composed of dark-gray, soft, silty to sandy, fissile shale. These rocks, now the Coulson Tongue, were deposited seaward of the lower shoreface sandstones of the McCourt Tongue. Water depths probably exceeded 100 ft.

Lower Shoreface Lithofacies

The lower shoreface lithofacies overlies the nearshore marine lithofacies along outcrops and constitutes the seaward part of the strand-plain sandstone. It was deposited in a low-energy marine environment hundreds of yards seaward of the strand-plain beach. It is composed of parallel to subparallel beds, a few inches thick, that consist of gray, very fine grained, silty sandstone and interbedded dark-gray, silty shale. It contains abundant trace fossils, such as *Ophiomorpha* and unidentified worm trails and burrows. Outcrops of the lower shoreface weather tan and drab gray and are less resistant than the overlying massively bedded sandstones of the middle shoreface. The lithofacies is well exposed at the base of the McCourt Tongue at the Richards Gap heavy-mineral placer deposit (fig. 9).

Middle Shoreface Lithofacies

The middle shoreface lithofacies is composed of fine- to medium-grained sandstone. It overlies the lower shoreface lithofacies in outcrops, where it commonly weathers to cliffs and ledges (fig. 10). The lithofacies usually consists of thick, parallel beds from 1 to 4 ft thick that are bioturbated by *Ophiomorpha* (fig. 11). A few beds exhibit low-angle, hummocky crossbedding.

Outcrops of the lithofacies weather tan to light brown, which contrasts sharply with the overlying surf and forebeach lithofacies that weather white or light gray and form distinctive "white caps" along the outcrops of the McCourt Tongue. The middle shoreface sandstones were probably deposited under water tens of feet deep, below normal wave base, but in areas where storm waves occasionally churned the sea floor.

Surf (Upper Shoreface) Lithofacies

The surf lithofacies is the product of sand deposition in a high-energy marine environment in near-

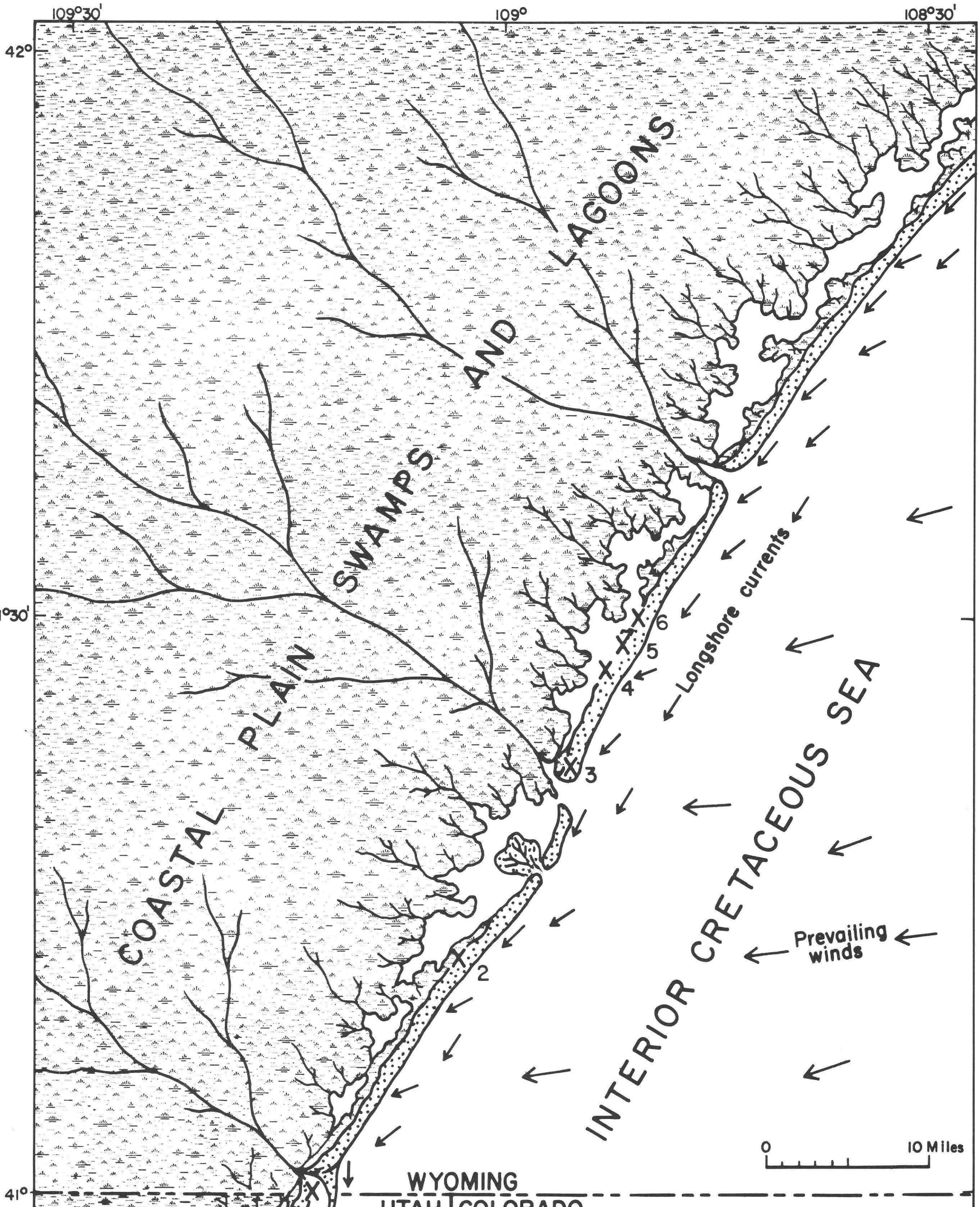


Figure 7. Paleogeographic map showing the location of the heavy-mineral placer deposits (Nos. 1–6) along a shoreline of the McCourt Sandstone Tongue of the Rock Springs Formation. The names and geographic locations of the deposits are shown in figure 1. Large arrows indicate the directions of prevailing winds; small arrows indicate the directions of longshore currents.

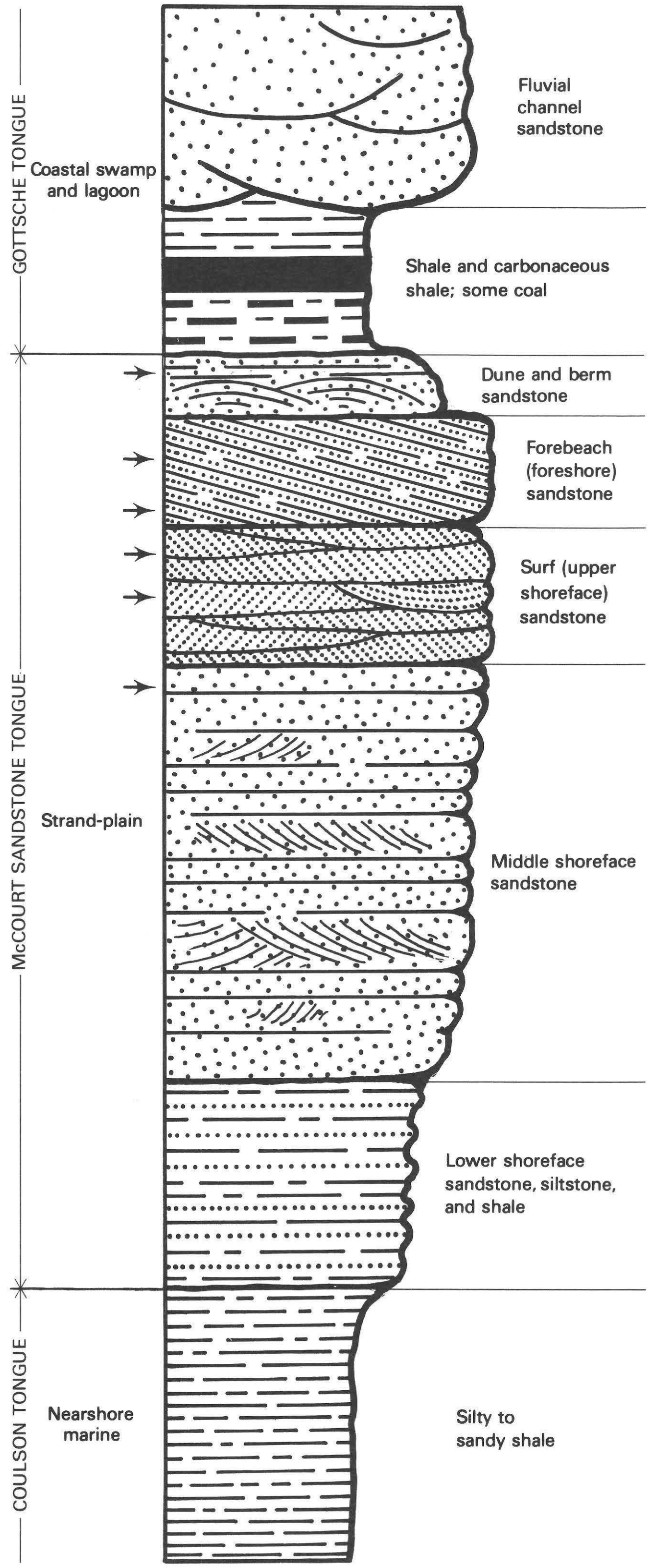


Figure 8. Generalized columnar section of the McCourt Sandstone Tongue and adjacent stratigraphic units illustrating typical lithofacies and sedimentary structures in the study area. The sedimentary structures are described in the text. The stratigraphic positions of heavy-mineral placer deposits are indicated by arrows.

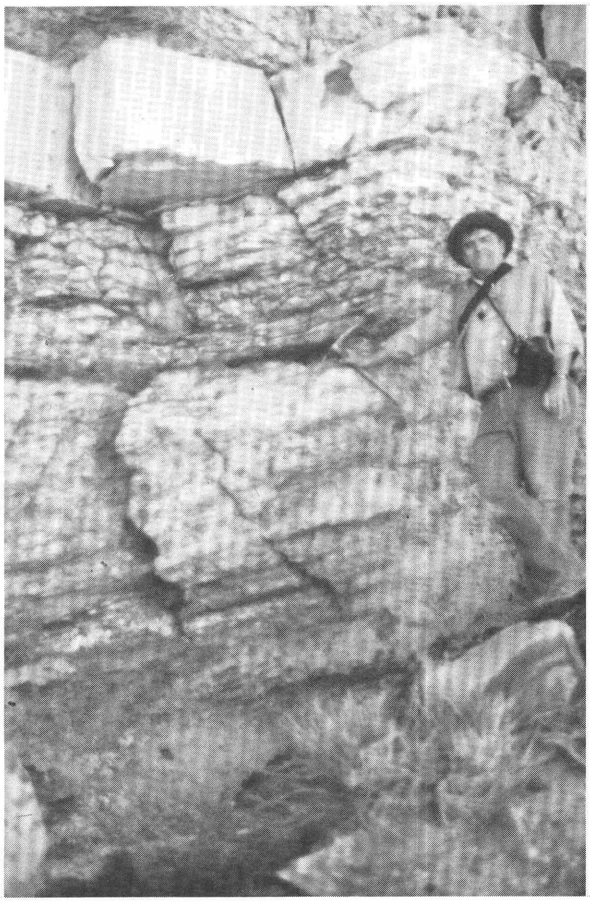


Figure 9. Thin interbedded silty sandstone and silty shale composing the lower shoreface lithofacies in the McCourt Sandstone Tongue of the Rock Springs Formation near the Richards Gap heavy-mineral placer deposit in NW¼SE¼ sec. 22, T. 12 N., R. 105 W.

shore areas where waves broke and dragged the sea floor as they approached the beaches. The surf lithofacies extended from the strandline seaward for several hundred yards and included all of the upper shoreface down to normal wave base at water depths of about 50 to 75 ft. The surf lithofacies is composed of light-gray, fine- to medium-grained sandstone in broadly lenticular, planar crossbeds up to 3 ft thick. Between the planar crossbeds are occasional low-angle troughs. The foreset laminae of the planar crossbeds are bidirectional as shown in figure 12. Rocks of the surf lithofacies usually weather light gray to white and crop out as steeply inclined slopes or as cliffs.

Forebeach (Foreshore) Lithofacies

The forebeach lithofacies is composed of light-gray, fine- to medium-grained sandstone in parallel, tabular beds from 1 to 4 in. thick (fig. 13). These beds

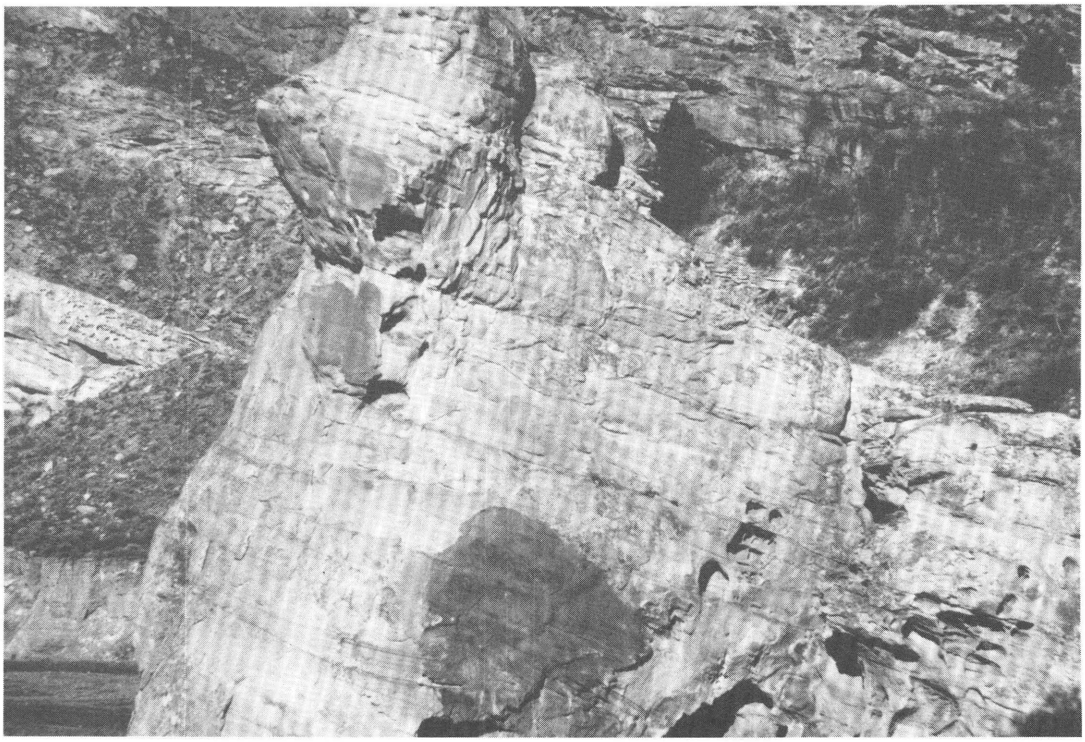


Figure 10. Thick, parallel-bedded sandstone composing the middle shoreface lithofacies in the McCourt Tongue of the Rock Springs Formation near the Richards Gap heavy-mineral placer deposit in NW¼SE¼ sec. 22, T. 12 N., R. 105 W.

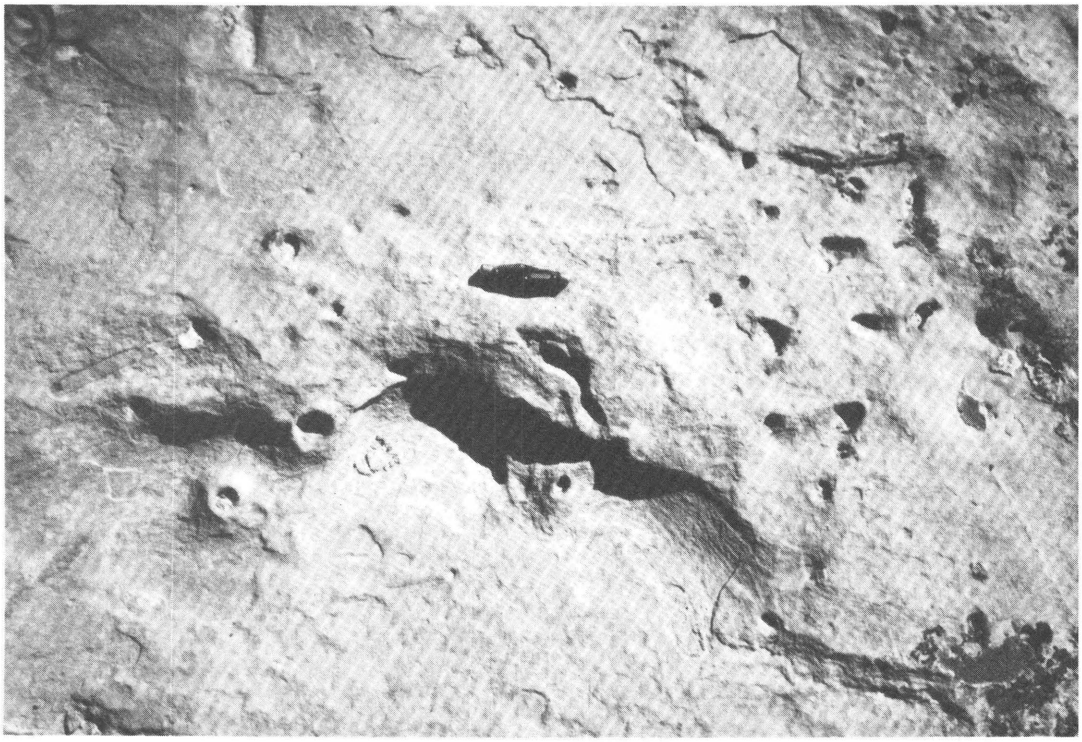


Figure 11. *Ophiomorpha* in a bioturbated middle shoreface sandstone lithofacies in the McCourt Sandstone Tongue of the Rock Springs Formation below the Richards Gap heavy-mineral placer deposit in NW¼ SE¼ sec. 22, T. 12 N., R. 105 W. Jackknife used for scale is 3.3 in. long.

Figure 12. Bidirectional dipping foreset laminae in planar crossbeds of the surf sandstone lithofacies in the McCourt Sandstone Tongue below the Richards Gap heavy-mineral placer deposit near the base of measured section 485 in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. View is northwest. Jackknife used for scale is 3.3 in. long.

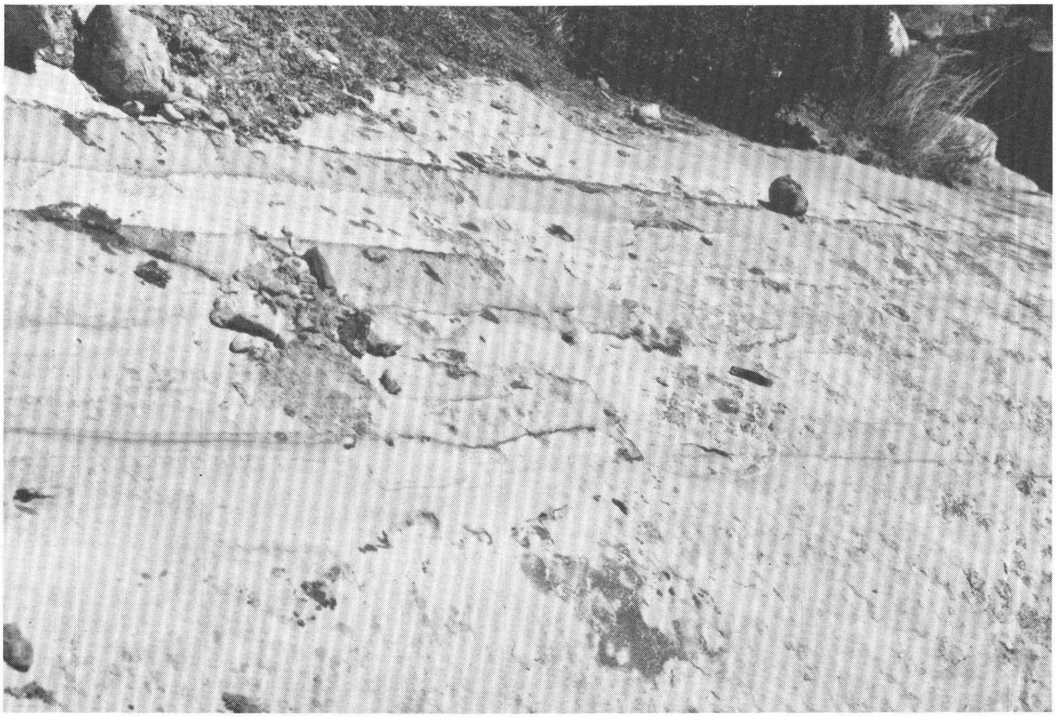


Figure 13. Tabular beds in a forebeach sandstone lithofacies adjacent to the Richards Gap heavy-mineral placer deposit in measured section 385 in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. Jackknife in right center of photograph is 3.3 in. long.

reflect the laminar flow of water produced by waves as they washed upwards from the surf onto subaerial parts of the beach.

Berm (Beach Ridge) and Dune Lithofacies

Sandstone beds at the top of the McCourt Tongue are in erosional contact with the overlying lagoonal rocks of the Gottsche Tongue. Consequently, berm and dune sandstone lithofacies above the level of the forebeach are rarely preserved. In a few places, however, thin remnants of berm or dune sandstone are preserved as discontinuous lenses that occupy depressions along the top of the forebeach sandstones. The berm lithofacies is composed of tan or light-gray, subparallel, wavy (pinching and swelling) beds, usually less than 1 in. thick, of fine- to medium-grained sandstone. These beds are thought to be mostly of eolian origin. Berm sandstones were identified at the Black Butte heavy-mineral deposit (fig. 14). Dune sandstones, also of eolian origin, exhibit concave downward crossbedding with prominent landward-dipping foreset laminae. Dune crossbedding several feet thick is particularly well preserved at the top of the McCourt Tongue above the Brady Road heavy-mineral placer deposit (fig. 15).

Lagoon Lithofacies

Lagoon lithofacies are present at the base of the Gottsche Tongue and overlie the McCourt Tongue within the study area. The lithofacies is mostly composed of splay, bay-fill, and carbonaceous swamp and bog deposits. Narrow, lenticular, shale-filled or sandstone-filled fluvial channels are present locally (fig. 16). The sandstone-filled channels exhibit large-scale, high-angle, trough crossbedding (fig. 17). The splay sandstones are usually several feet thick, coarsen upwards, and are mostly either current rippled (fig. 18) or wave rippled (fig. 19). Silty shale is usually interbedded and interlaminated with sandstone in the lower part of the splays. The bay-fill shales are dark gray and contain numerous thin lenses of siltstone and sandstone. The swamp deposits are mostly brown carbonaceous shale and the bog deposits consist of thin beds of dirty coal (fig. 20).

COMPOSITION OF SANDSTONES AND HEAVY MINERALS

The tan and gray quartzose sandstones that compose the shoreline of the McCourt Tongue are composed of 92–96 percent clear to milky quartz grains,

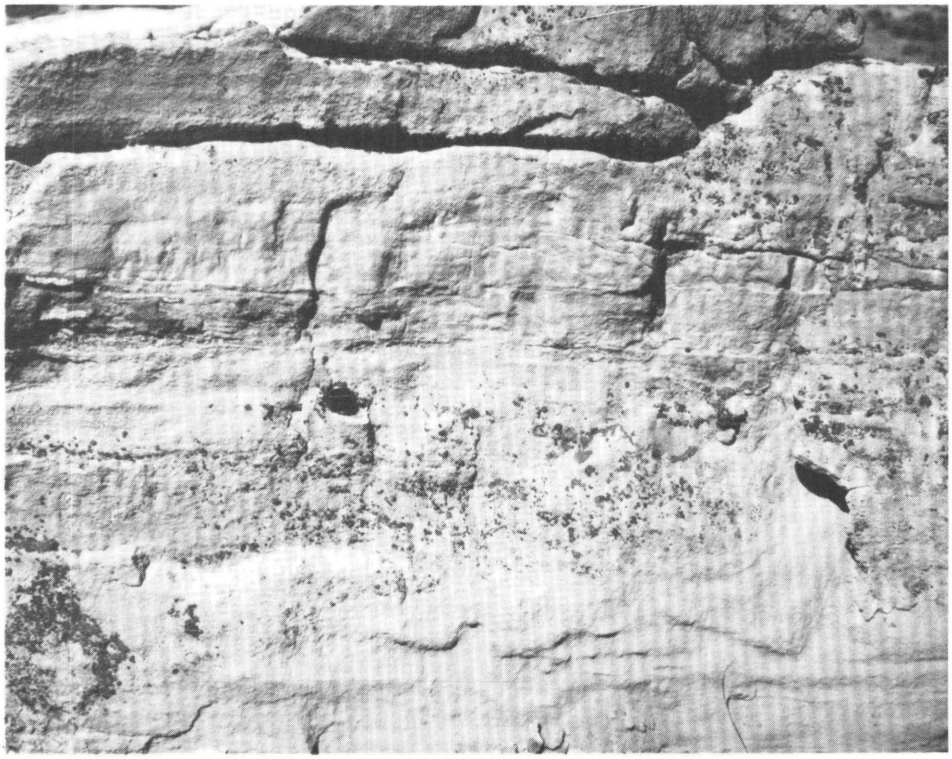


Figure 14. Thin, parallel beds comprising a berm sandstone lithofacies in the McCourt Sandstone Tongue of the Rock Springs Formation at the Black Butte heavy-mineral placer deposit in measured section 4785 NE¼SE¼ sec. 30, T. 18 N., R. 101 W. Scale is indicated by a penny near the center of the photograph.

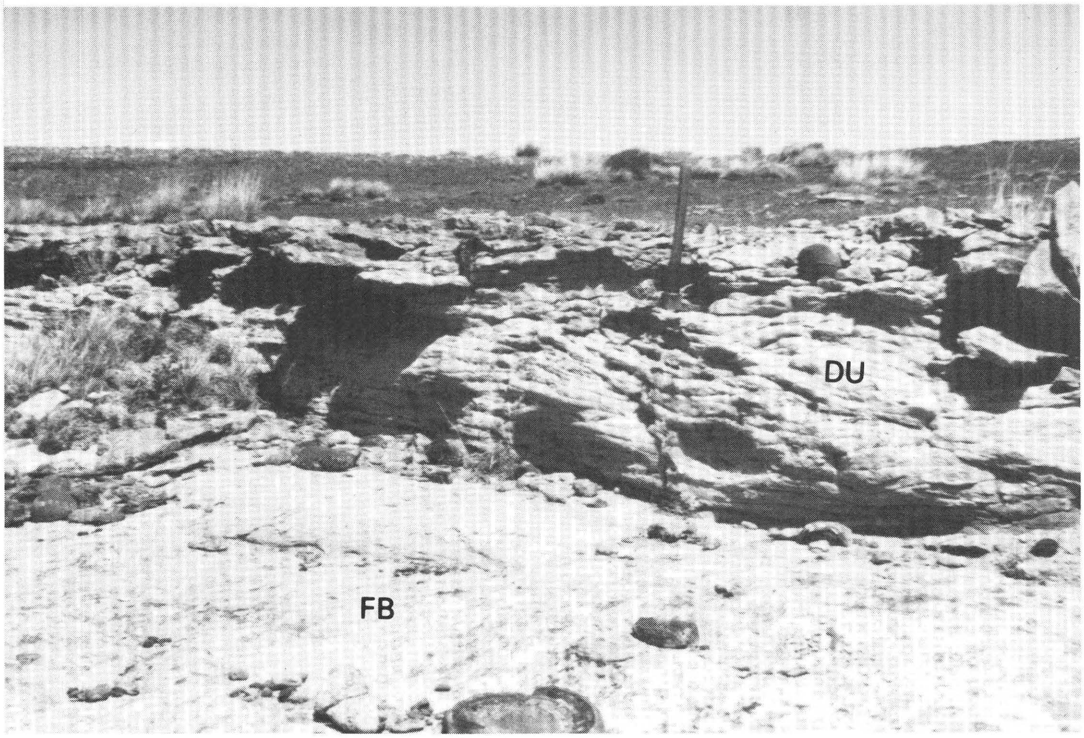


Figure 15. Crossbedding in sand dune (DU) lithofacies overlying a forebeach (FB) lithofacies in the McCourt Sandstone Tongue of the Rock Springs Formation near the Brady Road heavy-mineral placer deposit in measured section 3785 in SW¼NE¼NW¼ sec. 14, T. 17 N., R. 102 W. Pick handle is 17 in. long.

1–5 percent mica, feldspar, and miscellaneous rock fragments, and 1–3 percent heavy-mineral grains. The grain size usually ranges from very fine to medium and coarsens upward through the tongue. The cementing materials are an unidentified white clay in the upper part of the tongue and hematite in the middle and lower parts of the tongue.

The heavy-mineral placer deposits consist of dark-brown, fine- to medium-grained, ferruginous sandstones that form elongate lenses up to 6.6 ft thick and as much as 2,000 ft long. They occur intercalated with other parts of the quartzose shoreline sandstone that weather tan and gray. The heavy minerals are composed of about 85 percent opaque iron and titanium minerals, including mostly magnetite, hematite, and ilmenite. The remaining 15 percent is a nonopaque heavy-mineral fraction that has an average composition of about 80 percent rounded zircon, 15 percent euhedral zircon, and less than 1 percent each of tourmaline, rutile, garnet, sphene, hornblende, apatite, and with traces of other heavy minerals (G.B. Schneider, oral commun., 1986). The mineralogy indicates that more than 95 percent of the deposits are derived from plutonic source rocks.

Some of the zircon grains in the heavy-mineral suite are radioactive. As a result, all of the placer deposits in the study area were claimed for uranium in the 1950's. According to Houston and Murphy (1962), the radioactivity is attributed to the rare-earth elements cerium, neodymium, and ytterbium, and minor amounts of uranium, yttrium, lanthanum, hafnium, and niobium that are present in the zircon. Monazite may contribute some radioactivity, but it is present in only trace amounts. The titanium–iron oxide mineral, ilmenite, contains 35–65 percent TiO_2 and is potentially valuable for use as white pigment in the paint and ceramics industries. Rutile and zircon are possible sources for the metals titanium and zirconium, respectively (Fantel and others, 1986).

DEPOSITIONAL PROCESSES AND DISTRIBUTION OF HEAVY-MINERAL PLACER DEPOSITS

The sandstones constituting the McCourt Tongue were deposited along wave-dominated shorelines. Tidal influence was probably negligible, although some bidirectional tidal crossbedding was observed in channel sandstones in the Gottsche Tongue at the Camel Rock and Richards Gap heavy-mineral placer localities. Analyses of numerous wave ripples that are preserved in the sandstones in the McCourt Tongue indicate that prevailing winds were easterly (onshore). Southwest directed, wind-generated, longshore currents conse-

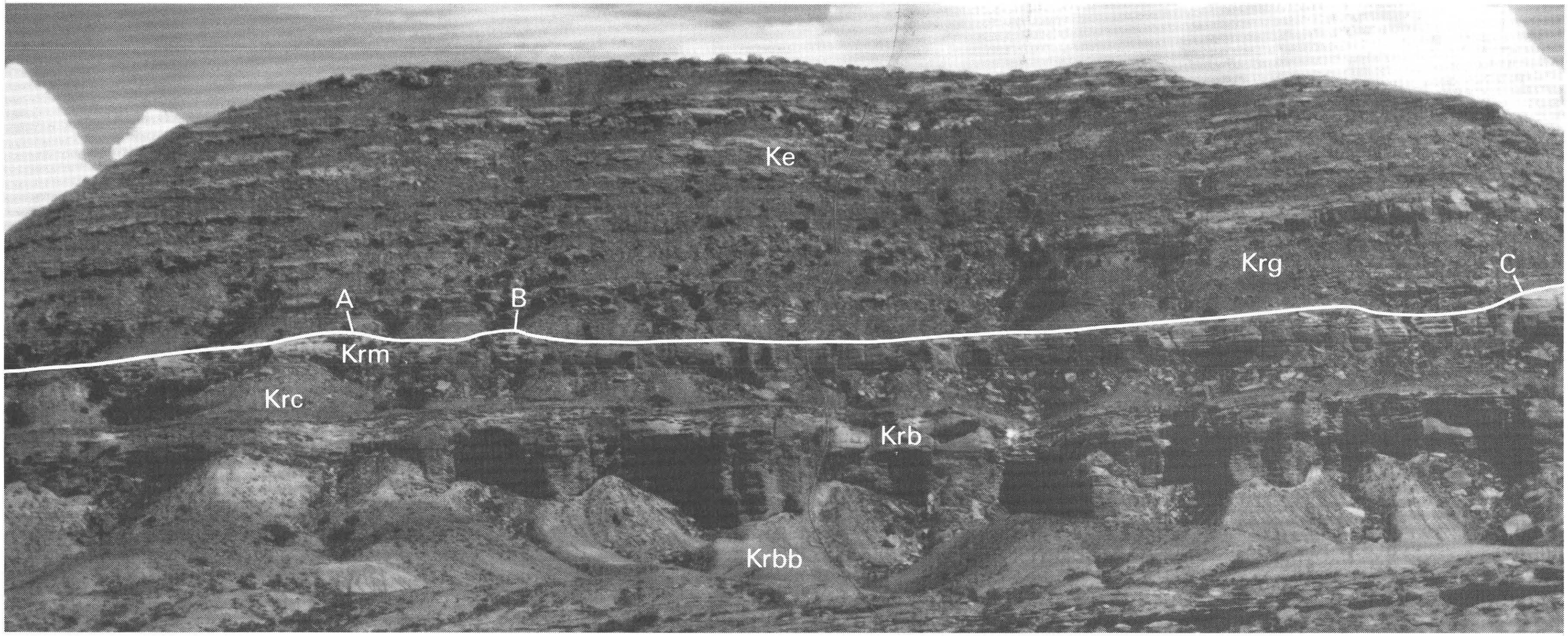


Figure 16. Outcrops at the Camel Rock heavy-mineral placer deposit in S½SW¼ sec. 8, T. 16 N., R. 102 W. Between points A and C are shale-filled and sandstone-filled fluvial channels scoured into the top of the McCourt Sandstone Tongue. Point B indicates the location of a mid-channel sandstone bar (between measured sections 3485 and 3685). The stratigraphic units at the top of the Rock Springs Formation include: Krbb, Black Butte Tongue; Krb, Brooks Tongue; Krc, Coulson Tongue; Krm, McCourt Tongue; and Krg, Gottsche Tongue. Ke, Ericson Sandstone is also shown.

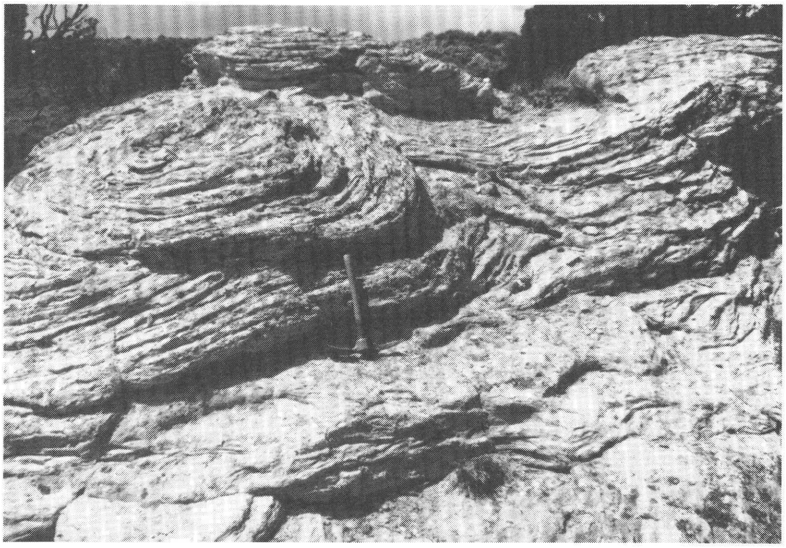


Figure 17. Large-scale, trough crossbedding in a fluvial channel sandstone in a lagoon lithofacies of the Gottsche Tongue overlying the Brady Road heavy-mineral placer deposit in measured section 3785 in NE¼NE¼NW¼ sec. 14, T. 17 N., R. 102 W. Pick handle is 17 in. long.

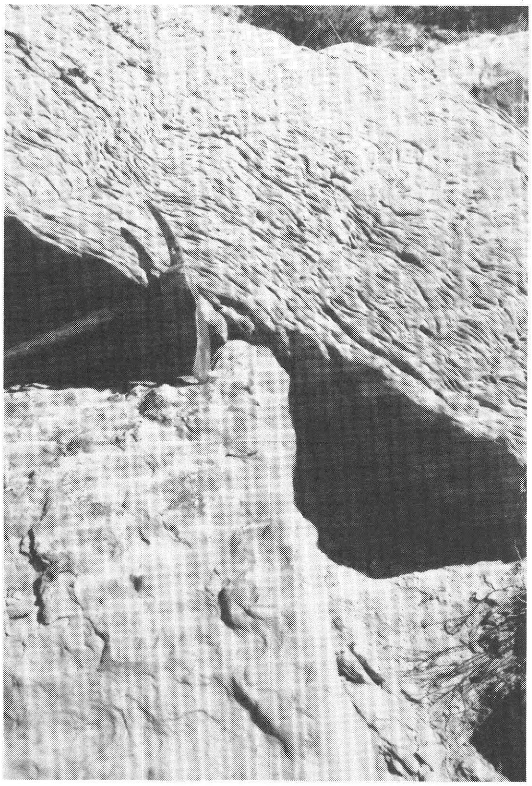


Figure 18. Current-rippled splay sandstone in a lagoon lithofacies of the Gottsche Tongue overlying the Camel Rock heavy-mineral placer deposit in SW¼SE¼SW¼ sec. 8, T. 16 N., R. 102 W. The outcrop at the top of the photograph shows a cross-sectional view of the current ripples and the boulder at the bottom of the photograph shows a plan view of the current ripples.

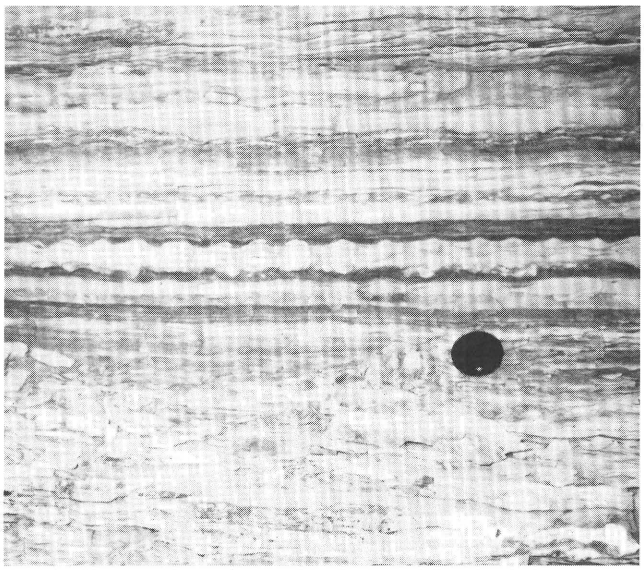


Figure 19. Wave-rippled splay sandstone in a lagoon lithofacies of the Gottsche Tongue near the Brady Road heavy-mineral placer deposit in NW¼ SE¼NW¼ sec. 14, T. 17 N., R. 102 W. Lens cap, 2 in. in diameter, is used for scale.

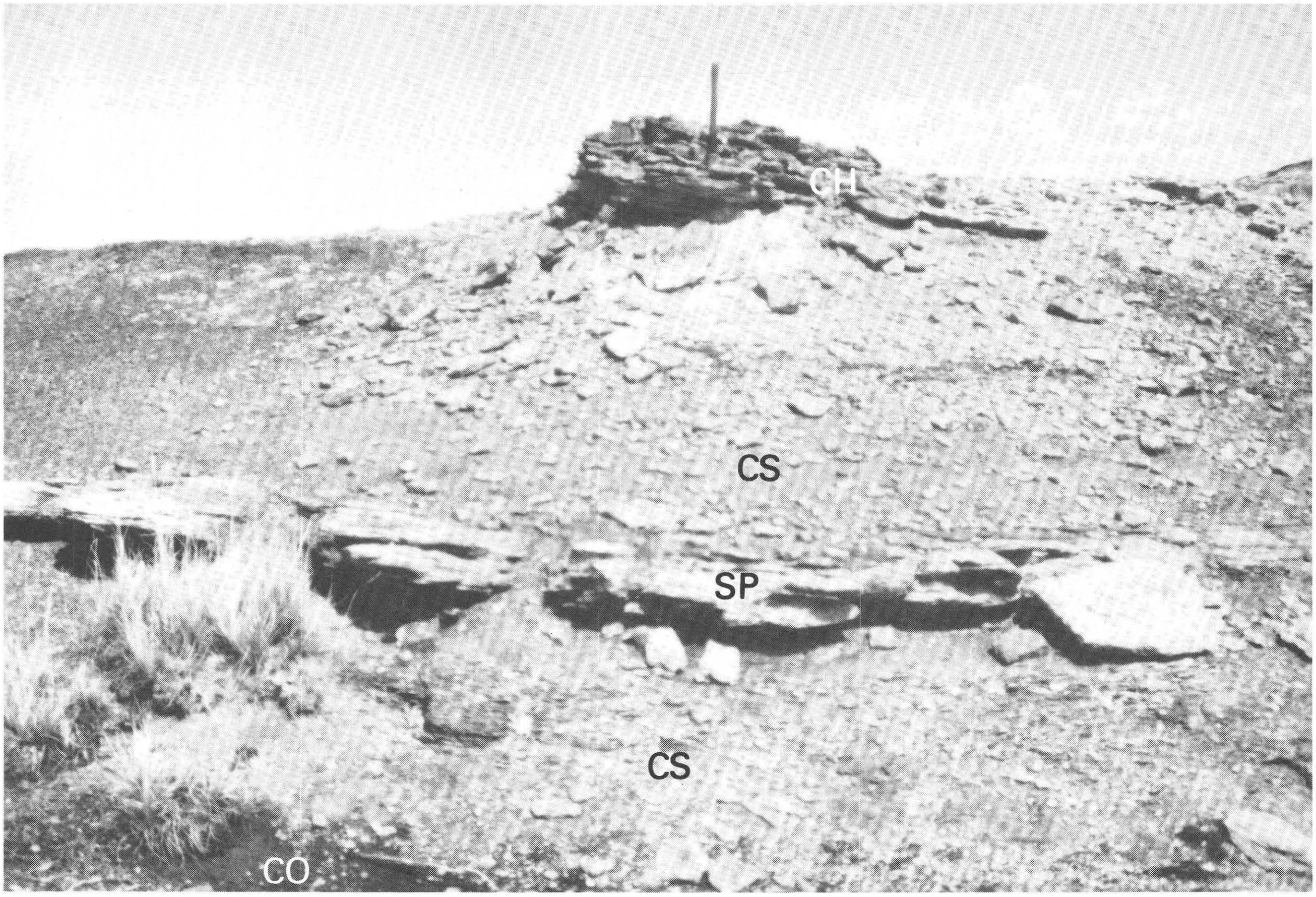


Figure 20. Typical lagoon lithofacies of the Gottsche Tongue overlying the Brady Road heavy-mineral placer deposit in measured section 3785 in NE¼NE¼NW¼ sec. 14, T. 17 N., R. 102 W. CO, coal; CS, carbonaceous shale; SP, splay sandstone; CH, basal part of a sandstone-filled fluvial channel. Pick handle is 17 in. long.

quently were produced when the waves intersected the shoreline at high-incidence angles (fig. 7). Evidence for pronounced longshore currents in a predominantly southwest direction is discernible in outcrops of surf (upper shoreface) sandstones, where the dip directions of foreset laminae are more than 90 percent southwest (fig. 12). A rose diagram, figure 21, was constructed from measurements of these dip directions using combined data from the six heavy-mineral placer deposits. It reveals that sediment transport was bidirectional (southwest and northwest) but predominantly southwest. The small number of northeast dips in figure 21 probably reflects seasonal reversals in the current direction from southwest during most of the year to northeast during short periods of the year.

The heavy-mineral placer deposits in the McCourt Tongue occur in middle shoreface, middle surf, upper surf, lower forebeach, upper forebeach, berm, and river mouth sandstones. The depositional settings are illustrated in figure 22. A heavy-mineral placer deposit of coastal swamp origin was discovered in stream channel sandstone stratigraphically above the top of the McCourt Tongue at the Richards Gap locality (fig. 22, No. 1c). This deposit is located in the basal part of the Gottsche Tongue, which was not included in this investigation.

The depositional setting of each of the six heavy-mineral placer deposits is unique, but all the deposits share common features. For example, they all occur as dark-brown to black sandstone in elongated lenses that roughly parallel the northeast trend of the shoreline, and all are intercalated with tan and gray quartzose sandstone. The deposits appear to be penecontemporaneous and probably result from a pronounced tectonic event that exposed plutonic source rocks in mountainous areas west of the study area.

The depositional processes and stratigraphic distribution of the heavy-mineral placer deposits in the McCourt Tongue have not been specifically explained by previous investigators. Dow and Batty (1961) stated that all the deposits were similar in composition and resulted from the action of waves and currents on the shores of a regressive sea. Houston and Murphy (1977) believed that the deposits resulted from the concentration of heavy minerals by storm waves at the landward edges of

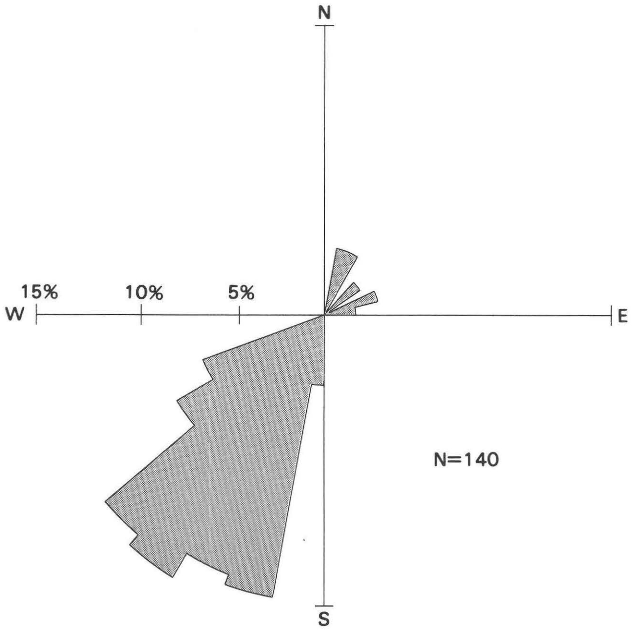


Figure 21. Rose diagram showing sediment transport directions in surf sandstones of the McCourt Sandstone Tongue of the Rock Springs Formation. Compare the configuration of the rose to the orientation of the shoreline of the McCourt Tongue in figure 7.

beaches. It is important to note that all the deposits are situated within a single stratigraphic unit—the McCourt Sandstone Tongue of the Rock Springs Formation. The data presented in this report provides evidence that the deposits were not restricted to beaches. Rather, the heavy-mineral placers were concentrated by a number of processes and were widely distributed through coastal sands. The deposits were formed by marine waves and longshore currents (Titsworth Gap, Camel Rock, Brady Road, and Cooper Ridge), fluvial currents (Richards Gap), and wind currents (Black Butte). Longshore currents appear to be the most important form of depositional control.

DESCRIPTION OF HEAVY-MINERAL PLACER DEPOSITS

Richards Gap Deposit

The heavy-mineral placer deposit at Richards Gap is located 45 mi southwest of Rock Springs, Wyo., in the SE¼ sec. 22, T. 12 N., R. 105 W. on the slopes east of Red Creek where it flows southward through hogbacks making up part of the Richards Mountains (pl. 1*A*). The deposit is located a few hundred feet north of the Wyoming-Utah State line. The outcrops at the locality consist of tan, cliff-forming, lower and middle shoreface sandstone lithofacies of the McCourt Tongue that rest upon less resistant, drab-gray marine shale of the underlying Coulson Tongue (fig. 23). The overlying surf and forebeach lithofacies, and an accretionary bar sandstone of the McCourt Tongue, weather to light-gray slopes and ledges. The heavy-mineral placer deposit at Richards Gap is situated at the top of the McCourt Tongue in sandstones deposited at the mouth of a small river.

The heavy-mineral deposit is situated east of and 150–400 ft above the level of the road through Richards Gap. It is visible from the road as a dark-brown band at the top of the McCourt Tongue on the north slopes of a shallow, steeply inclined ravine (fig. 23). The deposit has a maximum thickness of 6.6 ft (fig. 24, sec. 285) near the northwest end of a line of sections that were measured across the locality (pl. 1*A*). The heavy-mineral deposit thins rapidly northwest of measured section 285 (pl. 1*A*) and abruptly wedges out less than 150 ft away; and thus it is missing in measured section 385. To the southeast of measured section 285, in an upslope and updip direction along the top of the McCourt Tongue, the heavy-mineral placer deposit slowly thins by pinching and swelling, forms a distal lenticular bar, and wedges out near measured section 885. The sandstones in the upper part of the McCourt Tongue, above the surf lithofacies and lateral to the heavy-mineral deposit in measured sections 185 and 385 (pl. 1*A*), are light gray and tabular and constitute a forebeach lithofacies (fig. 13). At measured section 485 the heavy-mineral deposit rests unconformably upon a tan, planar crossbedded sandstone that has unidirectional, southwest dipping, foreset laminae (fig. 25). This lenticular sandstone is thought to be part of a linear channel bar that was present at the mouth of a small river. A delta did not form at the mouth of this river, because the sands that were transported by fluvial currents entering the sea were deflected southwestward and parallel to the shoreline by strong longshore currents. Southeast of measured section 485 the heavy-mineral deposit rests upon and merges with a medium- to dark-brown, small-scale, trough-crossbedded channel sandstone that was deposited across the mouth of the river (fig. 26). An arcuate spit developed from an upwind direction around the northeast margin of the river mouth as illustrated in figure 22 (No. 1b). The spit accreted southwestward around the river mouth and eventually formed an accretionary bar that protected the channel mouth from erosion by longshore currents. The accretionary bar first appears in outcrops between measured sections 685 and 785 (pl. 1*A*). The river mouth with its channel bars, associated heavy-mineral deposits, and protecting accretionary bar prograded seaward (southwestward) across the locations of measured sections 785, 885, and 985 (pl. 1*A*). Figure 27 shows the stratigraphic

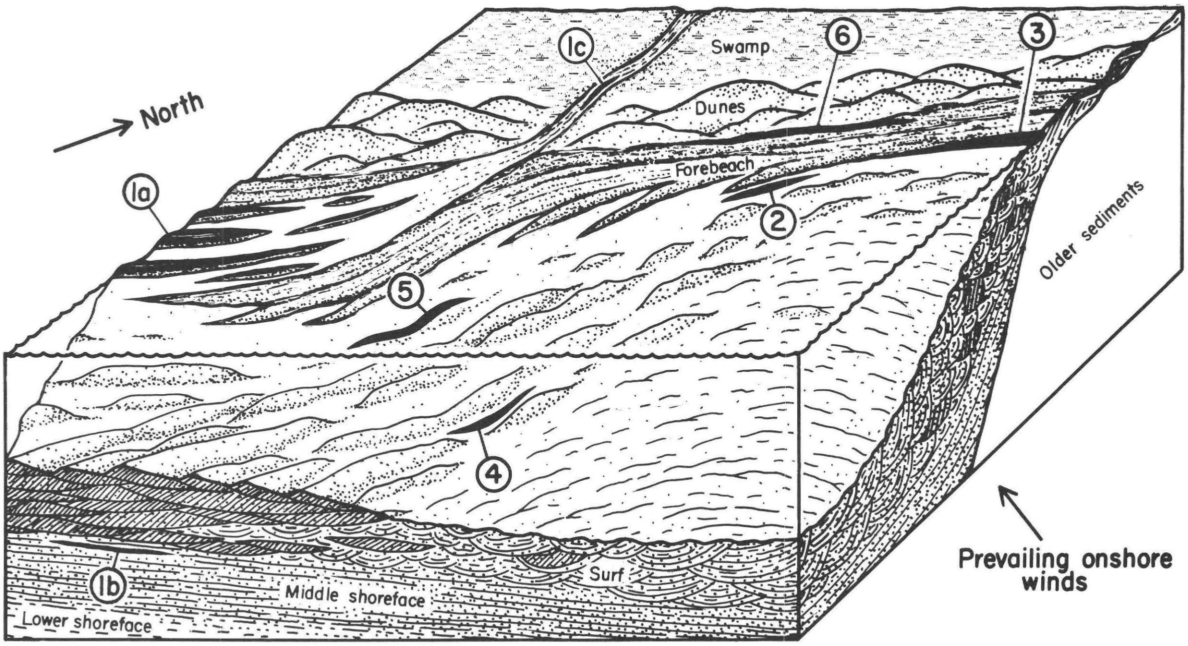


Figure 22. Sketch of depositional settings of heavy-mineral placer deposits in the McCourt Tongue of the Rock Springs Formation. 1a, 1b, and 1c, Richards Gap (river mouth, upper middle shoreface, stream channel); 2, Titsworth Gap (lower forebeach); 3, Camel Rock (upper forebeach); 4, Brady Road (middle surf); 5, Cooper Ridge (upper surf); and 6, Black Butte (berm). Not to scale.

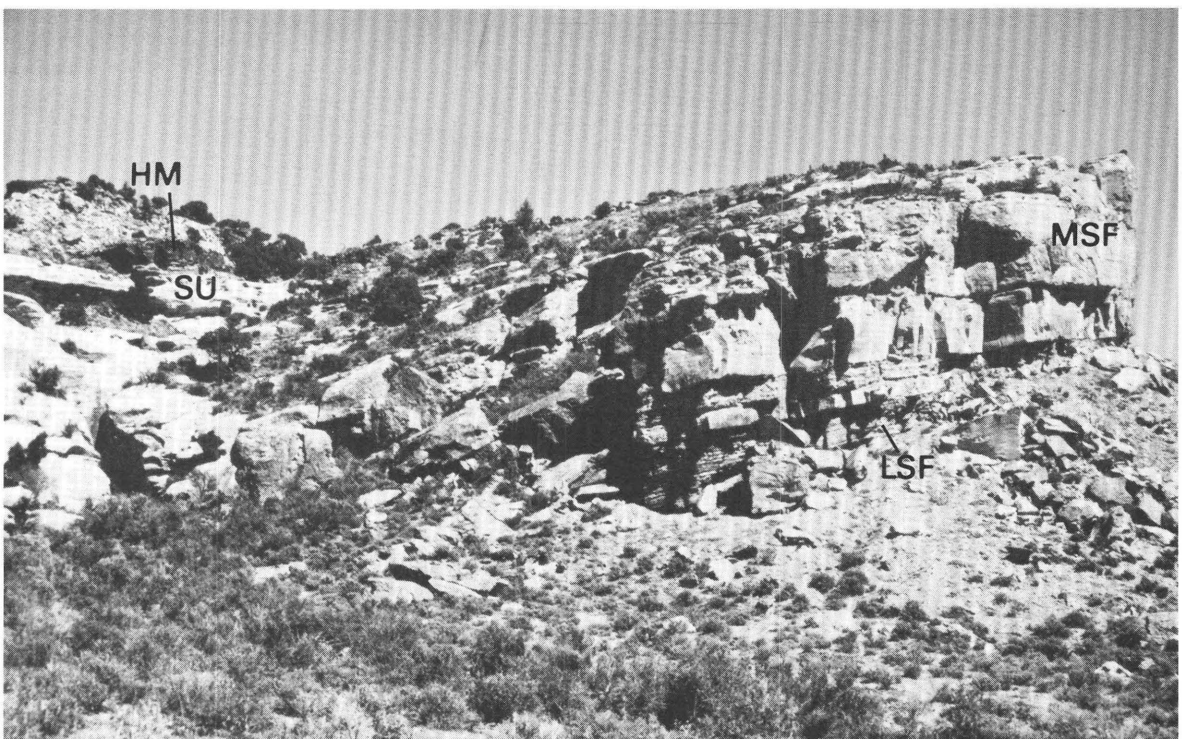


Figure 23. Outcrops of the McCourt Sandstone Tongue of the Rock Springs Formation at the Richards Gap heavy-mineral placer deposit near measured section 285 in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. View is toward the east. LSF, lower shoreface lithofacies; MSF, middle shoreface lithofacies; SU, surf lithofacies; HM, heavy-mineral placer deposit. The slopes in the lower right hand part of the photograph are in the Coulson Tongue of the Rock Springs Formation.

position of the accretionary bar in outcrops below the heavy-mineral deposit; figure 28 shows the sedimentary structures at the top of the accretionary bar at the point where it is unconformably overlain by the fluvial channel.

Two additional very thin and unimportant heavy-mineral placer deposits are present at the Richard Gap site. A 0.4-ft thick, dark-brown lens of ferruginous heavy-mineral sandstone is present in measured section 585 (pl. 1*A*), 2.5 ft below the top of the middle shoreface lithofacies. This lens is less than 250 ft long and wedges out laterally along outcrops in both directions from measured section 585. The origin of this lens of heavy minerals is attributed to either deepwater longshore currents or to storm waves. Storm waves are the most likely, however, as the normal low-energy regime of the middle shoreface seems to preclude the in situ segregation of light and heavy minerals. A 0.6-ft thick lens of ferruginous heavy-mineral sandstone is also present in large-scale trough crossbeds 3.5 ft above the base of a fluvial channel sandstone near the base of the Gottsche Tongue in measured section 885 (pl. 1*A*). The channel is situated within a swamp environment, and the heavy-mineral deposit undoubtedly owes its origin to fluvial currents (fig. 22, No. 1c). The presence of this lens of heavy minerals in a fluvial channel at the southwest end of the study area is significant, because the heavy-mineral placers appear to have drifted southwestward across the study area along the shoreline of the McCourt Tongue. The extreme southwest location of this lens suggests that many streams entering the interior sea from the west within the study area contributed the heavy minerals that ultimately were concentrated to form the placer deposits.

Titsworth Gap Deposit

The Titsworth Gap heavy-mineral placer deposit is located 28 mi southeast of Rock Springs, Wyo., near the center of the SE¼ sec. 7, T. 14 N., R. 103 W. (pl. 1*B*). It is accessible by a road that parallels the east side of Gap Creek where the creek flows northward through Titsworth Gap. The deposit weathers to a dark-brown lens near the top of the McCourt Tongue east of and about 300 ft above the level of the road (figs. 29 and 30).

The McCourt Tongue at Titsworth Gap is 105–117 ft thick (measured sections 1085 to 1585, pl. 1*B*). The lower shoreface lithofacies of the tongue is poorly exposed and is less than 10 ft thick. A tan, parallel-bedded, bioturbated, middle shoreface lithofacies, from 33 to 37 ft thick, overlies the lower shoreface. Above the middle shoreface, the surf lithofacies weathers light gray and consists of upper and lower units of mostly planar crossbeds that are separated by 10–14 ft of thin, parallel-

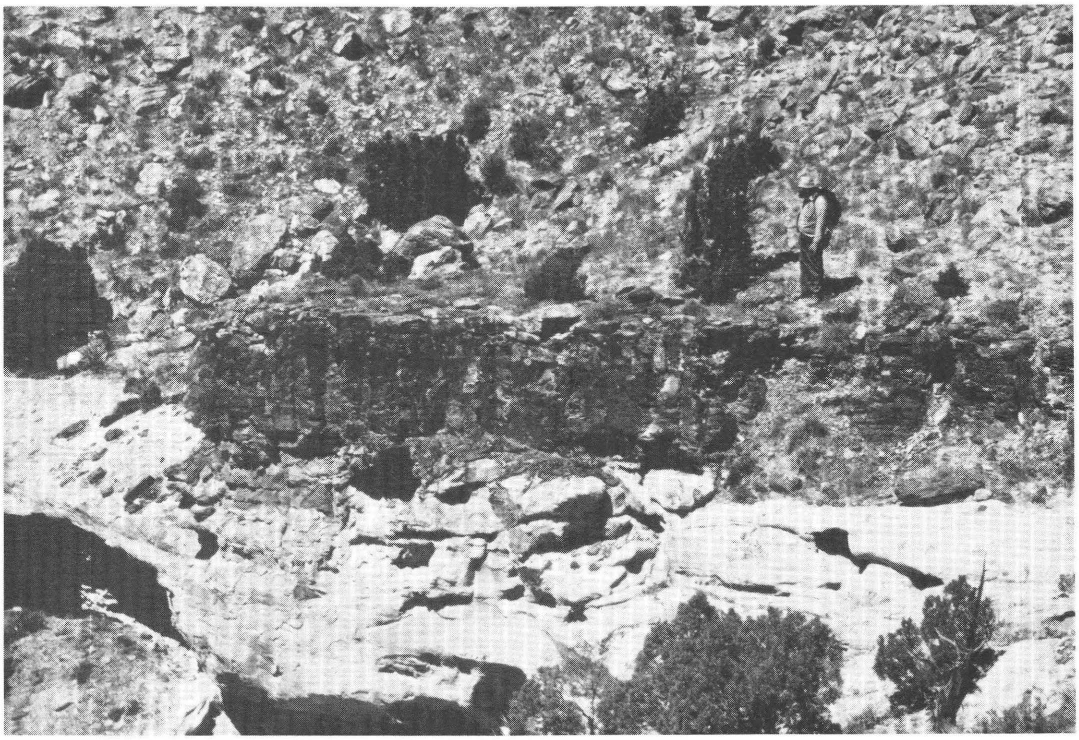


Figure 24. The Richards Gap heavy-mineral placer deposit in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. at measured section 285. The placer deposit here is 6.6 ft thick. Scale is indicated by a person standing on the placer deposit in the upper right part of the photograph.

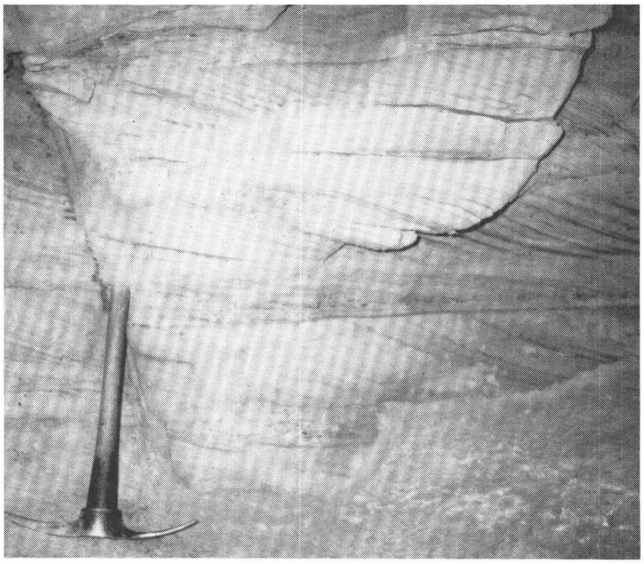


Figure 25. Unidirectional foresets in planar crossbeds of a linear fluvial channel sandstone bar underlying the Richards Gap heavy-mineral placer deposit near the base of measured section 485 in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. Pick handle is 17 in. long.

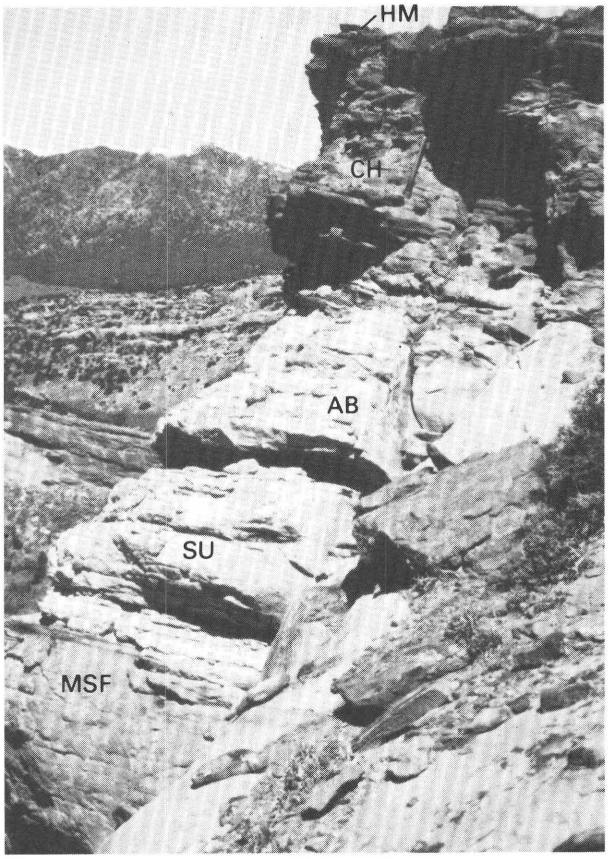


Figure 27. Outcrops of middle shoreface (MSF), surf (SU), accretionary bar (AB), and fluvial channel (CH) lithofacies in measured section 785 at the Richards Gap heavy-mineral placer deposit (HM). View is toward the west in NW¼SE¼SE¼ sec. 22, T. 12 N., R. 105 W. Pick handle is 17 in. long.

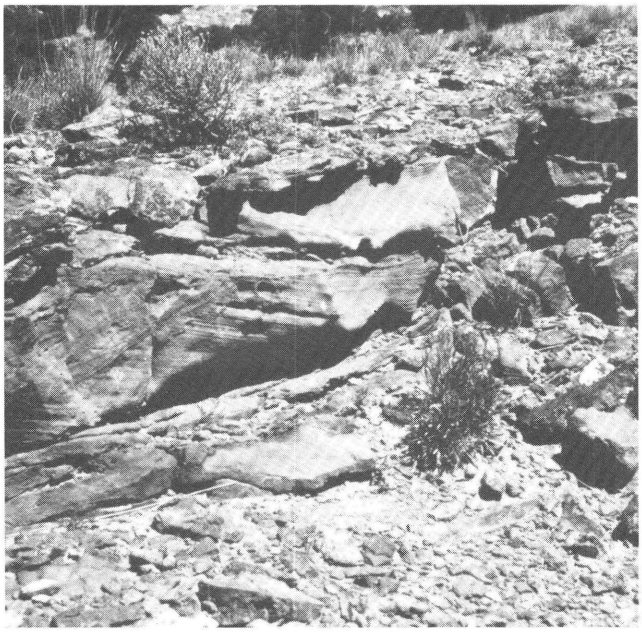


Figure 26. Small-scale trough crossbeds in a fluvial channel sandstone containing heavy-mineral concentrations at the Richards Gap placer deposit at the top of measured section 585 in NW¼SE¼ sec. 22, T. 12 N., R. 105 W. Width of outcrop is approximately 3 ft.

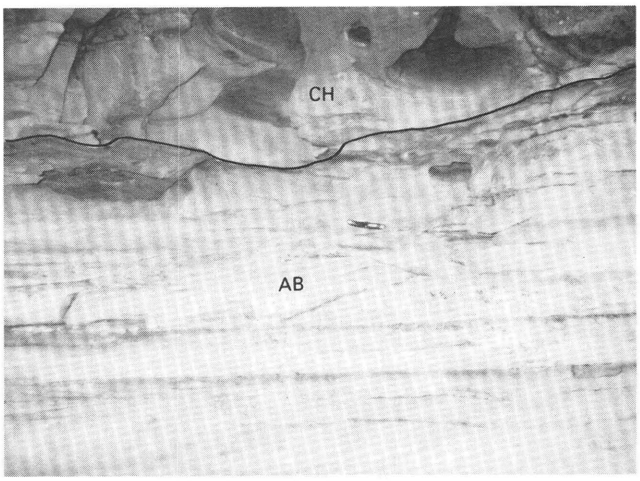


Figure 28. Subparallel beds of an accretionary bar sandstone (AB) overlain by a crossbedded fluvial channel sandstone (CH) at the Richards Gap heavy-mineral placer deposit. View is toward the north near measured section 785 in NW¼SE¼SE¼ sec. 22, T. 12 N., R. 105 W. Scale is indicated by jackknife 3.3 in. long.

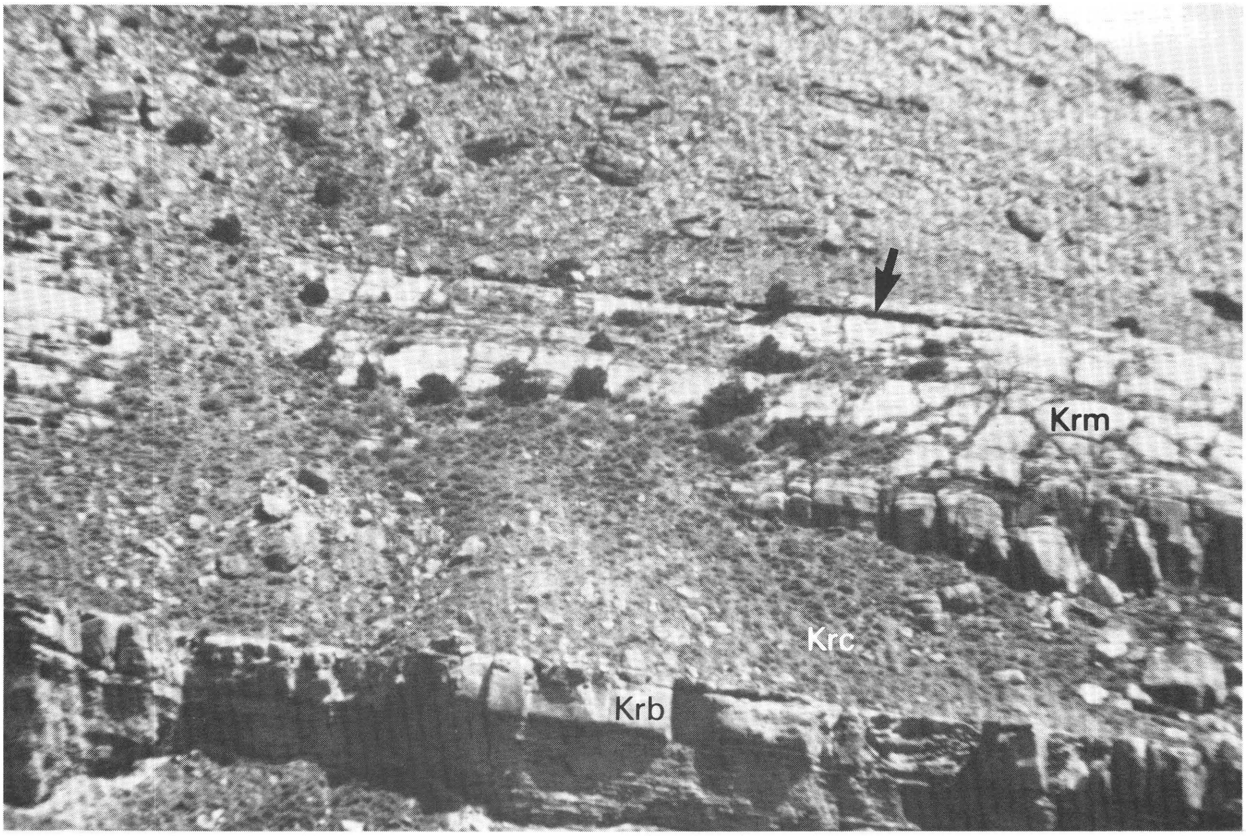


Figure 29. Titsworth Gap heavy-mineral placer deposit (arrow) in the center of the SE¼ sec. 7, T. 14 N., R. 103 W., viewed from the lower west slopes of Gap Creek. Subdivisions of the Rock Springs Formation include: Krb, Brooks Tongue; Krc, Coulson Tongue; Krm, McCourt Sandstone Tongue.

Figure 30. Outcrop of the heavy-mineral placer deposit (arrow) at Titsworth Gap. View is toward the south in the center of the SE¼ sec. 7, T. 14 N., R. 103 W.

bedded bioturbated sandstone. These parallel beds may represent a dislocated segment of the middle shoreface. If so, they indicate either a local change in the configuration of the shoreline, or a minor marine transgression that temporarily shifted the surf and middle lithofacies landward. Broadly lenticular, planar cross beds in the surf lithofacies exhibit mostly southwest dipping foreset laminae that reflect the direction of sediment transport by strong longshore currents (see rose diagrams, sec. 1085, pl. *1B*). The heavy-mineral deposit at Titsworth Gap occurs within light-gray forebeach sandstone lithofacies, 1.5–9.5 ft below the top of the McCourt Tongue. The deposit is lenticular and crops out for a distance of about 2,000 ft. It rises stratigraphically from south to north along the outcrop (pl. *1B*), and the inclination is interpreted to be the paleoslope of the forebeach upon which heavy-minerals were deposited. The inclination also suggests southeastward progradation (seaward offlapping) of the forebeach, as the sandstones overlying and underlying the heavy-mineral deposit are also of forebeach origin. The forebeach sandstone adjacent to the heavy-mineral deposit exhibits thick, bioturbated bedding, and in places, it contains abundant trace fossils, such as *Ophiomorpha* and *Skolithos*. Because of these trace fossils and because the thin, tabular bedding that usually characterizes the forebeach is missing, the mineral-bearing sandstones here are interpreted as having been deposited under shallow water in what was probably the lower part of the forebeach (fig. 22, No. 2).

Camel Rock Deposit

The Camel Rock heavy-mineral placer deposit is named for a prominent camel-shaped sandstone outlier of the Chimney Rock Tongue of the Rock Springs Formation that is located 21 mi southeast of Rock Springs, Wyo., in NE¼NW¼ sec. 7, T. 16 N., R. 102 W. The placer deposit is located 1¼ mi southeast of Camel Rock in the southern part of sec. 8, T. 16 N., R. 102 W. (pl. *1C*). The outcrops of the placer deposit are accessible by a Jeep trail that branches from Wyoming Highway 430 in SE¼ sec. 7, T. 16 N., R. 102 W., and continues eastward to the base of steep slopes located below the heavy-mineral outcrops.

The heavy-mineral deposit crops out on opposite sides of a small box canyon that is present near the base of gray cliffs formed by the Ericson Sandstone that overlies the Rock Springs Formation. The box canyon opens to the northwest, perpendicular to the northeast strike of the heavy-mineral deposit. Consequently, a mostly north-south trending line of sections that was measured along the northeast side of the box canyon displays a cross-sectional profile of the deposit (fig. 31), and an east-west-trending line of sections measured on the southwest side of the box canyon and for a distance to the west displays a longitudinal profile of the deposit (pl. *1C*). (Note that the east-west line of measured sections on plate *1C* is illustrated east to west. This orientation is not conventional, but it was intentionally used because of the orientation of outcrops.)

The McCourt Tongue has a minimum thickness of 65 ft in measured section 1685 and a maximum thickness of 85 ft in measured section 2985 (pl. *1C*). The lower shoreface, middle shoreface, and surf lithofacies are similar to those illustrated in figure 8 and discussed previously at other localities. In the north-south line of sections, the sandstone that overlies the surf lithofacies is very light gray and tabular; the sandstone formed as a prograding forebeach. The heavy-mineral deposit rises stratigraphically from south to north in similar fashion to the Titsworth Gap heavy-mineral deposit, and it probably also represents the preserved paleoslope of a forebeach. Progradation is apparent on plate *1C* from the stratigraphic positions of forebeach A, forebeach B, and forebeach C that offlap to the right, seaward, in the north-south line of measured sections. The northern end of the heavy-mineral deposit is thickest (4.2 ft) at measured section 2085. The deposit wedges out a short distance north of that section. South of measured section 2085 the deposit progressively thins across measured sections 2185, 2285, 2385, and 2485. The inclined profile and sedimentary structures of the forebeach indicate that the heavy minerals were deposited by waves along a swash zone but that the uppermost (probably subaerial) part of the forebeach, between measured sections 1785 and 1985, was devoid of heavy-mineral concentrations.

The heavy-mineral deposit in the east-west line of measured sections (pl. *1C*) begins at the seaward wedge-out of forebeach B between sections 2685 and 2785. The deposit thickens laterally westward along the direction of the facies strike across measured sections 2885, 2985, and 3085. A few feet west of section 3085 the heavy-mineral deposit begins to thin and drapes into the east edge of a small, shale-filled fluvial channel (fig. 32). It wedges out along the base of the channel west of measured section 3185 (pl. *1C*). The fluvial channel is associated with lagoonal deposition at the base of the Gottsche Tongue. The channel is only slightly younger age than the forebeach deposits at the top of the McCourt Tongue, as evidenced by the drape that took place of the soft, unconsolidated, heavy-mineral-bearing sands into the channel along its east bank (pl. *1C*). Fluvial currents subsequently scoured and removed all vestiges of heavy-mineral concentrations across the channel floor (pl. *1C*). In measured section 3285, scouring near the middle of the channel had progressed downward to near the base of the surf lithofacies. Thin remnants of the

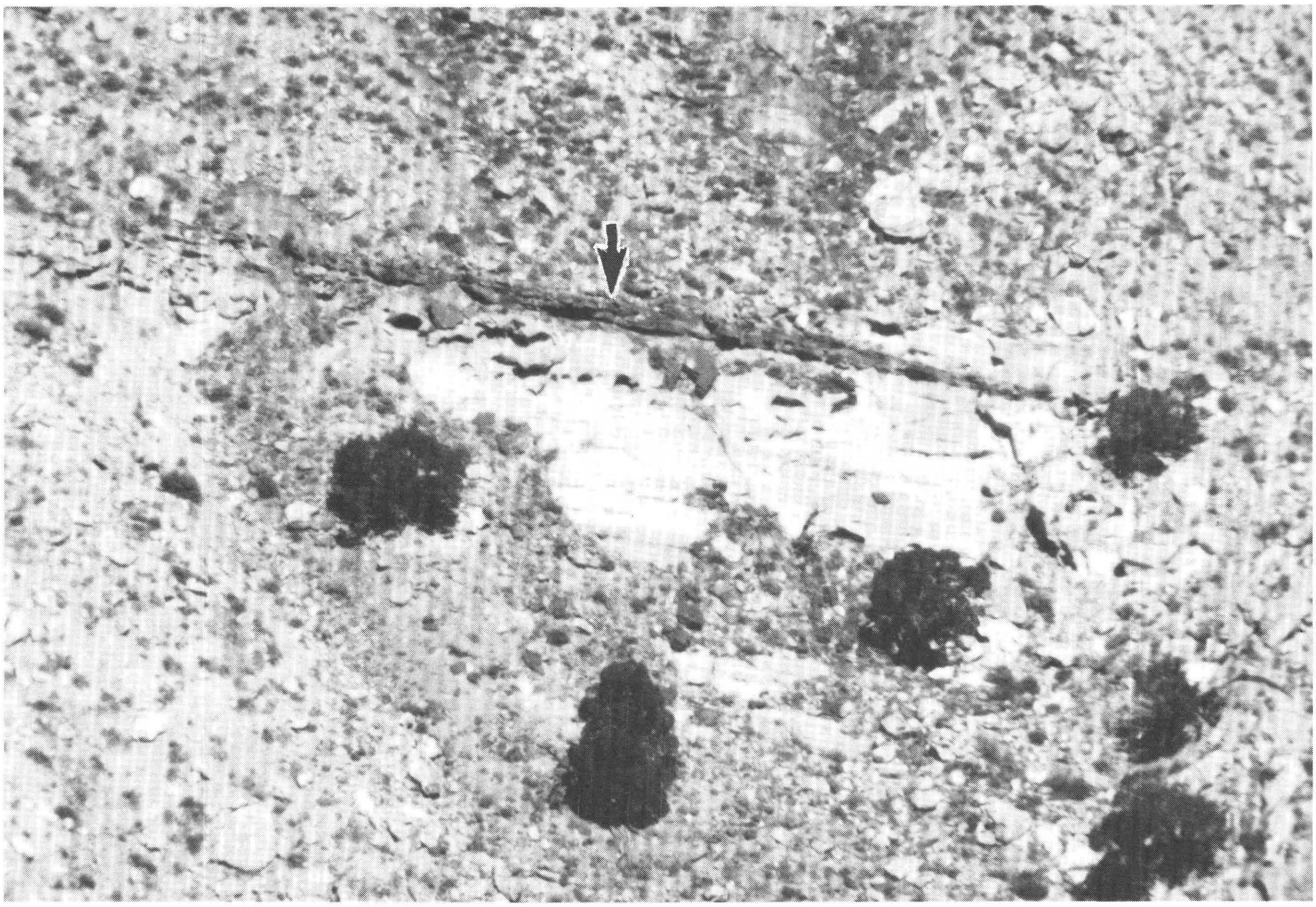


Figure 31. Cross-sectional view of the Camel Rock heavy-mineral placer deposit (arrow) on the east side of a box canyon located in the center of S½ sec. 8, T. 16 N., R. 102 W. The placer deposit here forms a lens 270 ft long.

heavy-mineral deposit are present on the west bank of the fluvial channel near measured section 3385 (pl. 1*C*). The deposit extends westward as a thin remnant across measured sections 3485 and 3585 and wedges out a short distance west of section 3585, before reaching section 3685. West of measured section 3685, another larger fluvial channel is present. The scouring associated with this channel removed most of the sandstones that compose the upper part of the McCourt Tongue for several hundred yards along outcrops west of the heavy-mineral deposit. The uppermost sandstones of the McCourt Tongue at measured sections 3485, 3585, and 3685 on plate 1*C* are tan, fine to medium grained, and lenticular. They rest unconformably on forebeach C, are current rippled along bedding planes, and exhibit low-angle, trough crossbedding. They are interpreted to be part of a mid-channel sandstone bar (fig. 33) that developed between the two fluvial channels during periods of flood, when the streams overflowed their banks and coalesced to form a single large river.

Brady Road Deposit

The Brady Road heavy-mineral deposit is located in E½SW¼ sec. 11 and NE¼NW¼ sec. 14, T. 17 N., R. 102 W. (pl. 1*D*). It is accessible by an improved gravel road to Brady gas field that branches eastward from Wyoming Highway 430, 18 mi southeast of Rock Springs, Wyo.. Five miles east of this road junction, a Jeep trail branches southwest from the road to Brady gas field in NE¼SW¼ sec. 1, T. 17 N., R. 102 W. (pl. 1*D*). The Jeep trail parallels the west side of Cooper Ridge for 1½ mi, climbs upward through sage-covered hills, and ends on the top of a northeast-trending, cedar-covered ridge that is capped by the heavy-mineral deposit (fig. 34). Rocks adjacent to the heavy-mineral outcrops are covered by sandy alluvium and vegetation, except at the southern end of the deposit. The heavy-mineral deposit dips 6° southeast.

Nine short sections (3885 to 4686) and one long section (3785) were measured along outcrops across a distance of about one-half mile (pl. 1*D*). The heavy-

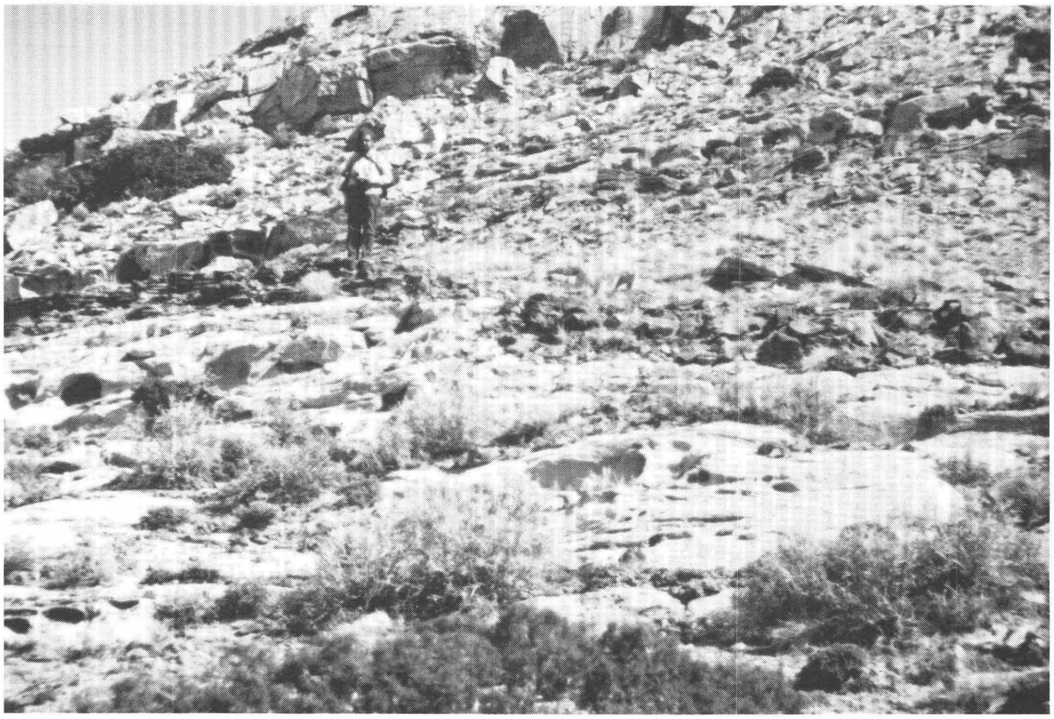
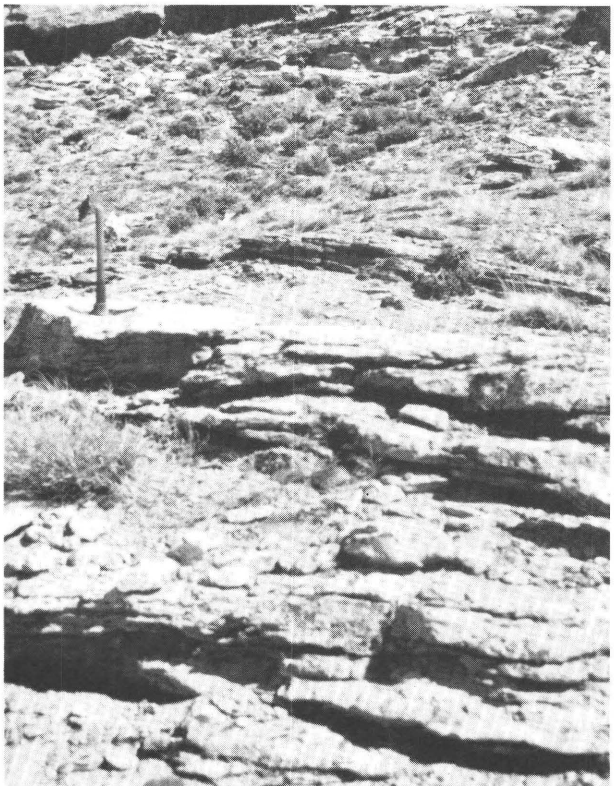


Figure 32. Drape of heavy minerals from a forebeach surface into a fluvial channel at the Camel Rock heavy-mineral placer deposit in SE¼SW¼ sec. 8, T. 16 N., R. 102 W. The person in the photograph is standing at measured section 3085 on the heavy-mineral deposit at the point where it begins to drape to the right (westward) into the fluvial channel.



mineral deposit wedges out at measured section 4685 at the north end of the locality, but it maintains a uniform thickness of 3–6 ft south along the deposit until it is absent a short distance south of measured section 3785 because of erosion.

The McCourt Tongue is 57 ft thick in measured section 3785. The lower shoreface lithofacies is less than 10 ft thick and is composed of thin, parallel-bedded, very fine grained sandstone and interbedded gray shale. The middle shoreface lithofacies is 26 ft thick and is composed of tan-gray, fine- to medium-grained cross-bedded sandstone. The surf sandstone is 20 ft thick. It consists of tan to gray, fine- to-medium-grained trough-crossbedded sandstone at the top and bottom and 4.7 ft of tan to dark-brown heavy-mineral placer sandstone in the middle. The heavy-mineral sandstone uniformly exhibits low-angle, trough crossbeds (fig. 35). The fore-beach lithofacies in measured section 3785 consists of 4.3 ft of gray, fine- to medium-grained sandstone in thin,

◄—**Figure 33.** Crossbedded sandstones comprising a mid-channel bar at the top of the McCourt Sandstone Tongue of the Rock Springs Formation at the Camel Rock heavy-mineral placer deposit in measured section 3685 in SE¼SW¼sec. 8, T. 16 N., R. 102 W. The mid-channel bar is visible at point B in figure 16. Pick handle is 17 in. long.

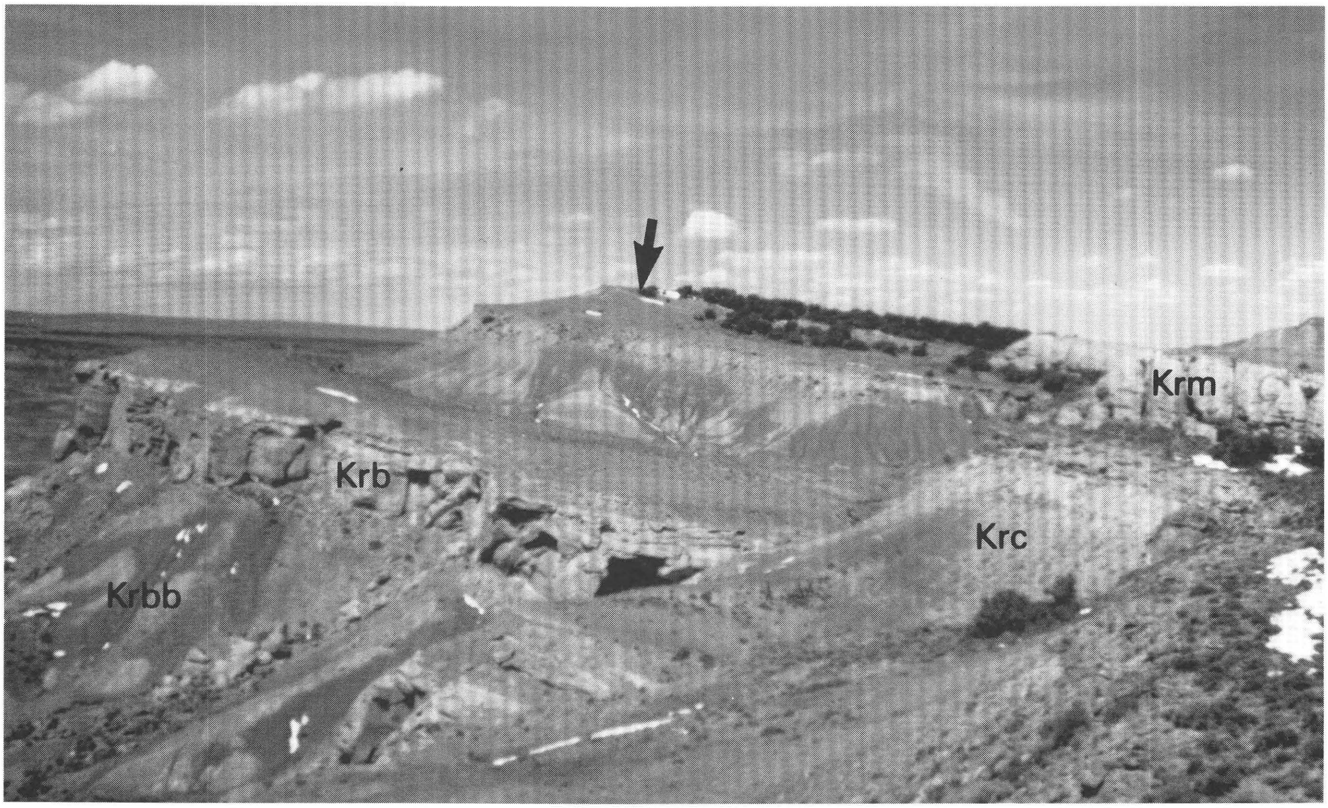


Figure 34. View to the north toward the Brady Road heavy-mineral placer deposit (arrow) that caps a cedar-covered ridge in SW¼ sec. 11, T. 17 N., R. 102 W. Stratigraphic units in the Rock Springs Formation include: Krbb, Black Butte Tongue; Krb, Brooks Tongue; Krc, Coulson Tongue; and Krm, McCourt Sandstone Tongue.

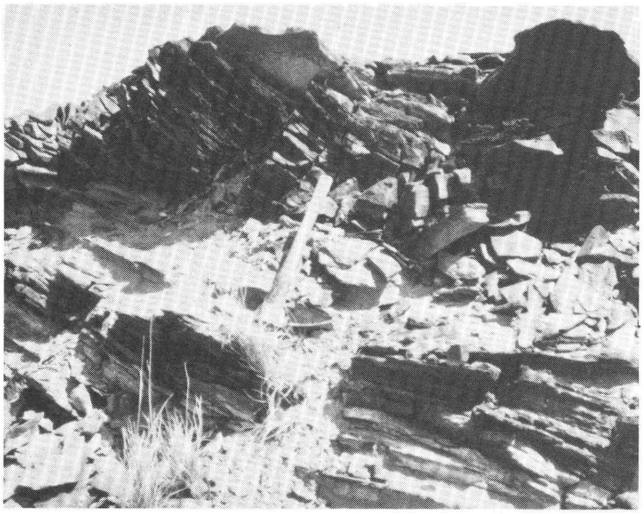


Figure 35. Crossbedded surf sandstones containing heavy-mineral concentrations at the Brady Road placer deposit in measured section 3785 in SW¼ sec. 11, T. 17 N., R. 102 W. Pick handle is 17 in. long.

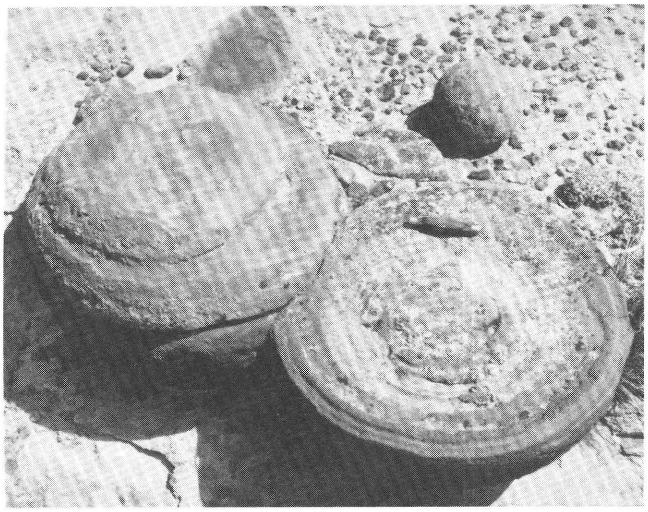


Figure 36. Cannonball-shaped concretions in forebeach sandstones at the Brady Road heavy-mineral placer deposit in NE¼NW¼ sec. 14, T. 17 N., R. 102 W. Jackknife used for scale is 3.3 in. long.

lenticular beds that contain scattered cannonball-shaped, concentrically banded, hematite concretions that are up to 1.5 ft in diameter (fig. 36). Resting upon and welded to the forebeach are 3.3 ft of eolian dune sandstone (fig. 15). The dune sandstone is extensively rooted and contains carbonized plant fragments. It is fine to medium grained in very low-angle, concave-downward crossbeds, with some scattered, round hematite concretions up to 0.5 ft in diameter.

The heavy-mineral placer deposit at the Brady Road locality is located stratigraphically in the middle of the surf lithofacies. Its position there suggests that it was deposited a few hundred feet seaward of the strandline in water probably 15-30 ft deep (fig. 22, No. 2). The southwest-northeast sediment transport direction, indicated by the rose diagram on pl. *1D* (measured section 3785), supports the conclusion stated previously that the heavy-mineral concentrations in the study area primarily drifted southwestward in response to strong longshore currents.

Cooper Ridge Deposit

The Cooper Ridge heavy-mineral placer deposit is the smallest of the six deposits that were investigated in the McCourt Tongue. The deposit is located 20 mi southeast of Rock Springs, Wyo., in NE¼NW¼SE¼ sec. 1, T. 17 N., R. 102 W., 250 ft east of Black Butte Creek and 1,500 ft northeast of the improved gravel road that trends eastward from Wyoming Highway 430 to the Brady gas field (fig. 37). The placer deposit is only 3.3 ft thick and 120 ft long, but it is visible from the road as a thin black streak within sandstone outcrops near the base of Cooper Ridge (fig. 38). The upper part of the McCourt Tongue at the locality is poorly exposed because of talus and vegetation, and the lower part is covered by alluvial fill along Black Butte Creek. A columnar section has been constructed from a single measured section at the deposit (fig. 39).

Sedimentary structures in sandstones exposed above and below the heavy-mineral placer deposit indicate that the deposit is situated stratigraphically near the top of a surf lithofacies. The sandstones overlying the deposit exhibit parallel, tabular bedding that is typical of a forebeach lithofacies. The underlying sandstones exhibit planar crossbedding that is typical of the surf lithofacies. The heavy-mineral placer deposit is thin bedded and exhibits small-scale, low-angle, trough crossbedding (fig. 40). Because of this crossbedding, the deposit is placed stratigraphically at the top of the surf lithofacies (fig. 22, No. 5).

The heavy-mineral concentration occurs in two distinct beds. A thin dark-brown sandstone containing heavy-mineral concentrations at the base is separated from a thicker similar heavy-mineral concentration at the top by a medium-brown sandstone that contains lesser amounts of heavy-minerals but is extensively iron stained (fig. 39). The heavy-mineral deposit is jointed and the joint blocks display Liesegang banding.

Black Butte Deposit

The Black Butte heavy-mineral deposit is located in SE¼ sec. 30, T. 18 N., R. 101 W. on the south slopes of an unnamed tributary of Black Butte Creek (pl. 1*E*). It is accessible by the road to the Brady gas field that branches eastward from Wyoming Highway 430, 18 mi southeast of Rock Springs, Wyo. Four and one-half miles east of this road junction, near the Cooper Ridge heavy-mineral placer deposit (fig. 37), the road to Brady gas field forks. The road to the left continues north for 6 mi to the Black Butte Ranch and the road to the right continues eastward for 8 mi to the gas field. One and one-half miles north of the fork in the road, on the road to the Black Butte Ranch, an improved road branches eastward, crosses Black Butte Creek, and continues to a gas well located in NW¼ sec. 29, T. 18 N., R. 101 W. (pl. 1*E*). The heavy-mineral deposit is situated about 500 ft south of the road to the gas well along the north face of a steep slope that rises from alluvial valley fill (fig. 41). The deposit is well exposed at the top of a bench-forming sandstone that is present along the lower part of this slope, but it is progressively covered to the northeast along outcrops by increasing amounts of alluvial valley fill.

The McCourt Tongue is 60–65 ft thick in measured sections 4785 and 4885 (pl. 1*E*), where it consists of a lower shoreface lithofacies, 7–10 ft thick; a middle shoreface lithofacies, about 25 ft thick; a surf lithofacies, about 23 ft thick; a forebeach lithofacies, 2–5 ft thick; and a berm lithofacies, 1–6 ft thick. (Note that the measured sections on plate 1*E* are illustrated east to west, in reverse perspective, because it is this view that is presented to the geologist in outcrops). The sedimentary structures in the sandstones at the locality are the same as those described previously for other localities, except for the beach berm. The beach berm was either not deposited or not preserved at the other localities. The berm at Black Butte is composed partly of tan or gray quartzose sandstone (fig. 14) and partly of dark-brown to black heavy-mineral sandstone (fig. 42). The upper 1 ft of the berm is unbedded and extensively rooted, and consists of a weathered surface, or paleosoil. The placer sandstones consist of thin, lenticular or subparallel, pinching and swelling, heavy-mineral layers that are separated by laminae of light-gray, quartzose sandstone

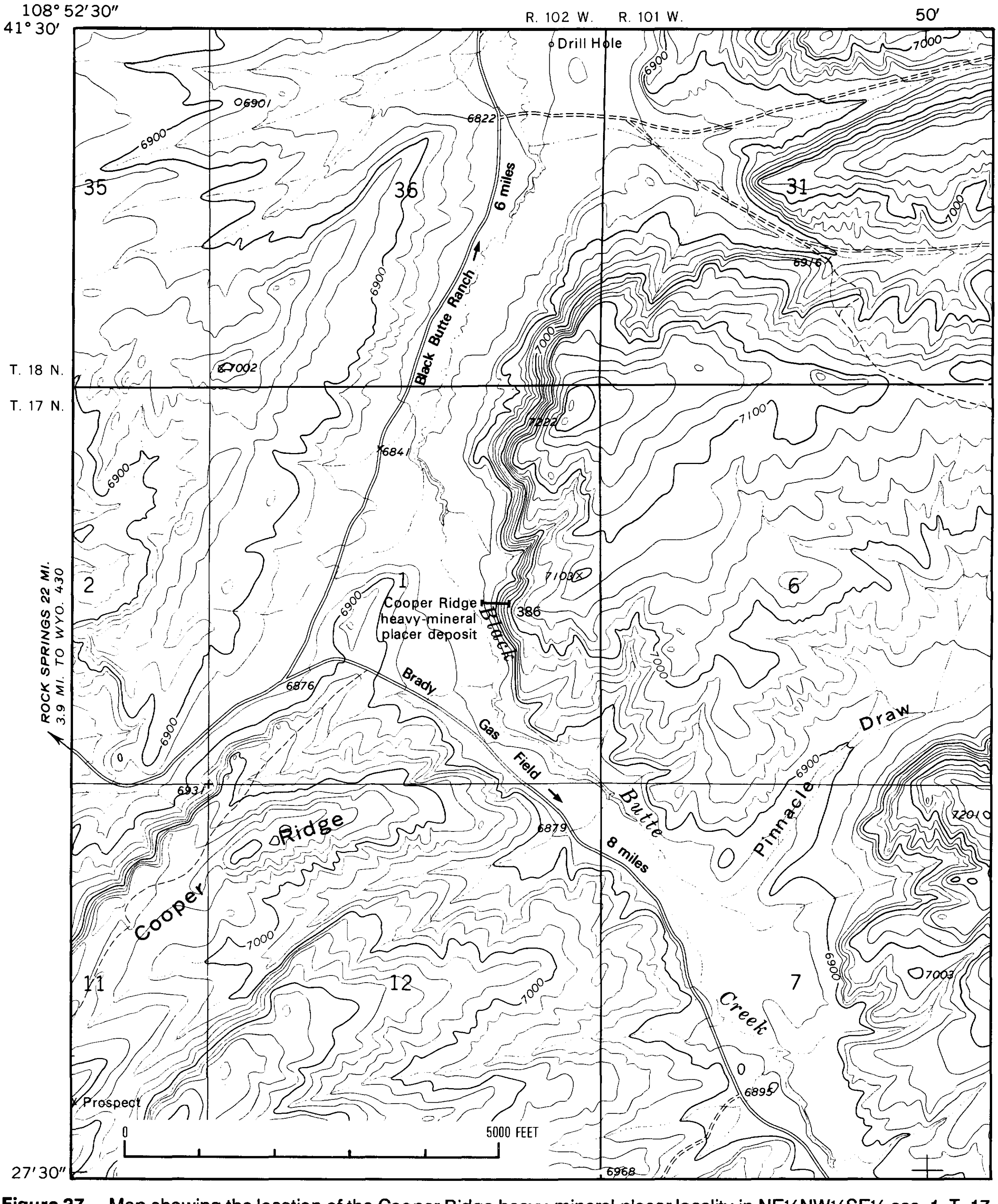


Figure 37. Map showing the location of the Cooper Ridge heavy-mineral placer locality in NE¼NW¼SE¼ sec. 1, T. 17 N., R. 102 W. Base from U.S. Geological Survey topographic quadrangle map, Cooper Ridge NE, Wyo., scale 1:24,000.

that highlights the heavy-mineral layers (fig. 42). The deposit is jointed and frequently weathers to small, irregularly shaped blocks with Liesegang banding in various shades of yellow, tan, red, and brown.

HOLOCENE ANALOGS

The Late Cretaceous paleogeography of the McCourt Sandstone Tongue of the Rock Springs

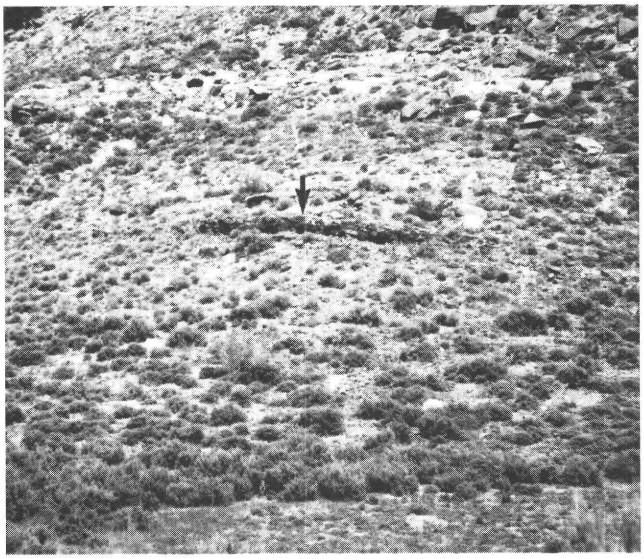


Figure 38. Outcrops of heavy-mineral sandstone (arrow) at the Cooper Ridge placer deposit in NE¼NW¼SE¼ sec. 1, T. 17 N., R. 102 W. View is toward the east. The heavy-mineral placer deposit here is 120 ft long and 3.3 ft thick.

Formation in the study area, on the western shores of an epicontinental sea, is not duplicated anywhere in the world today. This and other factors make it difficult to locate Holocene analogs for the heavy-mineral placer deposits in the McCourt Tongue. Ancient heavy-mineral placer deposits are usually only partly exposed, partly preserved, and observable in only two dimensions along outcrops. On the other hand, as pointed out by Foxworth and others (1962), recent heavy-mineral placer deposits are constantly shifting, because of changing currents, winds, and tides, and rarely is a set of conditions maintained long enough to complete a study. Publications on Holocene heavy-mineral deposits usually describe only one or two depositional processes; whereas, the deposits in the McCourt Tongue incorporate three—fluvial, eolian, and marine. Fortunately, the depositional settings and concentrating mechanisms of ancient and modern deposits are similar, which makes rough comparisons possible.

Apalachicola, Florida

Stapor (1973) has reported concentrations of heavy-minerals on open beaches, on sheltered beaches (facing bays), and in coastal dunes in the vicinity of Apalachicola, Florida. The open beach deposits occur as heavy-mineral-rich layers of less than ½ in. to 8 in. thick and from 6½ ft to 13 ft wide that are interlaminated or thinly interbedded with quartzose sand. The heavy

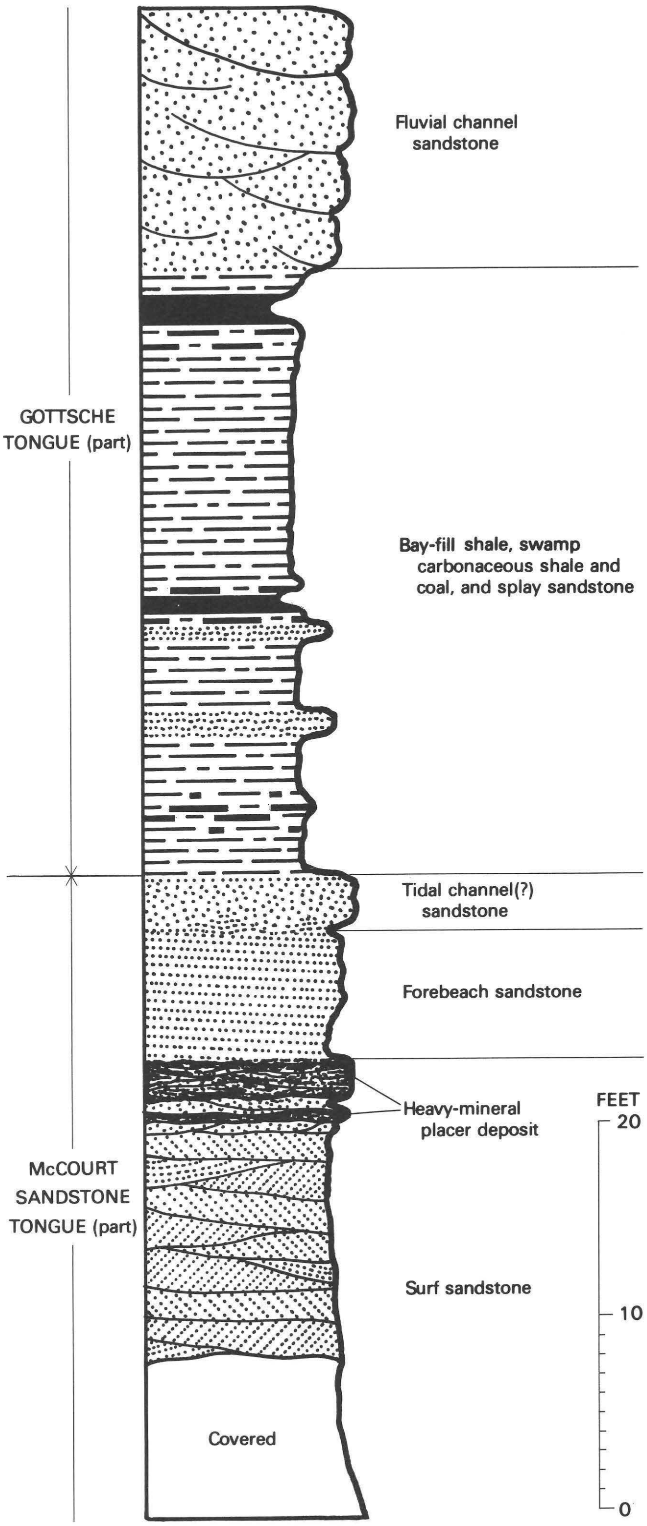


Figure 39. Columnar section of rocks exposed at the Cooper Ridge heavy-mineral placer deposit in NE¼NW¼SE¼ sec. 1, T. 17 N., R. 102 W.

minerals on the sheltered beaches occur as berm sand in beds 4 in. to 1 ft thick and less than 3 ft wide that parallel the beach for distances of less than 16 ft. The dune

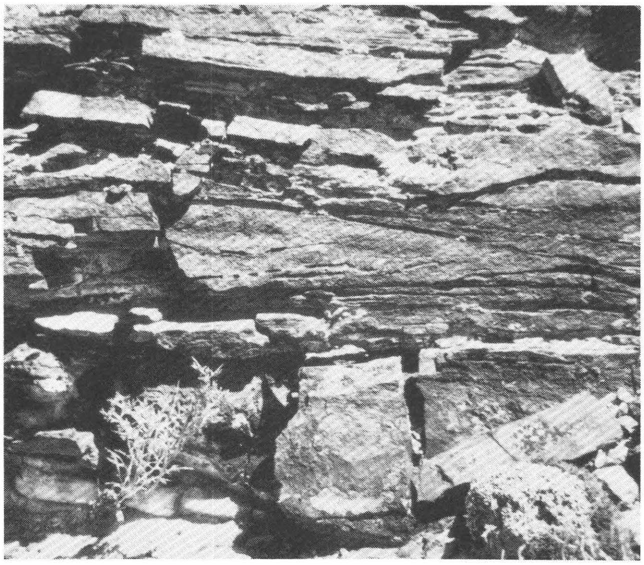


Figure 40. Small-scale, low-angle, trough crossbedding in sandstones of the Cooper Ridge heavy-mineral placer deposit in NE¼NW¼SE¼ sec. 1, T. 17 N., R. 102 W. Width of the outcrops shown in the photograph is about 4 ft.

concentrations are localized and occur as alternating laminae of black sand and quartzose sand in foreset laminae. The heavy-mineral suite is composed mostly of kyanite, staurolite, rutile, zircon, and ilmenite. Stapor (1973, p. 167) concluded from his investigations that the heavy minerals were initially concentrated in open waters of the Gulf of Mexico in a high-wave-energy regime and that the concentrations were delivered en masse to the beach face. There, the heavy minerals were further concentrated by eolian processes. In contrast to the Apalachicola deposits, the middle shoreface deposit at the Richards Gap locality (pl. 1*A*) probably formed in the surf zone and then was transported offshore during a severe storm.

Sapelo Island, Georgia

The effects of storm-wave erosion on heavy-mineral concentrations in backshore areas of Sapelo Island were investigated in 1971 and 1972 by Woolsey, Henry, and Hunt (1975). The heavy-mineral concentrations occur as thin black layers and laminae within bedded quartz sands composing beach- and dune-ridge deposits. The heavy-mineral suite is composed of epidote, hornblende, staurolite, sillimanite, zircon, tourmaline, and opaque minerals (mainly ilmenite). The greatest storm erosion took place during high spring tides, when waves broke along the backshore against dune slump material. As a result of this erosion, sand was transported seaward by backwash and wave-induced longshore drift. Concurrent with periods of high tides, strong northeasterly winds caused waves to reach the shoreline at high-incidence angles, which resulted in increased beach erosion and sand transport, leaving behind wind-winnowed, horizontal laminae of heavy minerals. Woolsey, Henry, and Hunt (1975, p. 268) concluded from their investigations that high energy factors (severe storms and high tides) resulted mostly in sand mixing and sand transport; whereas, low energy factors (waning storms and high tides or low tides and onshore winds) resulted in the winnowing of the light-sand fraction and the concentration of heavy minerals.

The heavy-mineral deposit in the McCourt Tongue at Black Butte is situated on the berm, is interpreted to be of mostly eolian origin, and is similar to the deposits described at Sapelo Island. The sedimentary structures indicate that the heavy-mineral concentration at Black Butte was probably the result of the winnowing action of strong onshore winds that approached the ancient shoreline from the east at high-incidence angles and then were deflected southward parallel to the beachface. The possibility that the heavy minerals at Black Butte were initially deposited along the berm by storm waves and then reworked and further concentrated by wind action cannot be ruled out.

Gulf Coast of Mississippi

Foxworth, Priddy, Johnson, and Moore (1962) made a number of discerning observations concerning the composition, source, transportation, deposition, and concentration of heavy minerals along recent beaches of the Gulf Coast of Mississippi and associated islands. They found that the coastal sands normally contain concentrations of heavy minerals that range from 2 to 6 percent. The heavy minerals concentrate as thin layers and laminae along beaches and in dunes. The heavy-mineral composition in decreasing order of abundance is staurolite, kyanite, tourmaline, ilmenite, magnetite, limonite-hematite, leucoxene, zircon, rutile, sillimanite, and andalusite. A metamorphic-igneous source for the heavy minerals is presumed to be in the southern Appalachian Mountains northeast of the study area. The authors determined that the mechanics of mineral transportation, deposition, and concentration are primarily as follows: (1) Longshore currents of 1–3 miles per hour (accelerated by tides to 3 to 6 miles per hour) scour shoreline areas and carry heavy minerals westward where the winnowing action of waves begins the concentrating process; (2) tidal currents effectively transport heavy minerals along mainland beaches, where they combine with the actions of waves to form spits and aprons of sand containing more than normal amounts of heavy-mineral grains; (3) swell waves, or waves produced by storms at sea, move the heavy minerals landward but

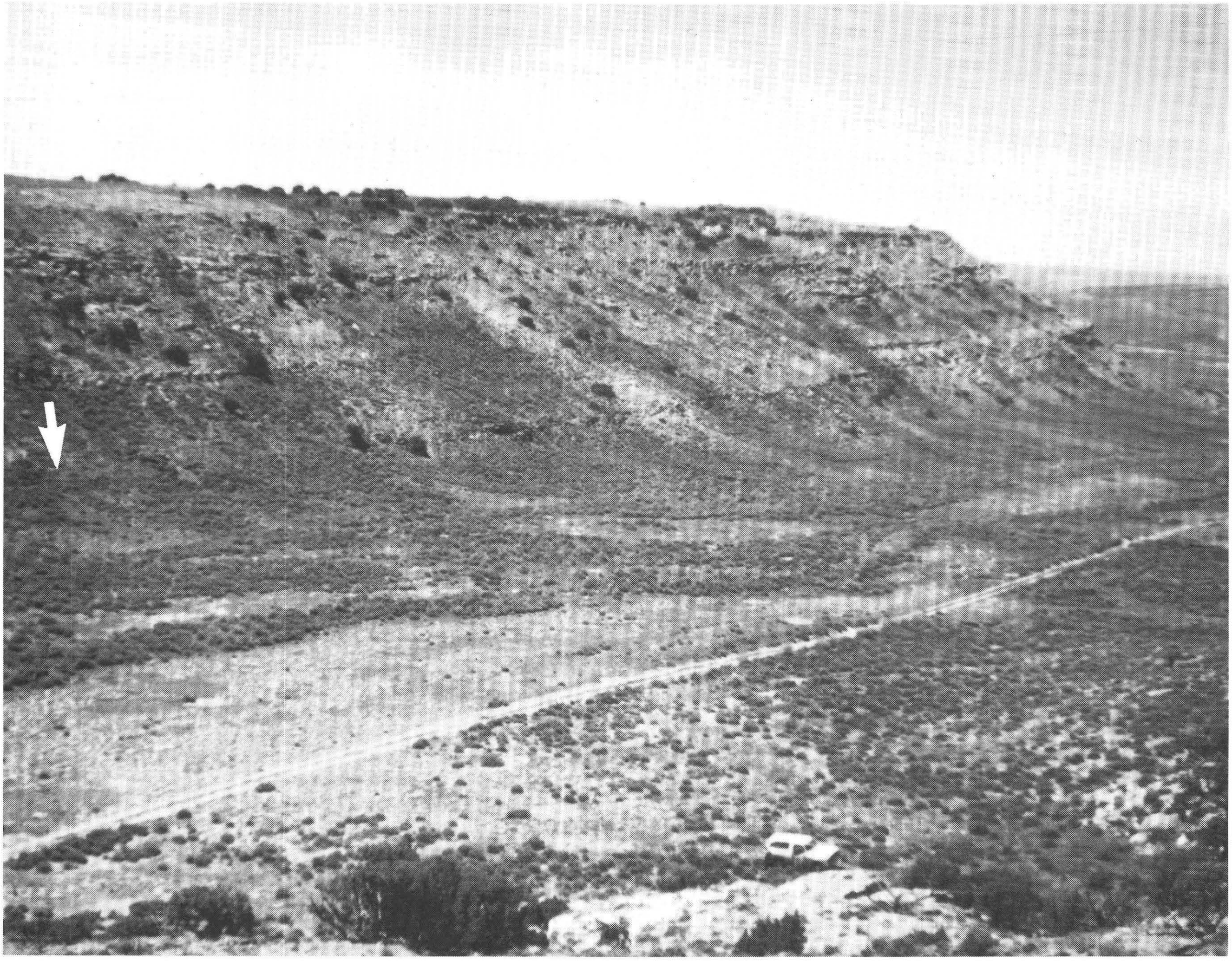


Figure 41. View to the southwest toward the Black Butte heavy-mineral placer deposit (arrow) in SE¼ sec. 30, T. 18 N., R. 101 W. Scale is indicated by vehicle parked in lower right part of photograph.

are not concentrating agents; (4) wind waves, often aided by high tides, are the most important concentrating agent for heavy minerals along beaches; (5) during squalls wave height increases and heavy minerals may be deposited high on the beaches to form berms, they may be washed onto adjacent tidal flats, or they may be transported inland to form pavements among sand dunes; (6) on low beaches rains winnow light grains and leave behind heavy grains as pavements covering gentle slopes; (7) dry winds, mostly onshore, concentrate heavy minerals by winnowing after rains have washed salt water from sands.

The heavy-mineral concentrations in the McCourt Tongue were probably transported, deposited, and concentrated in much the same way as those along the Gulf Coast of Mississippi. The heavy minerals in the McCourt Tongue were primarily transported and deposited by longshore currents as evidenced by sediment transport directions and by the stratigraphic position of the deposit within the surf lithofacies at the Brady Road locality. From the surf the heavy minerals probably moved shoreward (by wave swells?) onto the forebeach as indicated by the deposits at the Titsworth Gap and Camel Rock localities. The heavy-mineral deposits in the McCourt Tongue differ from those along the Gulf Coast of Mississippi in both thickness and lateral extent. The Mississippi deposits occur as localized layers and laminae; however, the McCourt Tongue deposits may be several feet thick and hundreds of feet long.

SUMMARY AND CONCLUSIONS

The heavy-mineral placer deposits in the McCourt Tongue consist of lenticular, elongated lenses of dark-brown to black, ferruginous sandstone that is intercalated

Figure 42. Heavy-mineral placer in berm sandstones at the Black Butte deposit near measured section 5685 in NE¼SE¼ sec. 30, T. 18 N., R. 101 W. The heavy-mineral deposit here is 3.6 ft thick.

with tan and gray quartzose sandstone of coastal-marine origin. The heavy-mineral suite is composed of about 85 percent opaque iron minerals—chiefly magnetite, hematite, and ilmenite. The remaining 15 percent of the suite is nonopaque and is composed nearly 95 percent of zircon and less than 1 percent each of tourmaline, rutile, garnet, sphene, hornblende, apatite, and traces of other minerals.

The sandstones of the McCourt Tongue crop out along exposures of a northeast-trending, wave-dominated, strand-plain shoreline. The sandstones that compose the shoreline are divisible into lower shoreface, middle shoreface, surf, forebeach, berm, dune, and river mouth lithofacies based upon their geometry, sedimentary structures, stratigraphic positions, and fossils. The localities where the heavy-mineral placer deposits and the enclosing sandstone lithofacies were studied are as follows: Richards Gap (middle shoreface and river mouth); Titsworth Gap (lower forebeach); Camel Rock (upper forebeach); Brady Road (middle surf); Cooper Ridge (upper surf); and Black Butte (berm).

Several factors are responsible for the multiple occurrence and widespread geographic and stratigraphic distribution of the heavy-mineral placer deposits in the McCourt Tongue: (1) A plutonic source area for the heavy minerals was present in the Sevier orogenic belt located in Idaho and Utah, 150–250 mi west of the study area; (2) a stable foreland was present between the Sevier orogenic belt and the marine shorelines along which the McCourt Tongue was deposited; (3) large streams and rivers carried heavy-mineral-laden sediments eastward across the foreland to the interior Cretaceous sea; (4) the western shores of the sea retreated southeastward and produced an extensive strand plain composed of sand that acted as a reservoir for heavy minerals; (5) strong easterly onshore winds produced southwest-directed longshore currents that resulted in southwest sediment transport parallel to the shoreline; and (6) rapid coastal subsidence and burial preserved the heavy-mineral concentrations.

Deposition of the heavy-mineral placer deposits, by fluvial, marine, and eolian processes, was at least partly sequential. The deposits were apparently transported en masse from one lithofacies to another along the marine shorelines of the McCourt Tongue. The currents in the streams and rivers that entered the sea from the west initially segregated light and heavy minerals and deposited them as layers in channel sandstones (for example, the channel deposit at the base of the Gottsche Tongue at Richards Gap). Thick, relict layers of heavy minerals were subsequently deposited at the mouths of the streams and rivers (the Richards Gap river mouth deposit). From the river mouths these concentrations were carried seaward to the surf during periods of flood. Within the surf the concentrations were transported along the shoreline by wind-driven longshore currents (the Cooper Ridge and Brady Road deposits). The heavy-mineral deposits were occasionally driven shoreward from the surf area onto the beach by storm waves (the Titsworth Gap and Camel Rock deposits). Once on the beach the concentrations were further reworked by waves and winds and were enriched by the winnowing of the quartzose beach sands that normally contained 1–3 percent disseminated heavy-mineral grains (the Black Butte deposit).

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