Table 2. Stratigraphic summary of Upper Cretaceous and Tertiary strata in the Kaiparowits Plateau, Utah. Lithologic descriptions and depositional interpretations are based on Sargent and Hansen (1982), Bowers (1972), Peterson (1969a, b) and Shanley and McCabe (1991).

Age	Formation	Thickness (ft)	Description and depositional interpretation
Miocene	Osiris Tuff	0-600	Gray, purplish-gray and red-brown welded ash-flow tuff. Volcanic.
Eocene and Paleocene	Wasatch Fm	1,350-1,650	Variegated Sandstone Member Red, pink, and purplish-gray, very fine to coarse-grained sandstone, mudrock and minor conglomerate (0-600 ft). Fluvial. White Limestone Member Light-gray to white, crystalline limestone and minor mudrock (0-600 ft). Lacustrine. Pink Limestone Member Gray, tan, white, pink or red, fine-grained clastic limestone, mudrock, sandstone, and minor conglomerate.(0-900 ft). Fluvial.
Paleocene?	Pine Hollow Fm	0-450	Lavender to red and gray mudrock and limestone with coarse-grained, pebbly sandstone in lower part. Low energy fluvial and lacustrine.
Paleocene? and Late Cretaceous	Canaan Peak Fm	0-900	Gray, tan, and brown conglomerate, conglomeratic sandstone, and minor gray and red mudstone. High energy fluvial.
Late Cretaceous	Kaiparowits Fm	600-3,000	Greenish- and bluish-gray, fine-grained, silty sandstone with subordinate beds of mudrock and limestone. Low energy fluvial (meandering river) and floodplain.
	Wahweap Fm	900-2,600	Light-gray and brownish-orange, fine- to medium-grained sandstone interbedded with gray mudrock and shale. Upper part is dominantly sandstone. Fluvial and floodplain.
	Straight Cliffs Fm	1,000-2,000	Drip Tank Member (140-400 ft) Light-gray, medium- to coarse-grained sandstone, conglomeratic sandstone, and minor mudrock. Braided river. John Henry Member (600*-1,500 ft) Light-gray to brown, very fine to medium-grained sandstone; minor coarse-grained and conglomeratic sandstone; olive-gray, brown, and black mudrock, and coal. Nearshore marine, estuarine, paludal, and alluvial. *Thickness based on subsurface data. Smoky Hollow Member (20-300 ft) Upper part is light-gray, medium- to coarse-grained and pebbly sandstone (Calico bed). Lower part is fine-grained sandstone, mudrock, and coal. Braided river (Upper part), coastal plain and paludal (lower part). Tibbet Canyon Member (60-185 ft) Yellowish-gray and grayish-orange, fine- to medium-grained sandstone with siltstone and mudrock in lower part. Estuarine and nearshore marine.
	Tropic Shale	600-900	Gray shale with thin beds of siltstone and fine-grained sandstone in upper part. Offshore marine.
	Dakota Formation	15-250	Upper member (0-68) Light-brown, fine-grained to fine-grained sandstone interbedded with gray mudrock. Coastal plain, brackish water, and nearshore marine. Middle member (4-76) Gray to brown, very fine grained to fine-grained sandstone interbedded with yellowish-green mudrock, carbonaceous mudrock and coal. Low energy fluvial, floodbasin, and paludal. Lower member (0-66) Gray to brown conglomerate and fine- to coarse-grained, pebbly sandstone and minor carbonaceous mudrock. High energy fluvial.

GEOLOGIC SETTING

General stratigraphy of Cretaceous and Tertiary strata of the Kaiparowits Plateau

Geologic cross sections by Lidke and Sargent (1983) indicate that as much as 7,500 feet of Upper Cretaceous strata and 3,000 feet of Tertiary strata underlie the Kaiparowits Plateau. Upper Cretaceous strata include, in ascending order, the Dakota Formation, Tropic Shale, and Straight Cliffs, Wahweap, Kaiparowits, and Canaan Peak (lower part) Formations (table 2). Paleocene strata include the Canaan Peak (upper part), Pine Hollow, and Wasatch (lower part) Formations (table 2). Eocene strata include the middle and upper part of the Wasatch Formation (table 2) and Miocene rocks are in the Osiris Tuff (table 2). The Dakota Formation, Tropic Shale, and Straight Cliffs Formation are exposed along the margins of the plateau but are buried by younger strata in the plateau's central areas (fig. 3). Thicknesses, lithologies, and depositional settings for Cretaceous and Tertiary strata in the plateau are summarized in table 2; additional sedimentological, stratigraphic, paleontological, and palynological data are provided in publications cited in table 3.

Coal in the Kaiparowits Plateau is contained in the Dakota Formation and the Smoky Hollow and John Henry Members of the Straight Cliffs Formation (table 2). The deposits of coal in the upper part of the Smoky Hollow Member and John Henry Member are described in detail throughout the remainder of this report. Coals in the Dakota Formation and lower part of the Smoky Hollow Member are described only briefly here, because they are generally thin, lenticular, and too deep to be mined in the foreseeable future. The basal 25 feet of the Smoky Hollow Member contains as many as four beds of coal that are generally less than 2 feet thick; coal beds are as much as 3 feet thick in the Wide Hollow Reservoir quadrangle and range from 4 to 5 feet thick in the Lone Rock and Smoky Hollow quadrangles (fig. 2). Coal is found in the Dakota Formation along all areas of outcrop except in the Seep Flat quadrangle (fig. 2). The Dakota Formation contains as many as seven lenticular beds of coal that are generally less than 2 feet thick; however, some coal beds are 4-6 feet thick in the Dave Canyon, Henrieville, and Wide Hollow Reservoir quadrangles (fig. 2). The quality of coal in the Dakota Formation is not well known, but proximate and ultimate analyses of a coal sample from the Dakota Coal Mine in the Lone Rock quadrangle (table 1), reported by Waldrop and Peterson, (1967), yielded 11,370 Btu/lb on a moist, mineral-matter-free basis and an apparent rank of subbituminous A using the Parr Formula described in American Society for Testing and Materials (1995).

Detailed stratigraphy of the Upper Cretaceous Straight Cliffs Formation

During the Late Cretaceous, the region now occupied by the Kaiparowits Plateau was located at a paleolatitude of about 41° N. (Irving, 1979; Beeson, 1984) on the western margin of the Western Interior Seaway (fig. 4). Shorelines were oriented approximately N.45°W. - S.45°E. (Peterson, 1969b; Shanley, 1991, Roberts and Kirschbaum, 1995) (fig. 4). Sediment deposited in the region of the Kaiparowits Plateau was supplied from the Sevier Highlands, located 100 miles to the west (Peterson, 1969a). Approximately 1,100-1,600 feet of strata were assigned to the Straight Cliffs Formation by Gregory and Moore (1931). The formation was initially mapped along the plateau's southern flank and divided into lower and middle members and an upper sandstone member (fig. 5). The middle member contains a minor coal zone (that includes a white sandstone marker bed), a major coal zone, and an upper barren zone (fig. 5).

Peterson (1969b) formally divided the Straight Cliffs Formation, in ascending order, into the Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank Members (table 2, fig. 5). Outcrops of the John Henry and Drip Tank Members are shown in figure 3. Peterson (1969a, b) interpreted the Tibbet Canyon and Smoky Hollow Members as a regressive stratigraphic succession, of middle to late Turonian age, consisting of shallow marine and beach deposits in the Tibbet Canyon Member and coal-bearing coastal plain strata and braided river deposits in the Smoky Hollow Member. Braided river deposits are contained in the Calico bed (fig. 5) located in the upper part of the member. Peterson (1969a, b) interpreted that the Calico bed was truncated by an unconformity (fig. 5) of late Turonian to early Coniacian age. However, the unconformity has not been recognized on the western flank of the plateau, and Shanley and

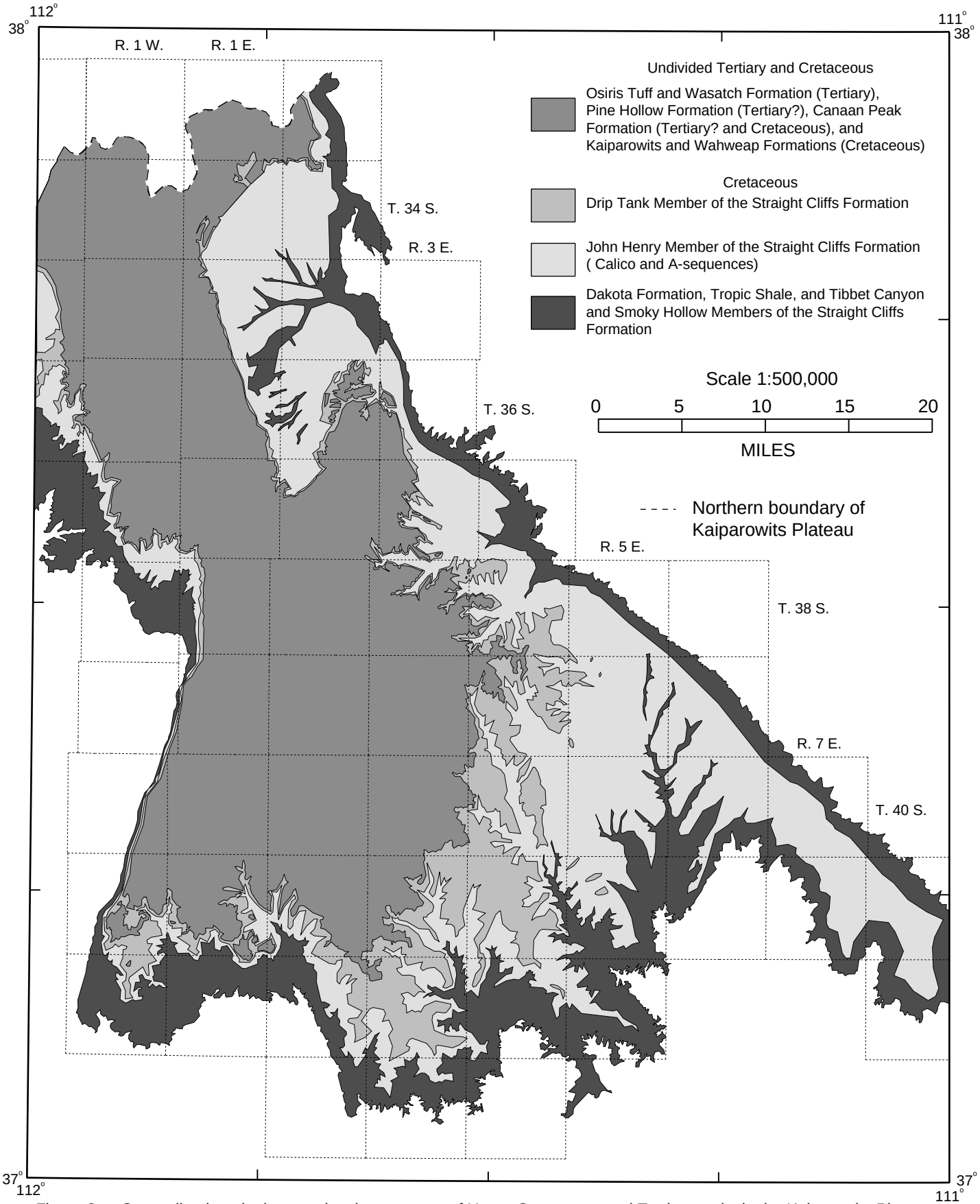

Figure 3. -- Generalized geologic map showing outcrops of Upper Cretaceous and Tertiary rocks in the Kaiparowits Plateau. At the mapped scale, outcrops of the John Henry Member of the Straight Cliffs Formation are nearly identical with outcrops of the Calico and A-sequences. Geologic map is modified from Sargent and Hansen (1982).

Table 3. Geologic publications regarding Upper Cretaceous and Tertiary strata in the Kaiparowits Plateau, Utah.

Formation	Authors of investigation and references
Wasatch, Pine Hollow, and Canaan Peak Fms.	Bowers (1972)
Kaiparowits Fm.	Lohrengel (1969)
Wahweap Fm.	Peterson (1969a), Eaton (1991)
Straight Cliffs Fm.	Peterson (1969a, b), Orlansky (1971), Doelling and Graham (1972), Vaninetti (1978), Johnson and Vaninetti (1982), Eaton (1991), Shanley (1991), Shanley and McCabe (1991), Shanley and others (1992), McCabe and Shanley (1992), Hettinger and others (1994), Hettinger (1995), Nichols (1995)
Tropic Shale and Dakota Fm.	Lawrence (1965), Peterson (1969a), May and Traverse (1973), Gustason (1989), Eaton (1991), Kirschbaum and McCabe (1992)

others (1992) have reinterpreted it as a ravinement surface cut by marine transgression. The John Henry Member is early Coniacian to late Santonian in age (Eaton, 1991) and consists of coal-bearing continental beds that grade eastward into a vertical stack of near-shore marine strata (Peterson, 1969a, b). Shoreface sandstones are named A through G (fig. 5) and are the dominant lithology along the Straight Cliffs escarpment. Continental strata within the John Henry Member contain coal in the lower, Christensen, Rees, and Alvey coal zones (fig. 5) as defined by Peterson (1969a, b). The Drip Tank Member is constrained to a late Santonian or early Campanian age (Eaton, 1991) and consists of sandstone that is interpreted to have been deposited in a fluvial environment (Peterson, 1969a, b).

The nomenclature of Peterson (1969b) has been applied to most areas mapped in the southern and eastern parts of the Kaiparowits Plateau. However, on the western flank of the plateau, the formation is simply divided and mapped into lower and upper parts (fig. 5). The lower part contains a basal marine sandstone (fig. 5) that is equivalent to the Tibbet Canyon Member, and a white marker sandstone (fig. 5) equivalent to the Calico bed. The upper part contains the Henderson coal zone (fig. 5) (defined by Robison, 1966) at its base and is capped by a thick massive sandstone (fig. 5) that is equivalent to the Drip Tank Member. Strata between the white marker sandstone and thick massive sandstone are equivalent to the John Henry Member. Correlations between the various units and members are shown in figure 5 and are based on Doelling and Graham (1972) and Bowers (1973c, 1975, 1983, 1993). In this report, all further references to the nomenclature of Peterson (1969b) include equivalent strata throughout the Kaiparowits Plateau.

Recent stratigraphic and sedimentological investigations by Shanley and McCabe (1991) have resulted in the identification of four unconformity-bounded sequences within the Straight Cliffs Formation. The unconformities are located in the Tibbet Canyon Member, near the base of the Calico bed, within the A-sandstone, and near the base of the Drip Tank Member. The unconformities are named the Tibbet, Calico, A-, and Drip Tank sequence boundaries, respectively, and each overlying sequence is named after its basal unconformity (figs. 5, 6). The sequence boundary unconformities are recognized by facies that have shifted abruptly basinward over regional surfaces of erosion. The basinward facies shifts are characterized by fluvial and estuarine strata juxtaposed over finer grained coastal plain and shoreface deposits (fig. 6) and are documented by Shanley (1991), Shanley and others (1992), and Hettinger and others (1994). Deposition in each sequence is interpreted to be controlled by fluctuations in base-level. Each sequence boundary unconformity is interpreted to have been cut during a fall in base-level, and each overlying sequence is deposited during a subsequent rise in base-level. During the initial stages of base-level rise, incised valleys are backfilled by fluvial, estuarine, and shoreface strata that are capped by a maximum marine flooding surface; these successively deepening upward successions are interpreted as transgressive systems tracts (TST) (fig. 6). Overlying aggradational and progradational deposits of marine, coal-bearing coastal plain, and alluvial strata are deposited during a slower rate of base-level rise and

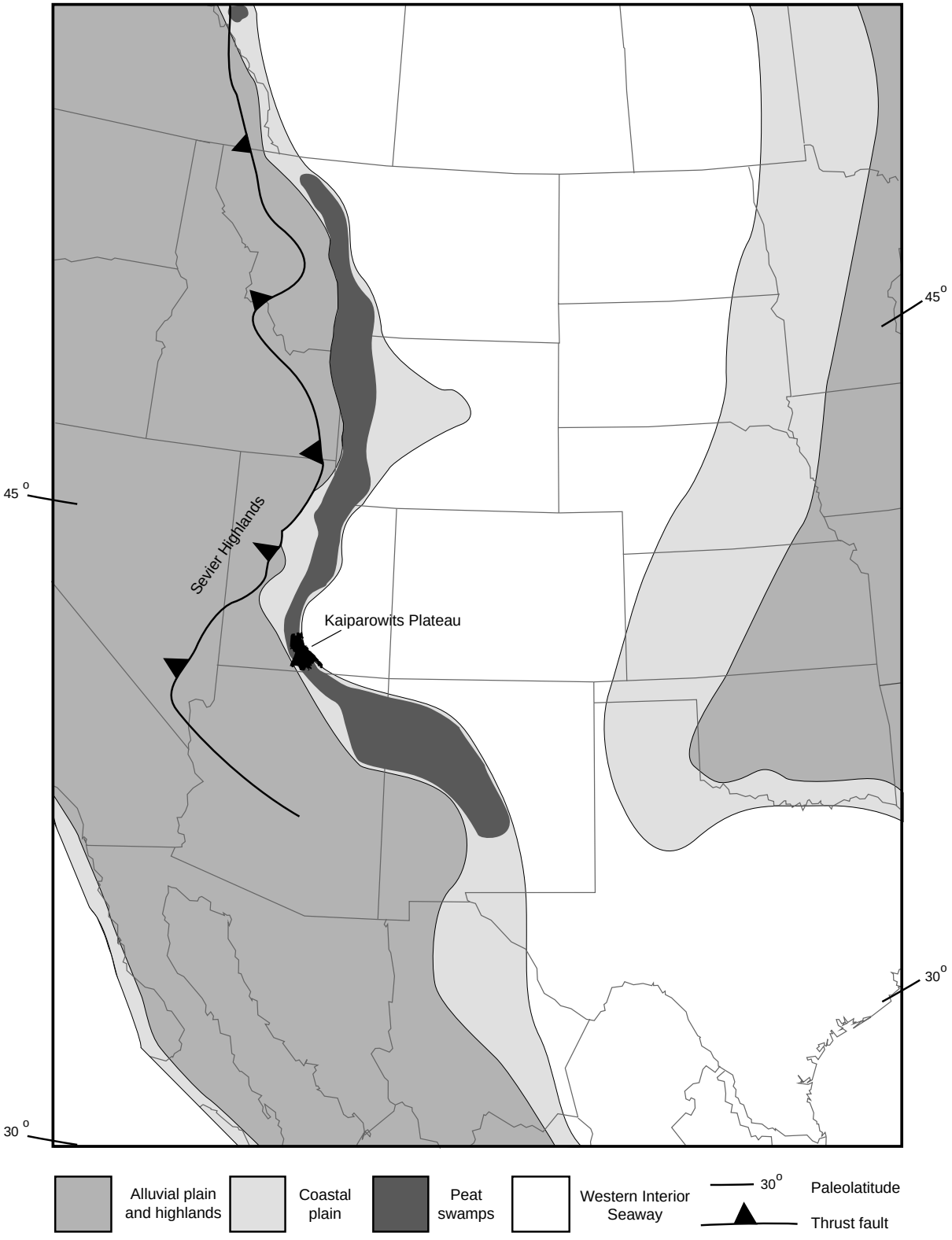

Figure 4. -- Paleogeographic map of the central part of North America during the Coniacian and Santonian Stages (88.5-83.5 ma.) of the Cretaceous Period. The Kaiparowits Plateau is shown in relation to shorelines, coastal plains, and peat swamps associated with the Western Interior Seaway; deposits from these depositional systems are preserved in the Straight Cliffs Formation. Map is modified from Roberts and Kirschbaum (1995).

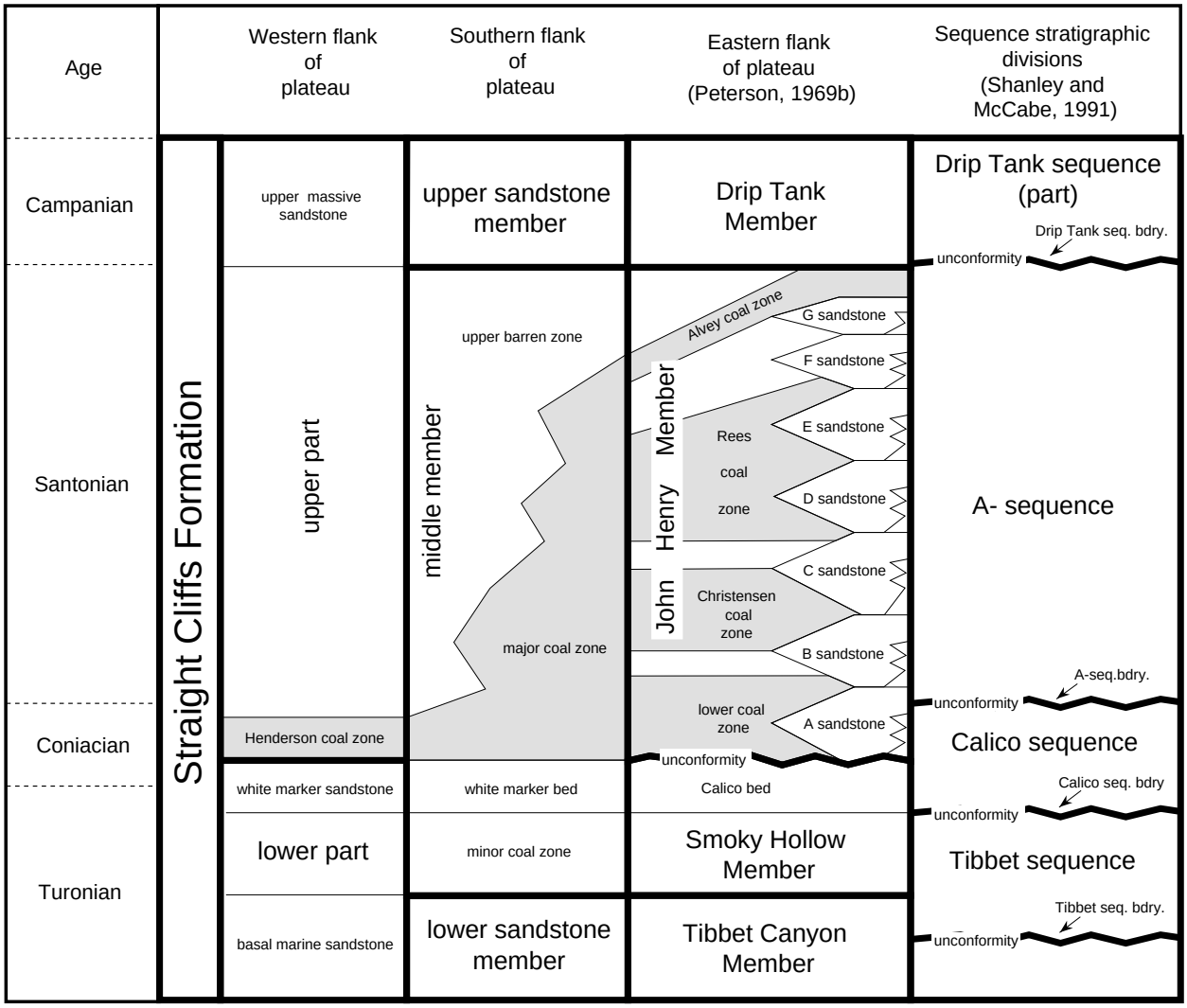

Figure 5. -- Stratigraphic divisions of the Straight Cliffs Formation used for mapping and stratigraphic studies in various parts of the Kaiparowits Plateau. Position of age boundaries are approximate.

are interpreted as highstand systems tracts (HST) (fig. 6).

The Calico and A-sequences contain all of the coal within the John Henry Member and upper part of the Smoky Hollow Member (figs. 5, 6). The Calico and Drip Tank sequence boundaries are easily recognized on geophysical logs and are useful correlative horizons throughout the plateau. Examples of geophysical log signatures and core descriptions for the Calico and A-sequences are given in figure 7. The Calico sequence boundary is recognized by a high natural gamma response (fig. 7) that is produced by a thick paleosol beneath the Calico bed (Hettinger, 1995). The Drip Tank sequence boundary is interpreted at or near the base of blocky log signatures (fig. 7) that are a response to thick sandstone in the basal part of the Drip Tank sequence (Hettinger, 1995). The logs and cores shown in figure 7 provide the basis for interpreted depths to the Calico and Drip Tank sequence boundaries that are given for other drill holes in the plateau in appendix 1. Down-hole depths to the Calico and Drip Tank sequence boundaries are used to construct isopach maps that portray the thickness and deformation of coal-bearing strata.

The Calico and A-sequences underlie an area of about 1,300 square miles within the Kaiparowits Plateau. Their lines of outcrop are nearly identical to those of the John Henry Member at the scale mapped in figure 3. The Calico and A-sequences have a combined thickness of approximately 600-1,600 feet (fig. 8); about 75-400 feet of strata are in the Calico sequence and 525-1,200 feet of strata are in the

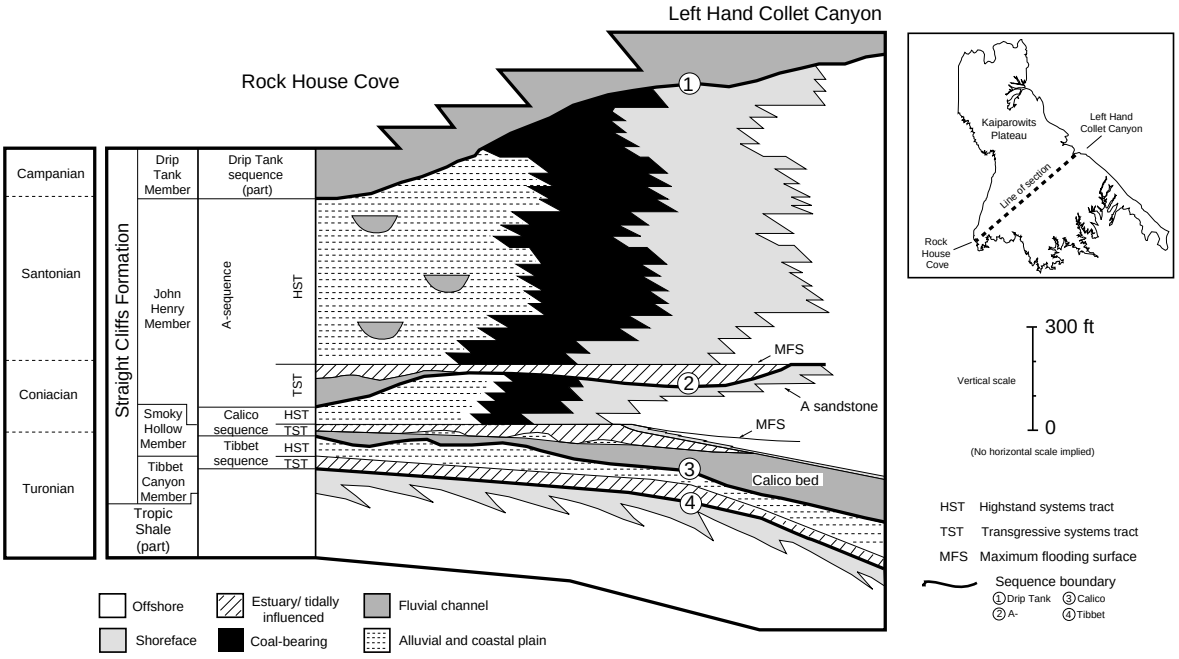

Figure 6. -- Sequence stratigraphic correlations and facies relationships in the Straight Cliffs Formation and upper part of the Tropic Shale. Line of section extends from Left Hand Collet Canyon to Rock House Cove (inset) and is perpendicular to paleoshorelines. Sequence stratigraphic divisions are compared to formal stratigraphic nomenclature. Diagram is modified from Shanley (1991). Position of age boundaries are approximate.

A-sequence. The combined sequences are 750-850 feet thick throughout much of the southwestern and south-central parts of the plateau and gradually thicken in the northern parts of the plateau. The sequences are thickest near the Straight Cliffs escarpment, where they contain thick aggradational stacks of shoreface sandstone and mudrock; conversely, the sequences are thinnest in the central part of the plateau, where they contain the greatest amount of mudrock and coal. These thickness variations were probably controlled, in part, by the differential compaction of sandstone, mudrock, and peat. Thicknesses of the Calico and A-sequences are based on interpretations of geophysical logs from 149 drill holes, 36 measured sections, and 7 control points listed in appendix 1. Thicknesses from measured sections are based on the stratigraphic interval between the base of the Calico bed and base of the Drip Tank Member. Thicknesses at the control points are based on general stratigraphic information published in geologic maps.

Structure

Strata within the Kaiparowits Plateau are inclined along numerous northerly trending folds that plunge into a deep central basin containing the Table Cliffs, Last Chance, and Coyote Creek-Billie Wash synclines (fig. 9). The northeastern flank of the central basin is defined by the westwardly dipping limb of the Dutton monocline, and its western flank is defined by eastwardly dipping limbs of the Johns Valley anticline and East Kaibab monocline (fig. 9). Strata are inclined by less than 6° throughout most of the plateau (fig. 9). However, beds dip as much as 25° along a westwardly dipping homocline near the town of Escalante, 30° on the eastern limb of the Johns Valley anticline, 45° along the Dutton monocline, and 80° along the East Kaibab monocline (fig. 9). Areas where strata are inclined 0° to 6°, 6° to 12°, 12° to 25°, and greater than 25° are also shown in figure 9 and are based on recorded strikes and dips in the field and structure contour lines published in geologic maps referenced in figure 2. Dips in the Posy Lake, Five Mile Valley, and Lower Coyote Spring quadrangles (fig. 2) are based on photographic interpretations by Detterman (1956), McQueen and Ray (1958), and McQueen (1958).

There are relatively few faults in the Kaiparowits Plateau; most are located around its peripheral areas (fig. 9) and displacements are generally insignificant related to the potential mining of the coal (Doelling and Graham, 1972). Faults having significant

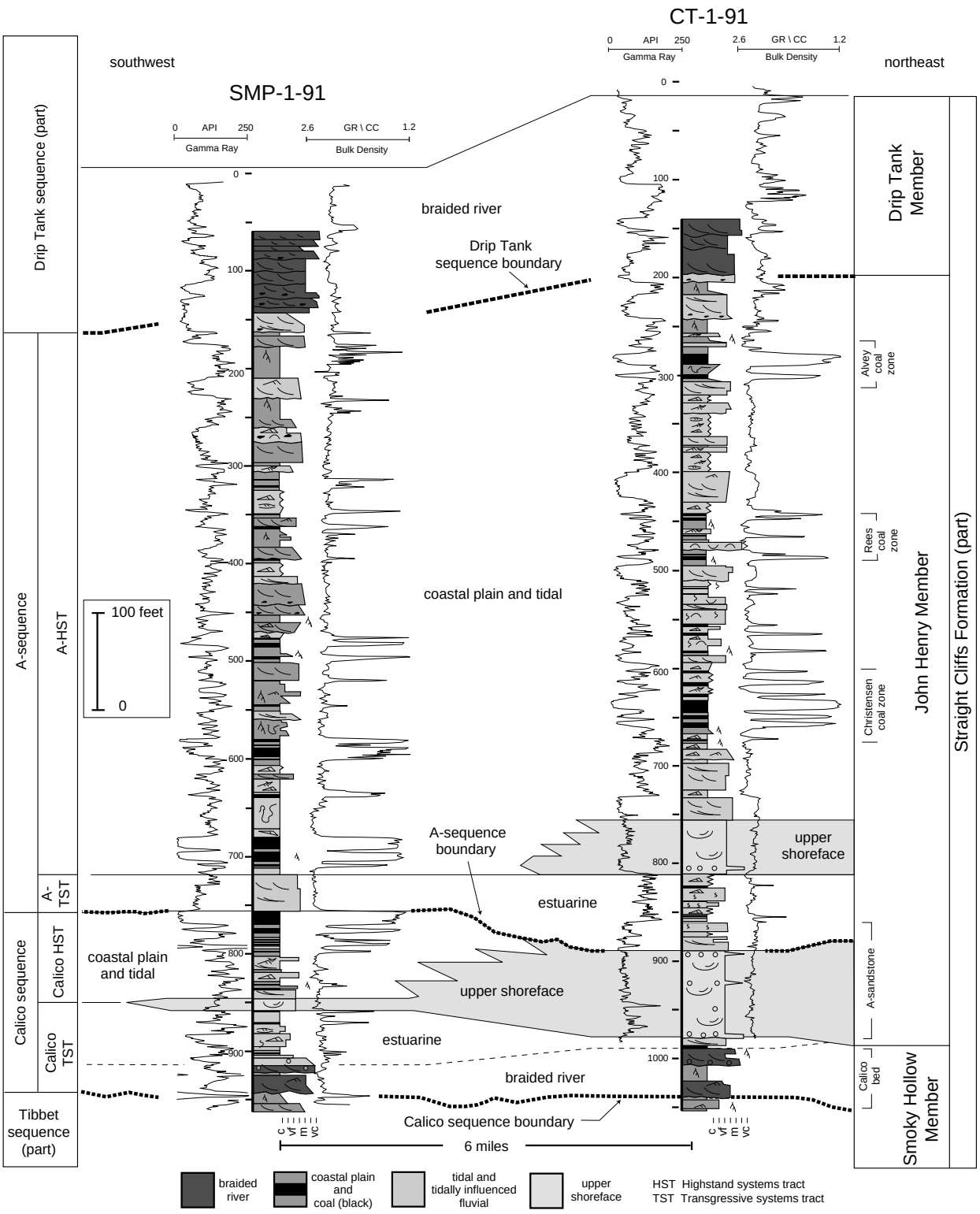

Figure 7. -- Responses of gamma ray and bulk density logs to lithologies in the Calico and A-sequences. Lithologies and geophysical logs are from cores CT-1-91 and SMP-1-91 (localities 5 and 6, respectively on plate 1). Explanations for grain size abbreviations (c, vf, m, vc) and symbols used for sedimentary structures are given on plate 1. Diagram is modified from Hettinger (1995).

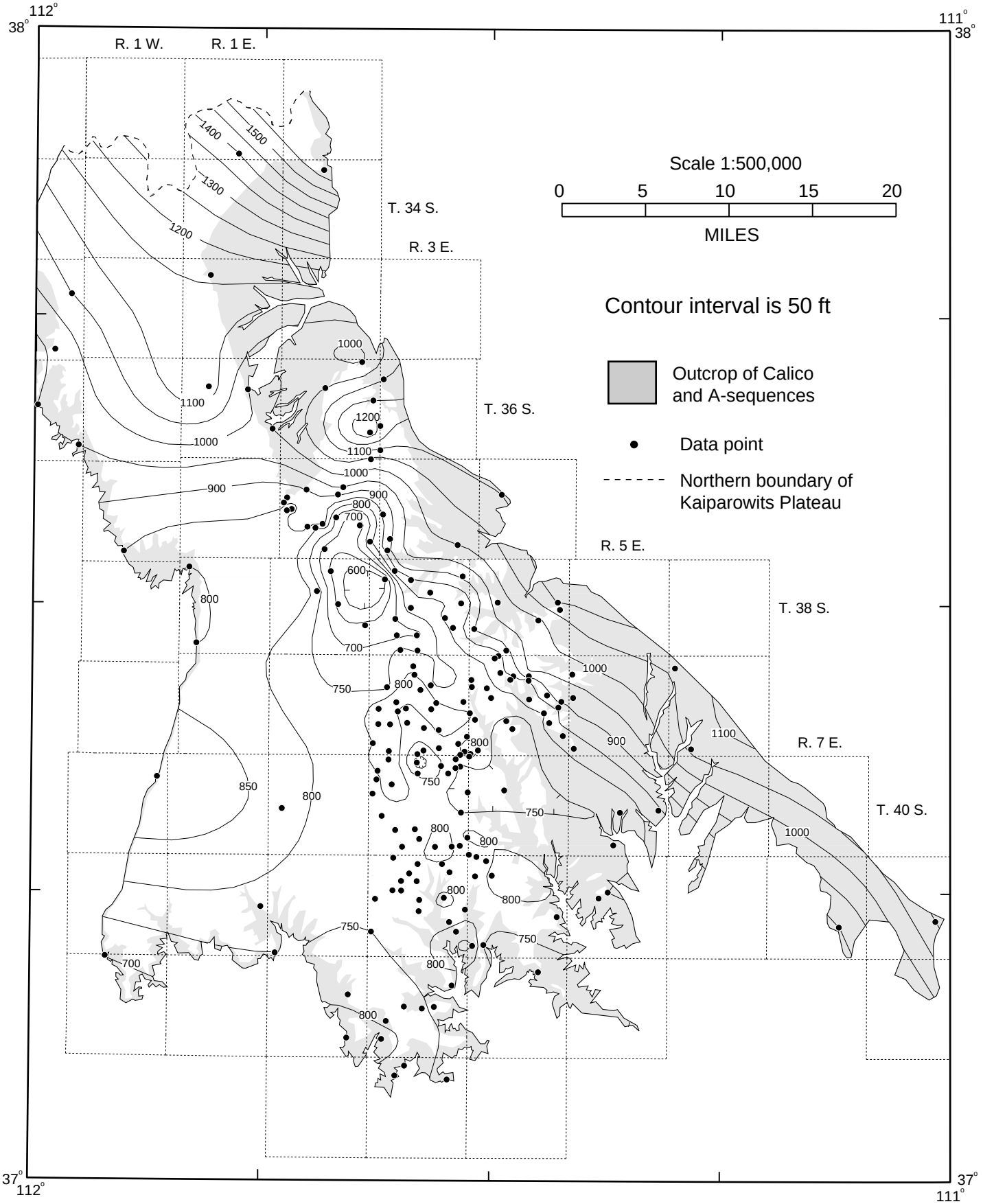

Figure 8. -- Isopach map showing the combined thickness of the Calico and A-sequences. Thicknesses are based on 192 data points. Data points are identified on figure A of plate 1 and the thickness of the combined sequences at each data point is given in appendix 1.

displacement include the northeast-trending Paunsaugunt fault and the bounding faults of the Jake Hollow graben, located along the plateau's northern margin (fig. 9). The Paunsaugunt fault has as much as 2,000 feet of displacement and truncates all coal-bearing strata along the northwestern flank of the plateau (Doelling and Graham, 1972). The Jake-Hollow graben extends about 6 miles, is 0.5-1.0 mile wide, and has as much as 500 feet of displacement (Bowers, 1973b). Northeast-trending faults on the west-central flank of the plateau near Henrieville (fig. 9) have a strong right-lateral strike-slip component and 200-250 feet of vertical displacement (Bowers, 1983). Further south, the East Kaibab monocline is cut by numerous southeast-trending faults (fig. 9) that have only minor displacement (Bowers, 1983, 1993). The southern margin of the plateau contains several additional northwest-trending faults that extend less than 10 miles and have less than 50 feet of displacement (Peterson, 1967; Waldrop and Sutton, 1967a; Zeller, 1990a).

Deformation of coal-bearing strata in the Calico and A-sequences is shown on a structure contour map of the Calico sequence boundary (fig. 10). The sequence boundary is 4,500-9,000 feet above sea level on outcrop and 2,000 feet above sea level in the Table Cliffs syncline (fig. 9). The structure contour map reflects most of the major folds shown in figure 9 and indicates that the folds are not related to compaction of coal-bearing strata. The map is based on measured elevations of the sequence boundary at 64 drill sites, estimated elevations at 102 drill sites (appendix 1), and subcrop elevations inferred at 50-100 feet below the mapped base of the John Henry Member around the entire perimeter of the plateau. Estimated elevations of the Calico sequence boundary at drill sites are made where drilling was terminated less than a few hundred feet above the sequence boundary and are based on correlations to nearby drill holes where the sequence boundary was penetrated.

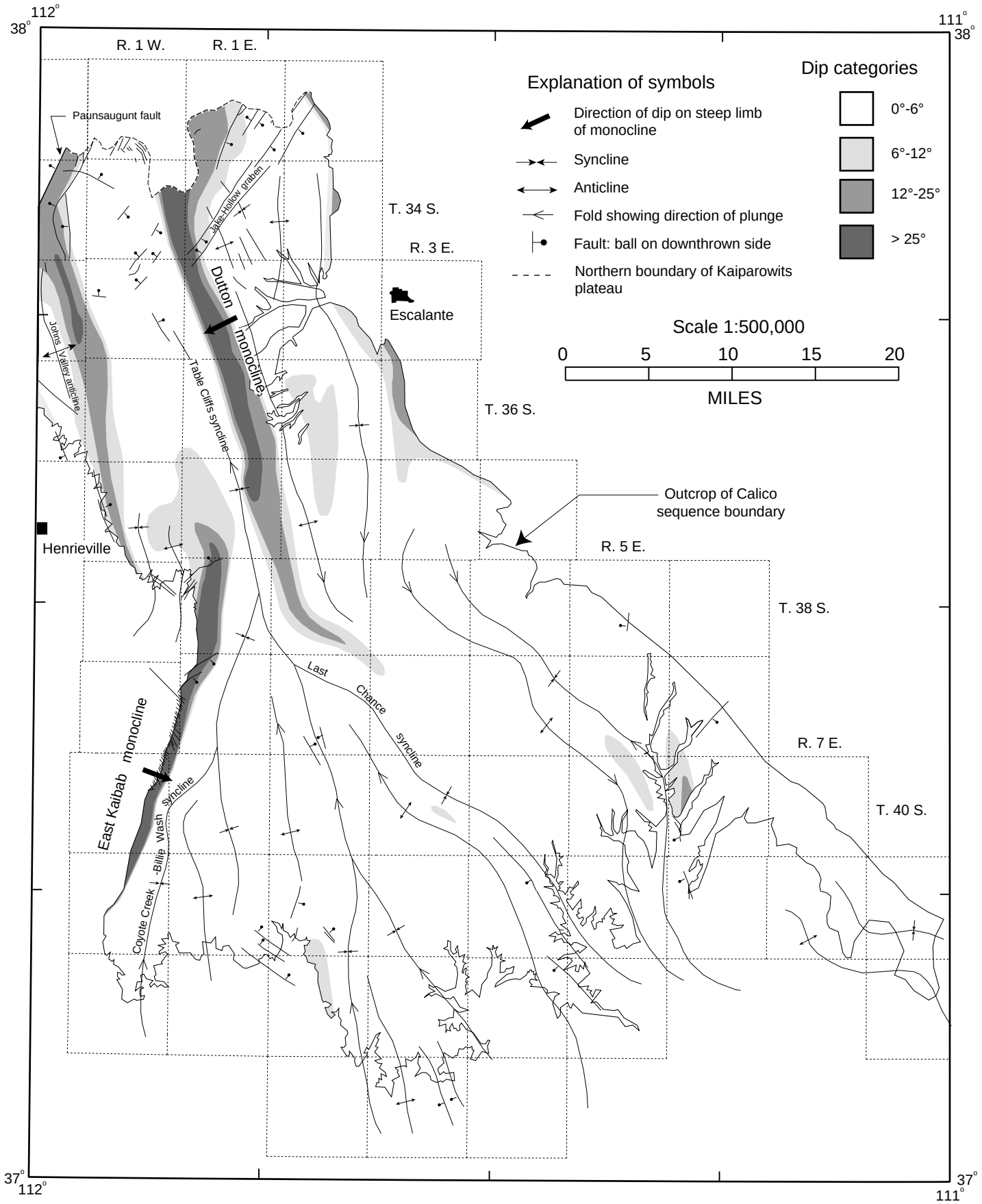

Figure 9. -- Structural features and inclination of strata within the Kaiparowits Plateau. Inclinations of strata are based on geologic mapping referenced in figure 2 are shown in categories that range from 0°- 6°, 6°- 12°, 12°- 25°, and > 25°. Fold axes and faults are from Sargent and Hansen (1982).

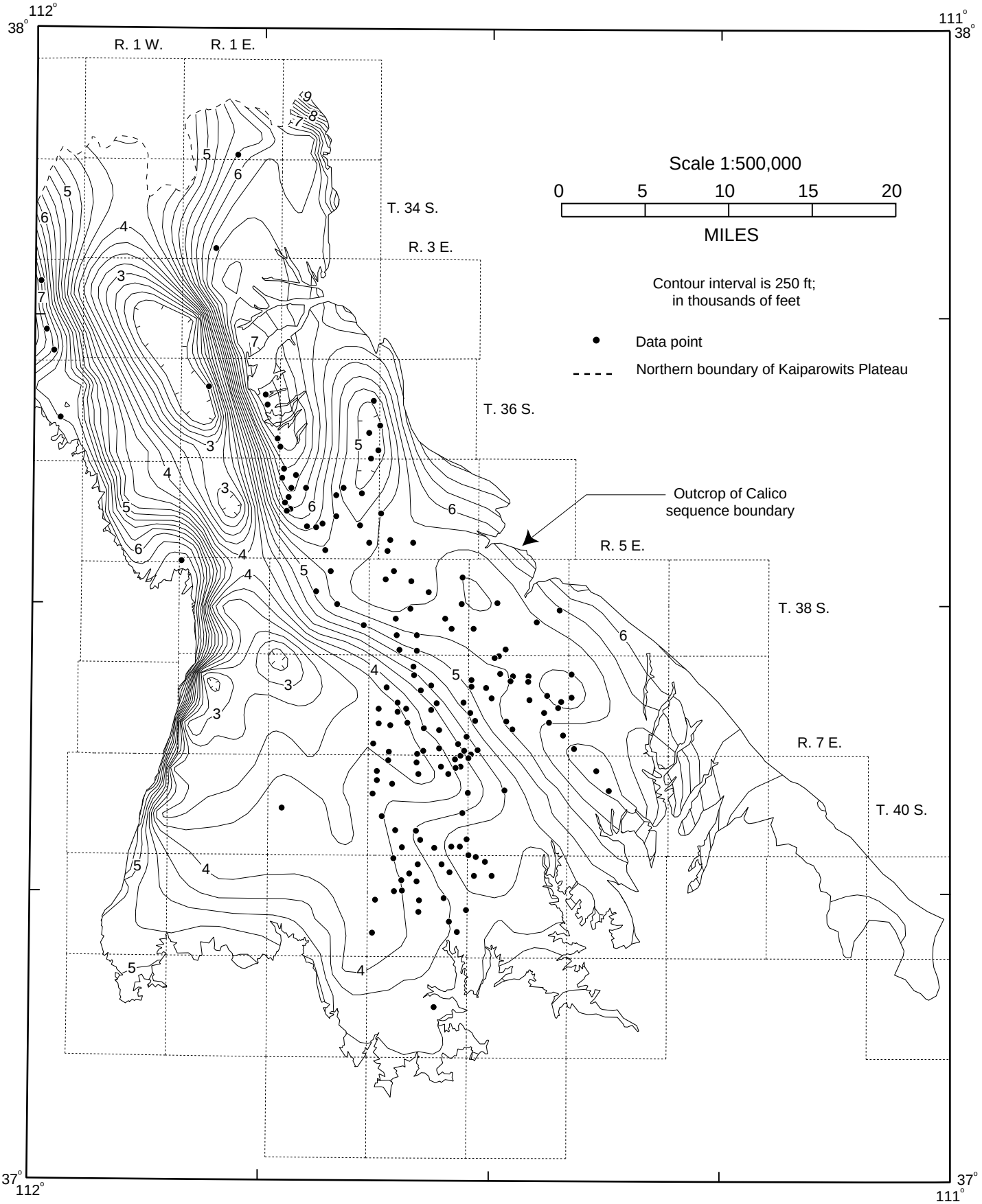

Figure 10. -- Structure contour map of the Calico sequence boundary. Sequence boundary elevations are based on 166 drill sites. The Calico sequence boundary occurs from 50-100 ft below the John Henry Member, therefore an inferred elevation of the sequence boundary was used at numerous locations along the outcrop where the John Henry Member was mapped. Data points are identified on figure A of plate 1 and sequence boundary elevations are provided in appendix 1.