COAL DISTRIBUTION, QUALITY, AND RESOURCES IN THE CALICO AND A-SEQUENCES

The Calico and A-sequences (figs. 5, 6) contain coal in the Henderson coal zone, the lower coal zone, and the Christensen, Rees, and Alvey coal zones. The Henderson and lower coal zones are in the Calico sequence, and the Christensen, Rees, and Alvey coal zones are in the A-sequence (fig. 5). We describe these coals in sequence stratigraphic context because, unlike formational contacts of the John Henry Member, the Calico and Drip Tank sequence boundaries provide excellent marker horizons that can be traced on geophysical logs throughout the plateau.

Coal distribution

Coal-bearing strata in the Calico and A-sequences extend as much as 60 miles from north to south and 30 miles from east to west across the plateau. Outcrop investigations reveal that coal is within distinct zones along the peripheral areas of the plateau. On the eastern flank of the plateau, the coal-bearing interval is 500-700 feet thick. Coals are in the lower coal zone, and the Christensen, Rees, and Alvey coal zones that intertongue with, and pinch out eastward into, thick deposits of shoreface strata in the A-sequence (fig. 5). The coal-bearing interval thins to less than 50 feet on the plateau's western flank where the only coals are within the Henderson zone (fig. 5) in the Calico sequence. Southwestward thinning of coal-bearing strata is seen in outcrops on the plateau's southern flank. The full extent of the coal-bearing interval is revealed only by drill-hole data collected from the plateau's interior region where the net coal accumulation is greatest. These data show that the distinct coal zones located along the peripheral areas of the plateau tend to merge and lose their identity in the subsurface of the plateau's interior. The following paragraphs provide a summary of coal distribution based on outcrop investigations and a detailed analysis of their distribution in the subsurface.

Coal distribution in outcrops

Outcrop investigations cited in figure 2 provide maps and measurements for coal beds within several distinct coal zones located along the peripheral margins of the plateau. Published coal thickness data from outcrops are summarized for each 7.5' quadrangle in appendix 3. In general, coal beds in the Kaiparowits Plateau have been reported to split and pinch out rapidly on outcrop and are difficult to trace because they are commonly burned and covered by slope wash and talus. Coals are extensively burned, and are still burning, in parts of the East of Navajo, Needle Eye Point, Smoky Hollow, and Sit Down Bench quadrangles (fig. 2). Baked rocks in these areas may extend more than 200-300 feet into the subsurface (Peterson and Horton, 1966; Peterson, 1967). The Henderson zone is 5-50 feet thick on outcrop and contains as much as 29 feet of coal on the northwestern flank of the plateau in the Pine Lake quadrangle (fig. 2). Coals in the Henderson zone thin to the south and pinch out completely on the southwestern flank of the plateau in the Horse Flat quadrangle (fig. 2). The lower zone is exposed only on the southern flank of the plateau, where it is as much as 40 feet thick and contains as many as four beds of coal that are 1-7 feet thick. The lower zone is split by the A-sandstone and the upper split is exposed in the East of Navajo and Needle Eye Point quadrangles (fig. 2). Outcrops of the Christensen zone are 70-130 feet thick and contain as many as six beds of coal that are 1-30 feet thick. The Rees zone is 70-200 feet thick in outcrops and contains as many as seven beds of coal that are 1-20 feet thick. Outcrops of the Alvey zone are 40-160 feet thick and have as many as eight beds of coal that are 1- 20 feet thick. These collective coal zones contain as much as 70 feet of net coal in outcrops located in the Sit Down Bench and Smoky Hollow quadrangles (fig. 2); the coal beds thin to the west and less than 3 feet of coal remains in the Nipple Butte quadrangle (fig. 2).

Coal distribution in the subsurface

A broad three-dimensional view of coal distribution throughout the subsurface of the Kaiparowits Plateau is demonstrated in three correlation diagrams shown on plate 1 (figs. C, D, and E) and a net coal isopach map shown in figure 11. The geographic distribution of net coal in the Calico and A-sequences (fig. 11) is based on coal measurements from 158 drill holes and 45 measured sections listed in appendix 1. Cross sections A-A' and B-B' are oriented perpendicular to paleoshorelines; A-A' extends 25 miles northeast from Tibbet Canyon to Left Hand Collet Canyon (fig. B on pl. 1). Cross section B-B' extends 11 miles northeast from the plateau's interior region to Alvey Wash (fig. B on pl. 1). Cross section C-C' is oriented nearly parallel to paleoshorelines; it is located 9-12 miles southwest of the Straight Cliffs escarpment and extends a distance of 19 miles (fig. B on pl. 1). Stratigraphic control for the cross sections is provided by measured sections at Alvey Wash (map number 177), Left Hand Collet Canyon (map number 196), and Tibbet Canyon (map number 211) and by core collected from CT-1-91 and SMP-1-91 (map numbers 5 and 6, respectively); map numbers are shown on plate 1 (fig. A). The measured section at Alvey Wash was published by Zeller (1973d), measured sections at Left Hand Collet Canyon were published by Peterson (1969a) and Shanley (1991), and the measured section at Tibbet Canyon was published by Shanley (1991). Cores CT-1-91 and SMP-1-91 are described in Hettinger (1995).

The net coal isopach map (fig. 11) and cross sections (figs. C, D, E on pl. 1) demonstrate that variations in net coal accumulation in the Calico and A-sequences are related to the distance from the paleoshorelines that the original peat accumulated. Along the Straight Cliffs escarpment, highstand deposits of both sequences are dominated by shoreface sandstone and mudrock and contain only minor beds of coal. As viewed along depositional dip in cross sections A-A' and B-B', thick coals are located immediately landward (southwest) of the shoreface sandstone pinch-outs. Shoreface sandstones in the Calico sequence extend about 15 miles southwest into the plateau's interior region, and thick beds of coal are not found in the Calico sequence along the eastern part of the plateau. In contrast, aggradational stacks of shoreface sandstone in the A-sequence pinch out within 1-7 miles of the escarpment. Measured sections in Alvey Wash (Zeller, 1973d) and Left Hand Collet Canyon (Shanley, 1991) show that within 2.5 miles of the escarpment the A-sequence contains about 30 feet of net coal in the Christensen, Rees, and Alvey coal zones. The coal zones are separated by thick clastic wedges consisting of shoreface sandstone. These clastic wedges thin and change facies to the southwest; their thinning is accompanied by an increase in net coal. Eventually, the coal zones merge and their boundaries become indistinct. A drill-hole core collected 5 miles from the escarpment at CT-1-91 reveals that the A-sequence contains 61 feet of net coal in beds that are as much as 11 feet thick (Hettinger, 1995); clastic strata in the A-sequence are dominantly tidal and coastal plain in origin and include some shoreface deposits.

Areas where net coal accumulations exceed 100 feet are located approximately 8-15 miles southwest of the Straight Cliffs escarpment (fig. 11) and are viewed along depositional strike in cross section C-C'. As much as 160 feet of net coal is contained in a 500-600 foot thick interval and coal beds are as much as 59 feet thick. Net coal accumulations of 150-160 feet have been drilled at map localities 8, 9, 12, 13, 101, and 108 (fig. A on pl. 1), which are located about 10-12 miles southwest of the escarpment. Core SMP-1-91 shows that these areas contain thick coal beds in both the Calico and A-sequences; clastic strata are mostly tidal and fluvial in origin, although some shoreface deposits remain in the Calico sequence (Hettinger, 1995). Coal beds in areas of maximum accumulation are concentrated in pods that extend laterally for about 1-3 miles. The pods eventually split into distinct coal zones that can be traced for several miles. Examples of pods are seen at locality 13 (B-B', C-C') between the depths of 1,595 and 1,670 feet and at locality 22 (B-B') between the depths of 1,315 and 1,472 feet. Within the areas of overall thick coal accumulation, several localities have a relative paucity of coal; as little as 70 feet of net coal was drilled at localities 15, 87, 94, and 152 (fig. A on pl. 1). Geophysical logs from these localities show a marked increase in sandstone as compared to nearby areas, and coal correlations are tentative. Although not proven, these areas may represent localities of northeast-flowing paleofluvial systems.

The net coal isopach map (fig. 11) and cross section A-A' (fig. C on pl. 1) show that net coal accumulations and coal bed thicknesses decrease southwest of the areas of maximum accumulation. A measured section described in Tibbet Canyon, located 22 miles southwest of the Straight Cliffs escarpment, shows that the A-sequence contains about 20 feet of net coal in beds that are all less than 3 feet thick, and only a few minor beds of coal remain in the Calico sequence (Shanley, 1991). The measured section also reveals that clastic deposits of both sequences are predominantly alluvial and, to a lesser degree, tidally influenced in origin (Shanley, 1991). Still further southwest at Rock House Cove (fig. B on pl. 1), both highstand deposits are entirely alluvial in origin and contain no coal (Shanley, 1991).

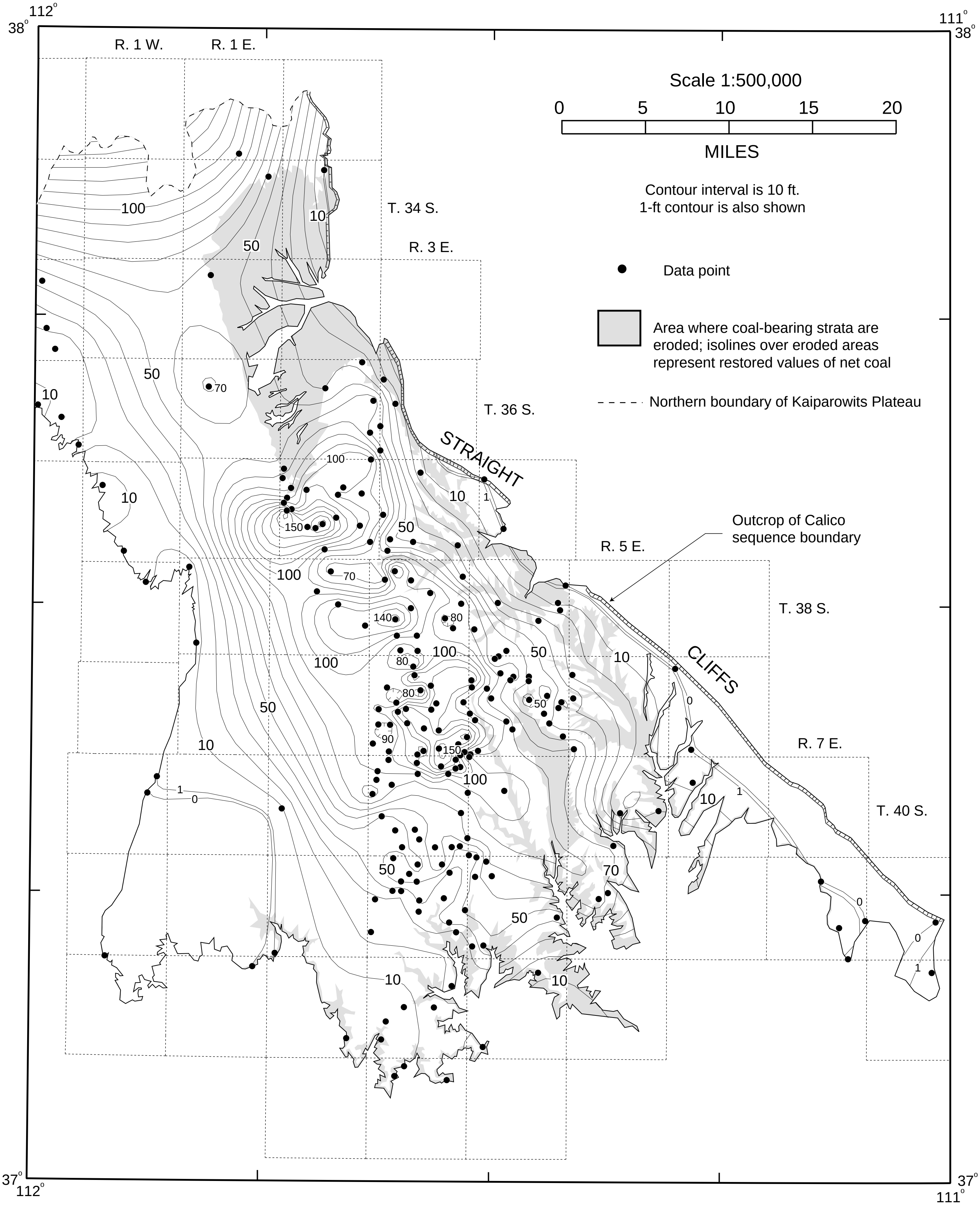

Figure 11. -- Isopach map of net coal in the Calico and A-sequences. Net coal values represent all coal beds that are more than 1 foot thick and are determined from 209 data points listed in appendix 1; data points are identified on figure A of plate 1. Isolines over areas where coal-bearing strata are eroded (gray stipple) represent restored values.

The profile of net coal distribution in the Calico and A-sequences is shown by two graphs (fig. 12). Graph A-A' (fig. 12*A*) is constructed along depositional dip using the same drill-hole data shown in cross section A-A' (fig. C on pl. 1), and graph C-C' (fig. 12*B*) is constructed along depositional strike using the same drill-hole data shown in cross section C-C' (fig. E on pl. 1). The vertical axis in each graph shows the net coal accumulation recorded at drill holes along the line of section, and the horizontal axis records the distance between drill holes. Both graphs also show net coal accumulations within bed thickness categories of 1-3.4, 3.5-14.0, and greater than 14.0 feet; bed thicknesses are based on data provided in appendix 1. Graph A-A' shows that coal distribution, as viewed along depositional strike, takes on the shape of a bell curve, in which thin coal beds and net coal accumulations of less than 20 feet are located along the flanks of the curve and thick coal beds and maximum coal accumulations of as much as 150 feet occupy the center of the curve. Graph C-C' shows that along depositional strike, areas of thick coal accumulation take on the shape of a more sinuous curve, in that three distinct areas having thick coal beds and net coal accumulations of 120-160 feet are separated by two areas where net coal accumulations are only 60-70 feet and thick beds are absent.

Coal quality

Coals in the Kaiparowits Plateau are reported to be subbituminous C to high-volatile bituminous A in rank (Doelling and Graham, 1972, p. 93). Proximate and ultimate analyses are provided from about 100 coal samples collected from abandoned mines and outcrops located throughout the plateau (Doelling and Graham (1972, p. 123-127). Analyses of coal from core DH-1 are also provided by Doelling and Graham (1972, p. 126) (information by Bowers (1973c) indicates that DH-1 is located 150 feet northwest of map number 151 (fig. A on pl. 1) in T. 35 S., R. 2 W.). Additional quality data are reported for coals collected from three cores (K-1-DR, CT-1-91, and SMP-1-91) drilled by the U.S. Geological Survey; the cores are collected from localities 4, 5, and 6 , respectively (fig. A on pl. 1). Proximate and ultimate analyses of samples collected from K-1-DR are reported by Zeller (1979) and Affolter and Hatch (1980); analyses of samples collected from CT-1-91 and SMP-1-91 are provided by Brenda Pierce (U.S. Geological Survey, unpub. data, 1996).

Ranges in values for proximate and ultimate analyses, as well as moist, mineral-matter-free BTU/lb and apparent rank, are reported in table 4 for coal collected from cores. We have also determined arithmetic means from proximate and ultimate analyses reported in Doelling and Graham (1972, p. 123-127) for samples collected from mines and outcrops. Arithmetic means and apparent ranks calculated from these average values are reported in table 5; the range of proximate and ultimate values is summarized in appendix 3. Apparent ranks determined from samples collected from cores range from subbituminous B to high-volatile A bituminous coal (table 4). The apparent rank of samples collected from outcrops and mines (as determined from average values of proximate and ultimate analyses) ranges from subbituminous B to high-volatile C bituminous coal (table 5).

Coal Resources

The Kaiparowits Plateau contains an estimated original coal resource of 62.3 billion short tons (table 6) within the Calico and A-sequences. That original coal resource includes all coal beds that are greater than 1 foot thick, as deep as 8500 feet, and within an 850 square mile area where the entire coal-bearing interval is preserved (fig. 11). Coal tonnages are calculated using the methodology of Wood and others (1983) and are determined by multiplying the estimated volume of coal by its average density. The volume of coal in the Calico and A-sequences is a product of its net thickness and its areal extent as shown in figure 11. The average density of bituminous coal is 1,800 short tons per acre-foot (Wood and others, 1983, p. 22). An average bituminous rank is assumed for coal in the Calico and A-sequences, based on analyses from mines and cores summarized in tables 4 and 5 and appendix 3. The original resource area shown in figure 11 contains most areas where State and Federal coal leases and Federal coal prospect permits were issued prior to 1972, as shown in Doelling and Graham (1972, p. 100-101). Doelling and Graham (1972, p. 106) reported that underground mining is the most likely method for extracting coal in the plateau, and although all localities within the reported resource area would have to be mined by underground methods, much of the coal is too deep or too thin to be economically mined in the foreseeable future.

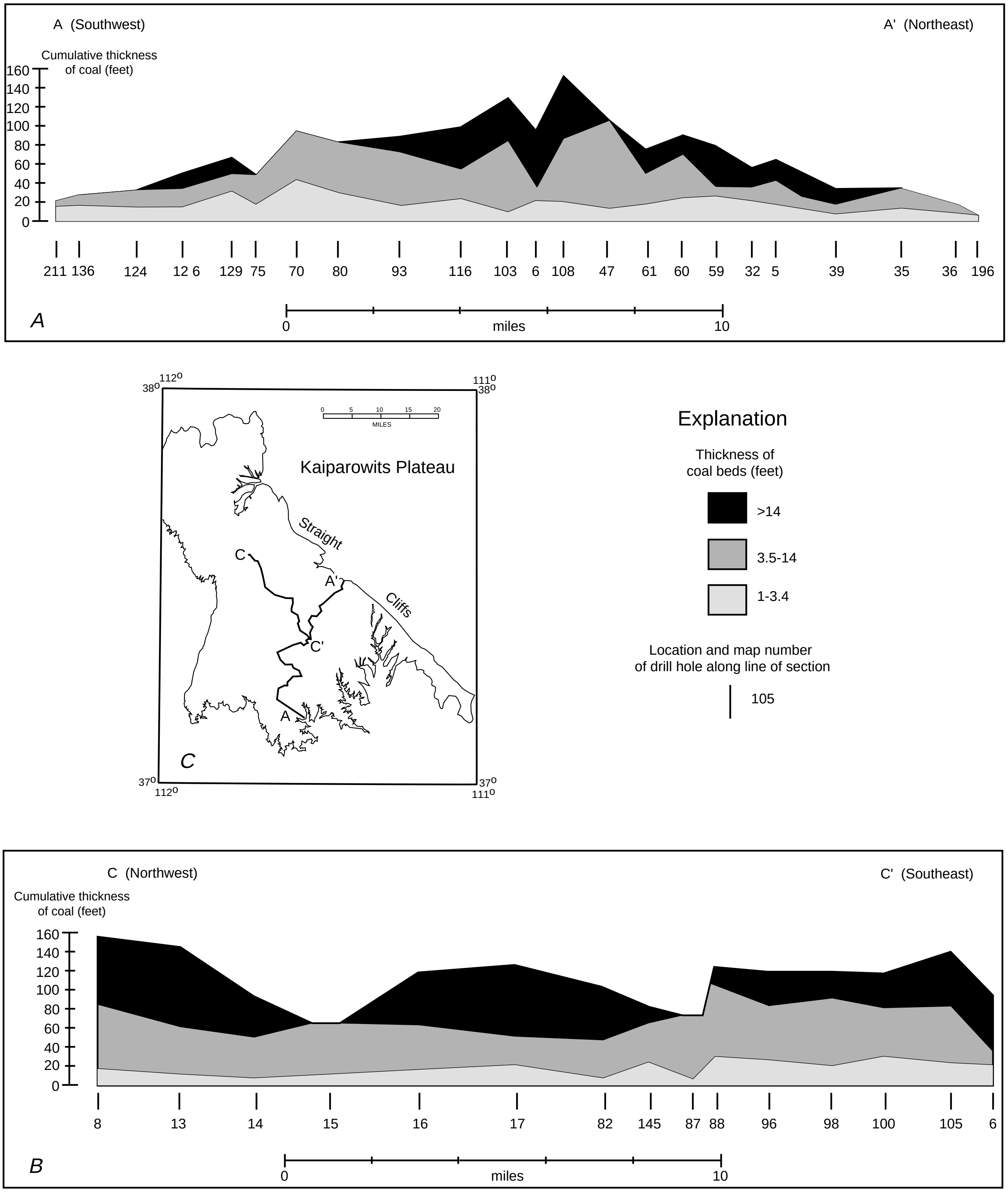

Figure 12. -- Coal distribution in the Calico and A-sequences. *A*, shows coal distribution along A-A', which trends perpendicular to the paleoshorelines. *B*, shows coal distribution along C-C', which trends parallel to the paleoshorelines. Horizontal axes show distance between drill holes; vertical axes show the cumulative coal thicknesses for beds that range from 1-3.4, 3.5-14.0, and greater than 14 feet thick. *C*, shows the locations of A-A' and C-C'; stratigraphic correlations are shown in figures C and E of plate 1. Drill hole locations are shown on figure A of plate 1; coal bed thicknesses are listed in appendix 1.

Table 4. Coal quality summary for samples collected from cores of the Calico and A-sequences in the Kaiparowits Plateau, Utah. Coal zone queried where uncertain. Apparent rank calculated using the Parr formula (American Society for Testing and Materials, 1995).

Coal zone	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Sulfur %	Heating value Btu/lb	Moist-, Mineral-Matter-Free Heating value Btu/lb	Apparent Rank
Coals sampled from core K-DR-1 (map no. 4, figure A on plate 1)								
Alvey (2 samples)	19.7-20.4	34.7-35.1	37.0-37.7	7.2-8.2	1.0	9,440-9,510	10,240-10,440	Subbituminous B
Rees (3 samples)	15.6-18.4	29.6-35.0	29.9-36.3	10.3-24.9	0.6-0.7	7,640-9,280	10,450-10,460	Subbituminous B
Christensen (3 samples	19.7-21.1	33.3-34.7	39.8-40.9	4.4-5.8	0.5-0.6	9,830-9,860	10,320-10,520	Subbituminous A and B
Coals sampled from core SMP-1-91 (map no. 6, figure A on plate 1)								
Rees ? (6 samples)	8.2-9.7	41.7-43.9	41.8-44.7	2.7-8.2	0.4-0.7	11,488-12,381	12,390-12,760	High volatile C Bituminous
Rees (17 samples)	0.7-7.8	27.9-50.7	24.9-45.4	4.3-42.5	0.5-2.3	6,962-12,387	12,700-13,710	High volatile B and C Bituminous
Christensen (13 samples)	5.5-7.9	35.3-44.5	34.6-48.0	2.3-24.7	0.3-1.0	9,464-12,477	12,360-13,590	High volatile B and C Bituminous
lower (15 samples)	4.5-7.1	35.4-46.5	32.1-45.5	3.5-26.4	0.4-2.3	9,002-12,620	12,610-16,720	High volatile A, B, and C Bituminous
Coals sampled from core CT-1-91 (map no. 5, figure A on plate 1)								
Christensen (23 samples)	8.5-15.5	34.5-41.1	34.8-4.6	3.7-17.6	0.4-2.2	9717-11721	11,110-12,590	Subbituminous A to High volatile C Bituminous
Coals sampled from core DH-1 (150 ft northeast of map no. 151, figure A on plate 1)								
Henderson (5 samples)	9.4-18.9	32.4-38.2	26.4-35.6	8.4-29.9	NR	9,740-10,300	11,010-11,350	Subbituminous A

Additional coal resources underlie the Kaiparowits Plateau's eastern and southern flanks where the coal-bearing interval is partially eroded. The eroded areas are shown in gray stipple in figure 11. Coal resources were not calculated in these areas because the resources would have to be determined from individual beds based on their outcrop geometry and thicknesses. Unfortunately, most coals in these areas are mapped in zones rather than individual beds, and recorded coal thickness cannot be applied to specific coal beds. In addition, the zones are commonly burned and covered by slope wash over large outcrop areas, making resource determinations difficult if not impossible. However, coal tonnage estimates have been made previously for many of the 7.5' quadrangles that contain the eroded areas, and these estimates are reported in appendix 3.

The original resource is reported in identified and hypothetical reliability categories that are based on the distance that the resource is calculated from a data point. Identified resources are located within a 3-mile radius of a data point and hypothetical resources are located beyond a 3-mile radius from a data point (Wood and others, 1983). Although confidence levels have not been established for these reliability categories, they reflect decreased levels of

Table 5. Coal quality summary for samples collected from mines and outcrops within the Calico and A-sequences in the Kaiparowits Plateau, Utah. Arithmetic means are reported for moisture, volatile matter, fixed carbon, ash, sulfur, and heating value and are based on proximate and ultimate analyses from about 100 samples reported in Doelling and Graham (1972, p. 123-127). Moist- and mineral-matter-free heating values and apparent ranks are determined from these average values. Apparent rank calculated using the Parr formula (American Society for Testing and Materials, 1995).

Coals collected from mines								
Coal zone	**Moisture %**	**Volatile Matter %**	**Fixed Carbon %**	**Ash %**	**Sulfur %**	**Heating value Btu/lb**	**Moist-, Mineral-Matter-Free Heating Value Btu/lb**	**Apparent Rank**
Alvey	16.4	38.4	38.0	7.3	0.6	9,350	10,150	Subbituminous B
Rees	5.0	41.4	48.7	5.0	0.7	11,600	12,270	High volatile C Bituminous
Christensen	6.7	39.2	44.2	7.3	2.1	11,600	12,640	High volatile C Bituminous
Henderson	18.7	39.1	36.5	8.6	1.0	9,260	10,210	Subbituminous B
Coals collected from outcrops								
Coal zone	**Moisture %**	**Volatile Matter %**	**Fixed Carbon %**	**Ash %**	**Sulfur %**	**Heating value Btu/lb**	**Moist-, Mineral-Matter-Free Heating Value Btu/lb**	**Apparent Rank**
Alvey	11.3	40.2	41.7	6.6	0.9	10,310	11,110	Subbituminous A
Rees	10.3	41.0	39.3	9.2	1.1	9,250	10,280	Subbituminous B
Christensen	10.9	38.8	43.1	7.2	0.9	10,390	11,280	Subbituminous A
Henderson	20.5	36.1	37.1	8.3	0.9	9,000	9,890	Subbituminous B

accuracy for calculated resources based on their distance from a data point. Approximately 47.2 billion short tons of coal (76 percent of the original resource) is calculated for areas located less than 3 miles from a data point and is therefore considered to be an identified resource (table 6). About 15.1 billion short tons of coal (24 percent of the original resource) is calculated for areas that are located more than 3 miles from a data point and are considered to be a hypothetical resource (table 6). Identified and hypothetical resource areas are shown in figure 13 and are based on the distribution of 209 coal data points; the hypothetical resources areas generally reflect where coal measurements are lacking because coals are either thin or deeply buried.

Coal resources were reported for areas in the Kaiparowits Plateau where coal is owned by the Federal Government, as well as for areas that underlie Kane and Garfield Counties and for each 7.5' quadrangle and township. Areas of Federal coal ownership are shown in figure 14. County locations are shown in figure 1; township and 7.5' quadrangle locations are shown in figure 2. Of the 62.3 billion short tons of coal reported for the original resource, approximately 57.2 billion short tons (92 percent) are Federally owned; of the remaining 5.1 billion short tons, 4.7 billion tons underlie areas where the surface is owned by the State, and 0.3 billion tons underlie areas where the surface ownership is private. Approximately 27.7 billion short tons of coal are within Garfield County and 34.6 billion tons are within Kane County (table 6). Coal resources within each 7.5' quadrangle and township are reported in appendix 2. Coal resources reported within these more restricted areas are useful because they can be compared to resource estimates made in the previous investigations cited in figure 2.

Geologic restrictions to coal availability

In order to better quantify the original coal resource of the Calico and A-sequences, various aspects of coal

Table 6. Coal resources (in millions of short tons) in the Calico and A-sequences in the Kaiparowits Plateau, Utah. Resource reliability categories are defined in Wood and others (1983). Areas having identified resources are within a 3-mile radius of a data point and areas having hypothetical resources are beyond a 3-mile radius from a data point. Resources represent all areas of the plateau where the entire coal-bearing section is preserved (fig. 12) and are calculated using an average density of 1800 short tons per acre-foot for all coal beds thicker than 1 foot. Resources are reported in overburden and reliability categories for each county.

		ESTIMATED COAL RESOURCES (in millions of short tons)					
County	Reliability	Overburden (thickness in feet)					Total
		0-1,000	1,000-2,000	2,000-3,000	3,000-6,000	> 6,000	
Garfield	Identified	2,780.2	6,629.7	3,143.8	4,381.6	76.2	17,011.5
	Hypothetical	61.2	364.3	1,320.4	7,296.9	1,659.1	10,701.9
	Subtotal	2,841.4	6,994.0	4,464.2	11,678.5	1,735.3	27,713.4
Kane	Identified	13,227.0	9,219.5	7,672.7	77.3	0	30,196.5
	Hypothetical	304.5	150.7	3,326.7	618.7	0	4,400.6
	Subtotal	13,531.5	9,370.2	10,999.4	696.0	0	34,597.1
	Total	16,372.9	16,364.2	15,463.6	12,374.5	1,735.3	62,310.5

distribution were investigated, including overburden, coal bed thickness, and dip of strata.

Overburden

Maximum overburden overlying coal in the Calico and A-sequences has been delineated utilizing the topography of the Calico sequence boundary (fig. 10) and surface elevations imported from a 1:250,000 Digital Elevation Model constructed by the U.S. Geological Survey. Maximum overburden lines are shown on the resultant map, figure 15, at 1,000, 2,000, 3,000, and 6,000 foot intervals. The maximum overburden map indicates that coals in the Calico and A-sequences are less than 2,000 feet deep in all areas of the Kaiparowits Plateau except for the central basin, where maximum overburden ranges from 2,000 to 8,500 feet. Estimated coal resources are calculated in overburden categories of 0-1,000, 1,000-2,000, 2,000-3,000, 3,000-6,000, and greater than 6,000 feet by integrating the overburden map (fig. 15) with the net coal isopach map (fig. 11). Coal resources in each category are reported in table 6. About 32.7 billion short tons of coal are under less than 2,000 feet of overburden, 48.2 billion short tons of coal are under less than 3,000 feet of overburden, and 14.1 billion short tons of coal are under more than 3,000 feet of overburden.

In order to check the accuracy of the overburden map shown in figure 15, it was compared to an overburden map constructed for the Christensen coal zone by Hansen (1978b). The two maps generally compare favorably in most areas of the Kaiparowits Plateau; minor discrepancies are attributed to generalities in the Digital Elevation Model and the use of different horizions. However, overburden differences of as much as 500 feet are found in the northeastern part of the plateau in the Griffin Point quadrangle (fig. 2) where overburden is affected by the Jake Hollow graben (fig. 9). Additionally, our overburden values are as much as 1,000 feet too thick in the extreme northeastern part of the plateau (central part of the Posy Lake quadrangle, fig. 2), where thick successions of shoreface strata are located between the lowermost beds of coal and the Calico sequence boundary.

Coal bed thickness

The Calico and A-sequences contain as many as 30 beds of coal that range from 1 to 59 feet in

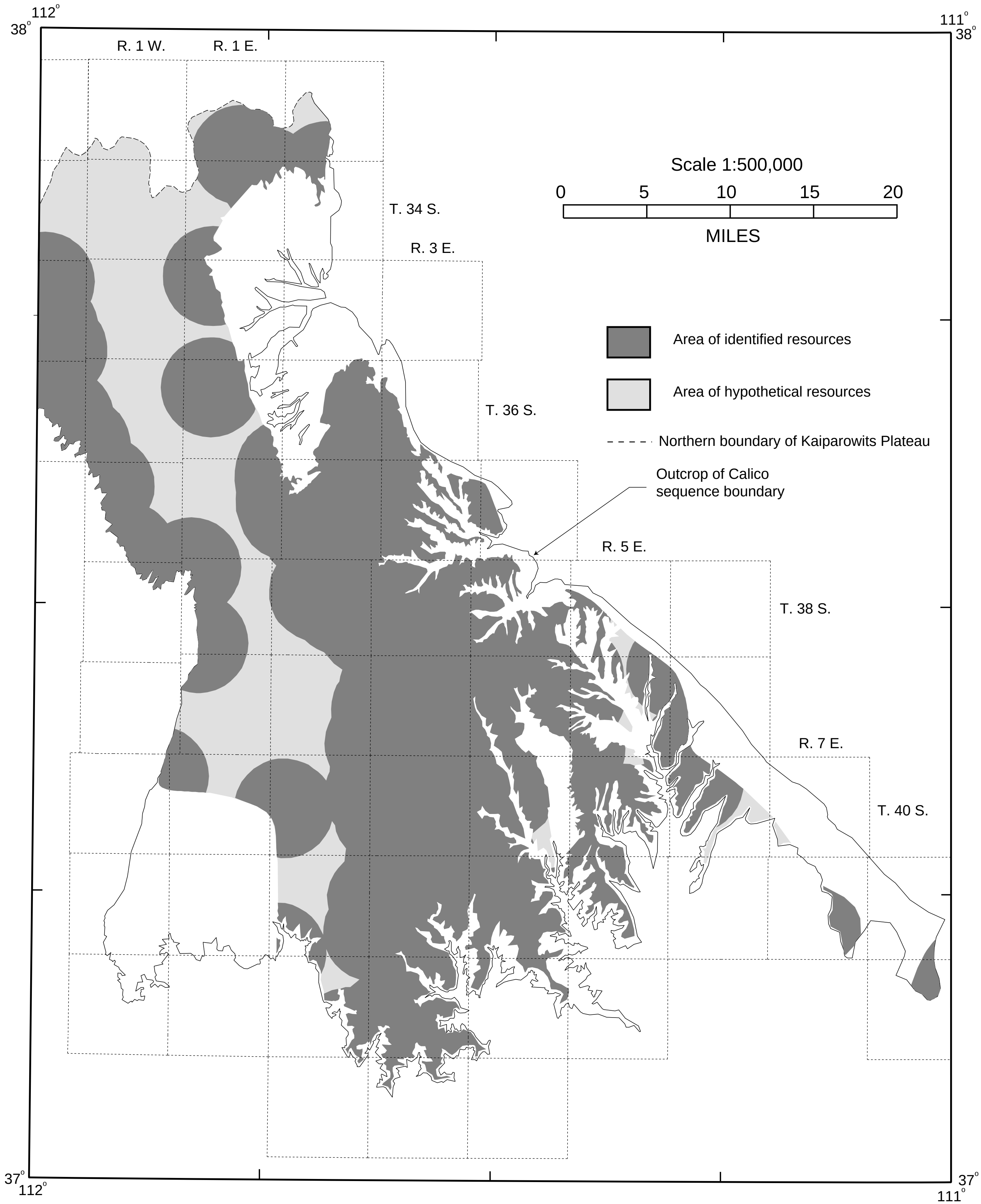

Figure 13. -- Map showing areas of reliability for coal resources in the Calico and A-sequences. Areas having identified resources are within a 3-mile radius of a data point and areas having hypothetical resources are beyond a 3-mile radius from a data point; areas are based on 209 data points shown in figure 11 and apply only to localities underlain by the total coal-bearing interval where coal beds are greater than 1 foot thick.

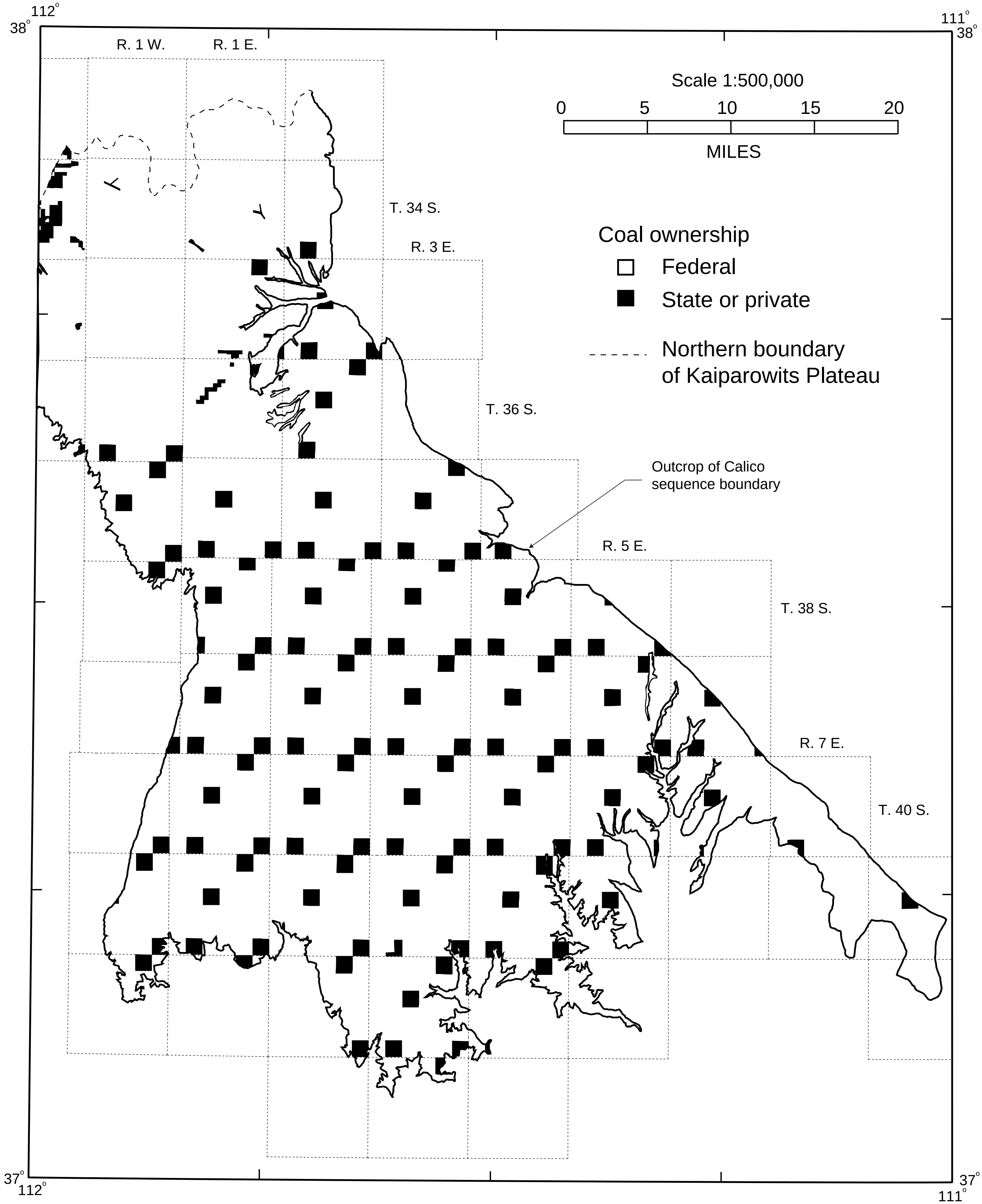

Figure 14. -- Mineral ownership for areas underlain by the Calico and A-sequences.

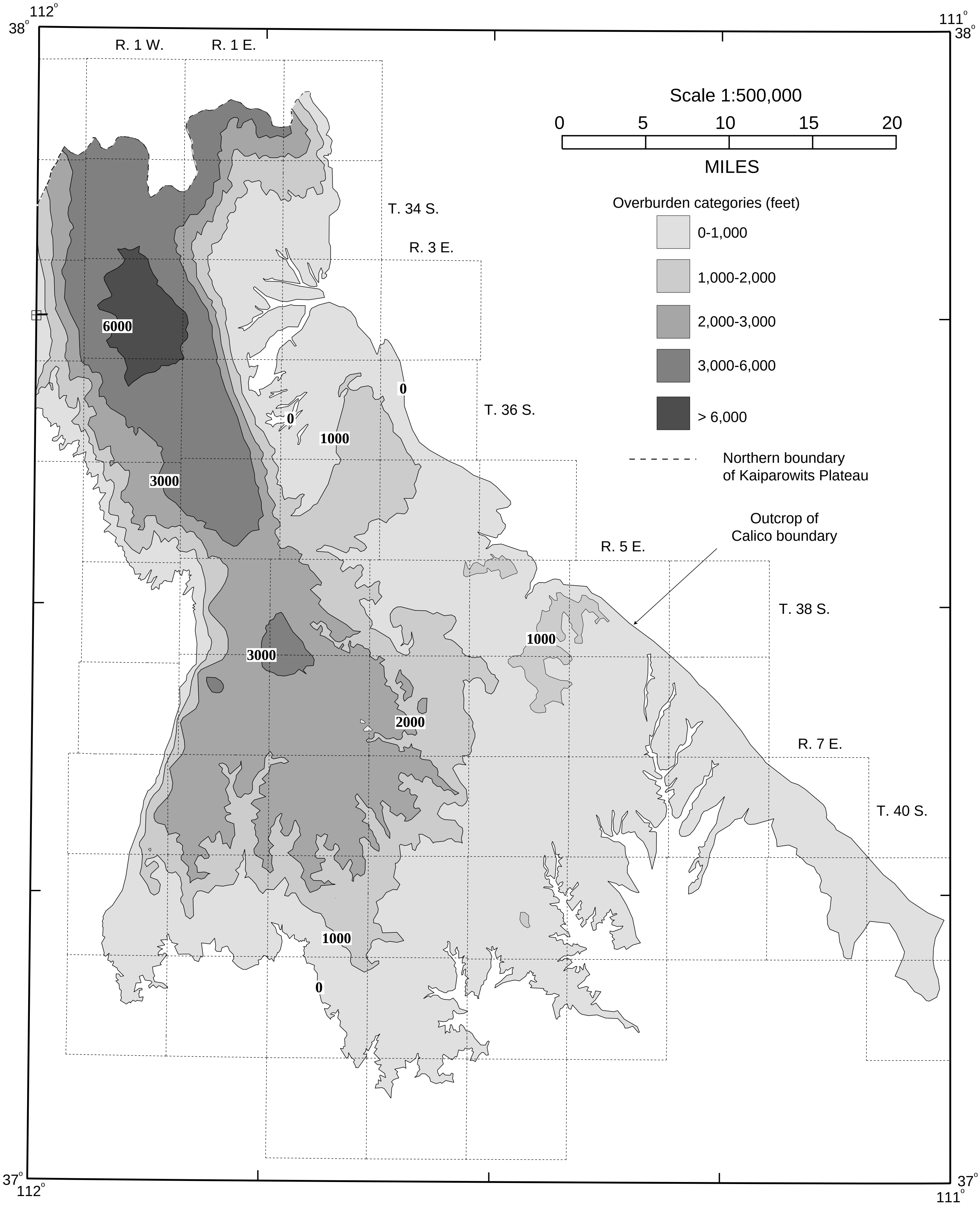

Figure 15. -- Overburden on the Calico sequence boundary. Thickness categories show range of maximum overburden above coal in the Calico and A-sequences.

thickness. In order to better understand the distribution of these coal beds, we have constructed a series of isopach maps that show net coal in bed thickness categories of 1.0-2.4, 2.5-3.4, 3.5-7.4, 7.5-14.0, 14.1-20.0, and greater than 20.0 feet (figs. 16*A*-21*A*), respectively. The number of coal beds within each thickness category is shown in figures 16*B*-21*B*, respectively. Each isopach map has been constructed using coal data listed in appendix 1. The estimated coal resource in each thickness category is listed in table 7. However, the sum of coal tonnages from each individual thickness category in table 7 is only 55 billion tons, about 12 percent less than the 62 billion short tons reported in table 6 for the original coal resource. This discrepancy appears because the area mapped for each coal thickness category is slightly underestimated, because an artificial value of "zero" was assigned to data points that lack coal within the specified bed thickness category. The discrepancy is relatively minor, and the isopach maps and reported tonnages in each category provide a reasonable estimation of coal distribution by bed thickness.

Coal beds less than 3.4 feet thick are widely distributed across the entire resource area. As many as 22 coal beds range from 1 to 2.5 feet in thickness and have a maximum net accumulation of 30 feet (fig. 15*A*, *B*). As many as nine coal beds range from 2.5 to 3.4 feet in thickness, and the maximum net accumulation in this category is 27 feet (fig. 17*A*, *B*). Approximately 11 billion short tons of coal are in beds that range from 1 to 3.4 feet in thickness (table 7).

Coal beds between 3.5 and 4.1 feet in thickness are also distributed widely throughout the plateau, but they occupy a slightly smaller area than do coals in the thinner categories. As many as nine beds of coal range from 3.5 to 7.4 feet in thickness, and these beds have a maximum net accumulation of 65 feet (fig. 18*A*, *B*). As many as seven beds of coal are 7.4-14.1 feet thick, and these beds have a maximum net accumulation of 66 feet (fig. 19*A*, *B*). Approximately 28 billion short tons of coal are in beds that range from 3.5 to 14.1 feet in thickness (table 7).

Coal beds greater than 14.1 feet thick occupy an elongated area situated in the central region of the Kaiparowits Plateau (figs. 20*A*, 21*B*). The elongated area is about 20 miles wide in the northern part of the plateau and narrows to about 10 miles wide in the plateau's southern areas. As many as four coal beds range from 14.1 to 20.0 feet in thickness and have a maximum net accumulation of 71 feet (fig. 20*A*, *B*). Coal beds greater than 20.0 feet thick occupy an area along the northern part of the plateau as well as several areas that are 2-17 miles long and 3-9 miles wide in the central regions of the plateau (fig. 21*A*). As many as three beds of coal are greater than 20.0 feet thick, and as much as 59 feet of coal is contained in 1 bed (fig. 21*A*, *B*). Approximately 16 billion short tons of coal are in beds that range from 14.1 to 59 feet in thickness (table 7). However, current longwall mining technology can economically extract no more than 14 feet of coal from beds of any thickness (Timothy J. Rohrbacher, U.S. Geological Survey, oral commun., 1996). Therefore, only about 5 billion short tons of coal are actually available for mining from these thicker beds. This 5 billion ton figure does not account for any restriction to mining other than bed thickness and is determined by treating each mapped bed shown in figures 20*B* and 21*B* as if it was only 14 feet thick.

Table 7. Estimated coal tonnages (in billions of short tons) in beds ranging from 1-2.4, 2.5-3.4, 3.5-7.4, 7.5-14.0, 14.1-20.0, and greater than 20.0 feet in thickness within the Calico and A-sequences, Kaiparowits Plateau, Utah. Thickness categories used here are standard for estimating resources of bituminous coal (Wood and others, 1983). Tonnage estimates are calculated using an average density of 1800 short tons per acre-foot for coal and represent all areas of the plateau where the entire coal-bearing section is preserved.

Coal bed thickness in feet	Estimated tonnage (in billions of short tons)
1-2.4	7
2.5-3.4	4
3.5-7.4	15
7.5-14.0	13
14.1-20.0	8
> 20.0	8

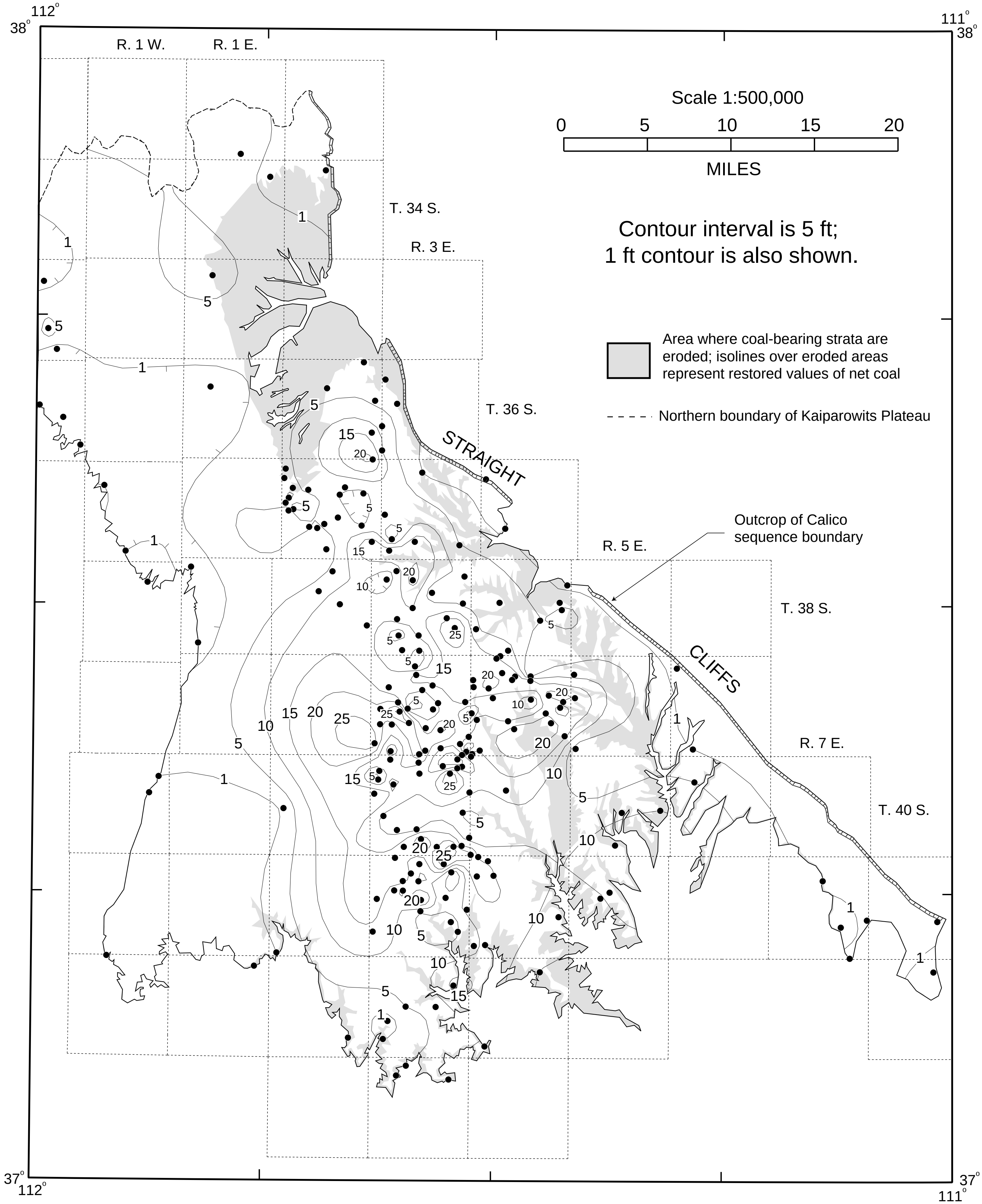

Figure 16*A*. -- Distribution of 1.0-2.4 foot thick coal beds in the Calico and A-sequences. Isopach map showing net coal in beds 1.0-2.4 feet thick.

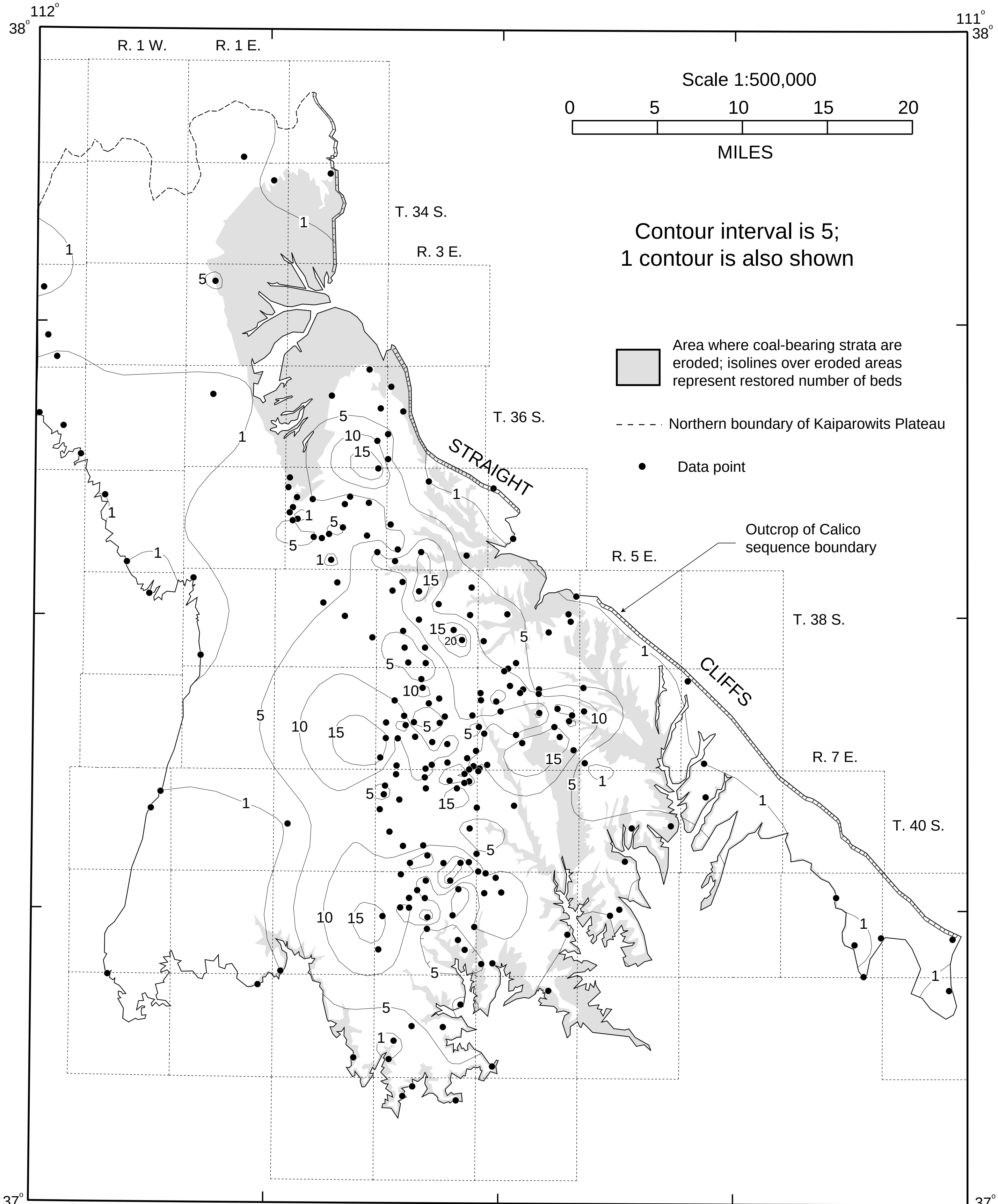

Figure 16*B*. -- Distribution of 1.0-2.4 foot thick coal beds in the Calico and A-sequences. Isopleth map showing the number of coal beds that are 1.0-2.4 feet thick.

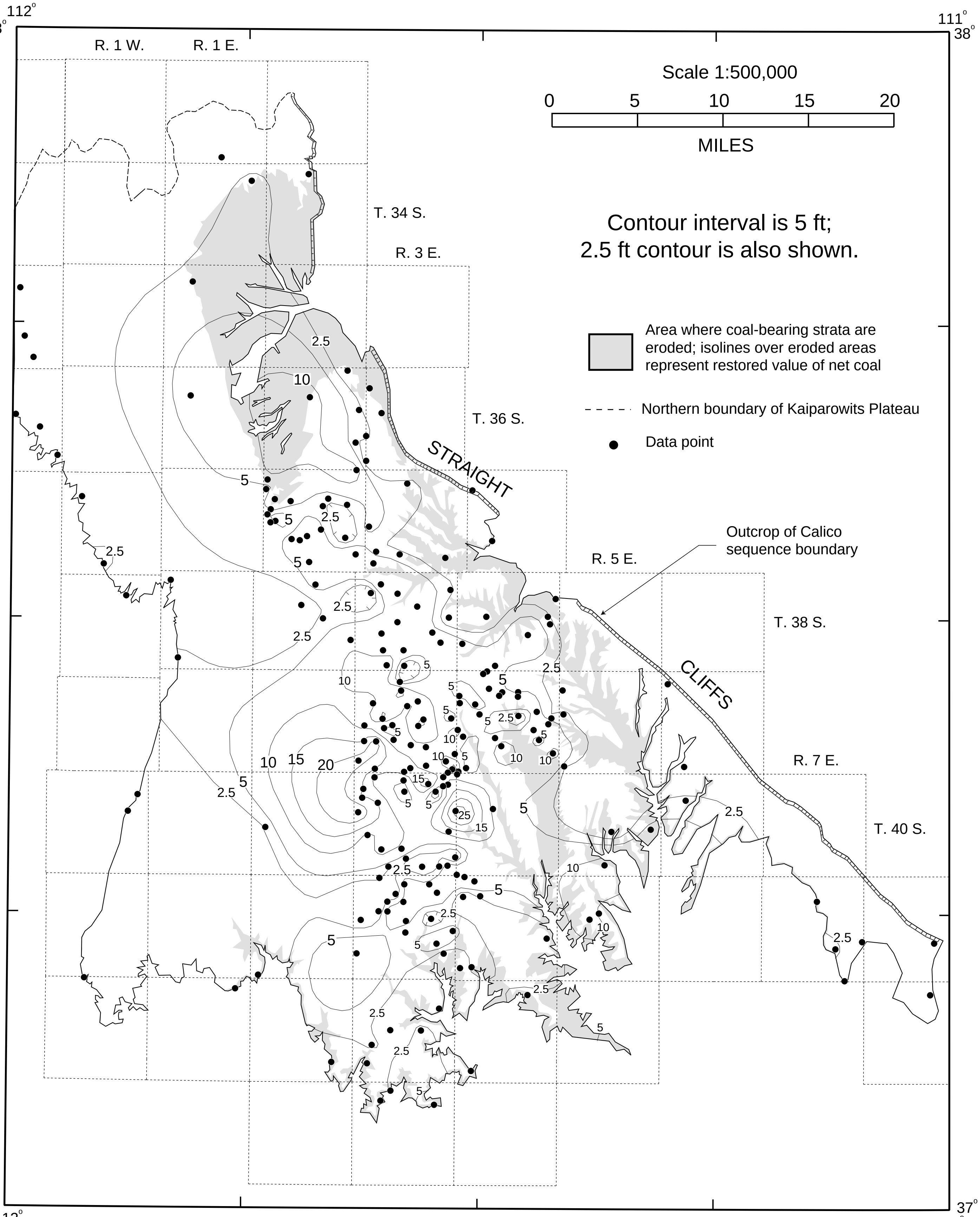

Figure 17*A*. -- Distribution of 2.5-3.4 foot thick coal beds in the Calico and A-sequences. Isopach map showing net coal in beds 2.5-3.4 feet thick.

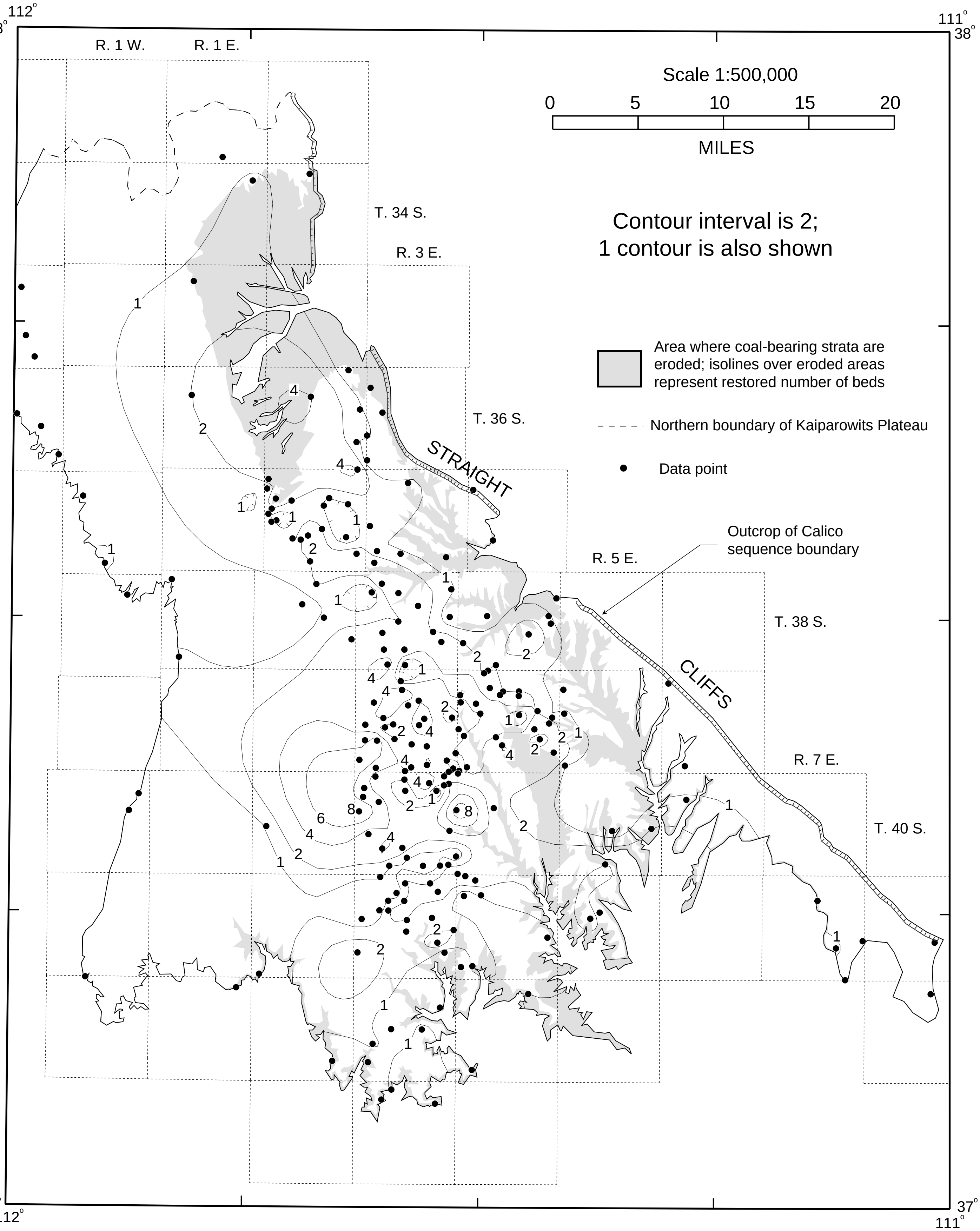

Figure 17*B*. -- Distribution of 2.5-3.4 foot thick coal beds in the Calico and A-sequences. Isopleth map showing the number of coal beds that are 2.5-3.4 feet thick.

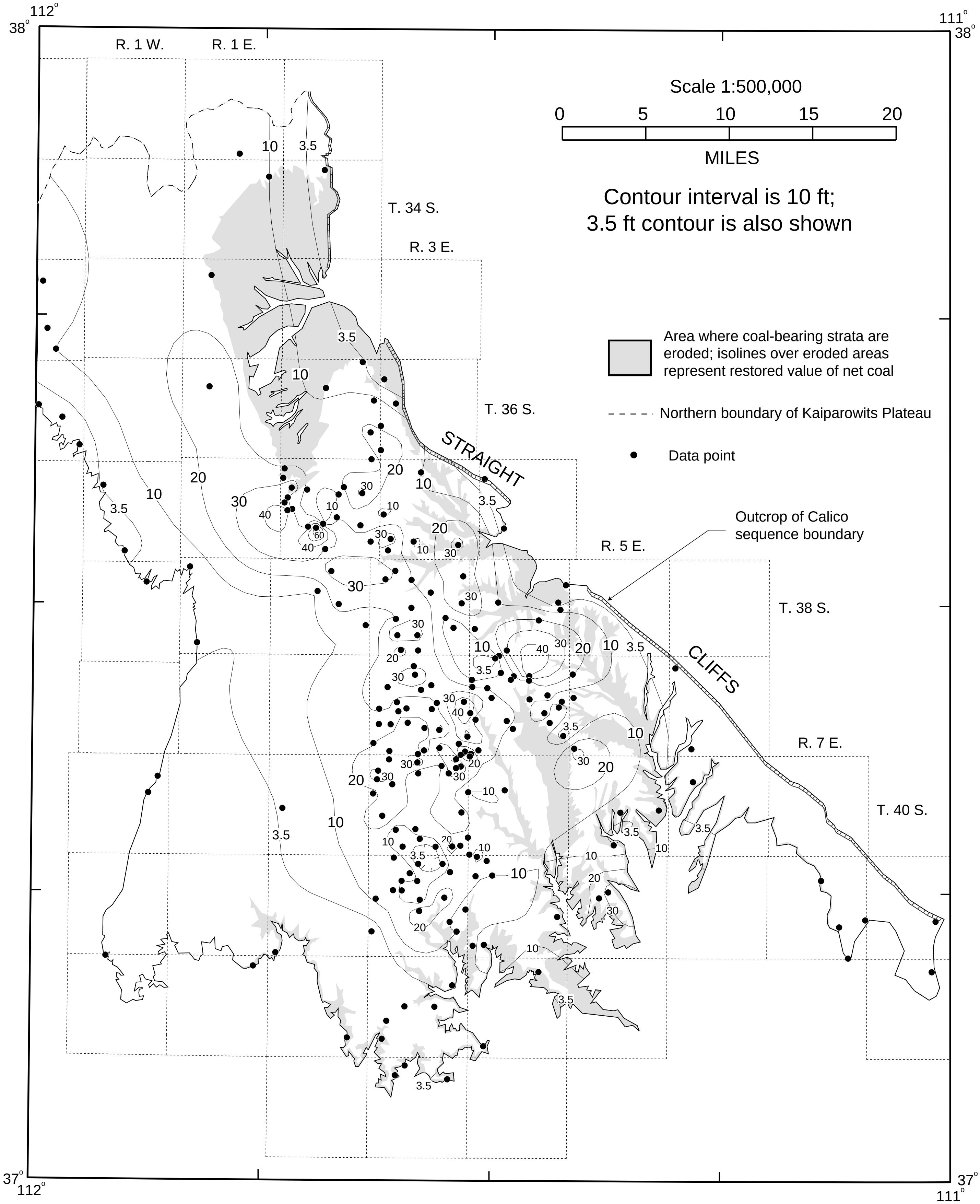

Figure 18*A*. -- Distribution of 3.5-7.4 foot thick coal beds in the Calico and A-sequences. Isopach map showing net coal in beds 3.5-7.4 feet thick.

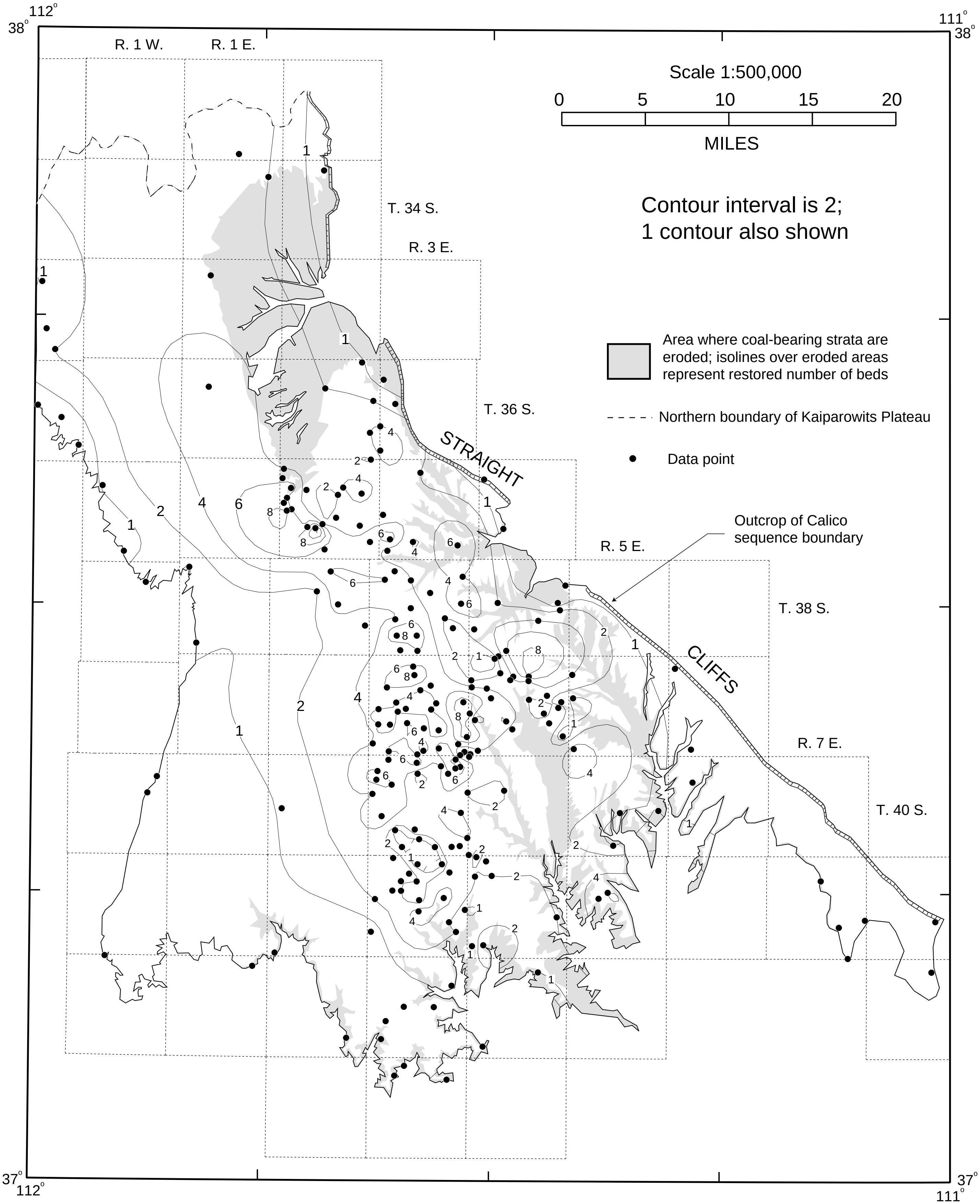

Figure 18*B*. -- Distribution of 3.5-7.4 foot thick coal beds in the Calico and A-sequences. Isopleth map showing the number of coal beds that are 3.5-7.4 feet thick.

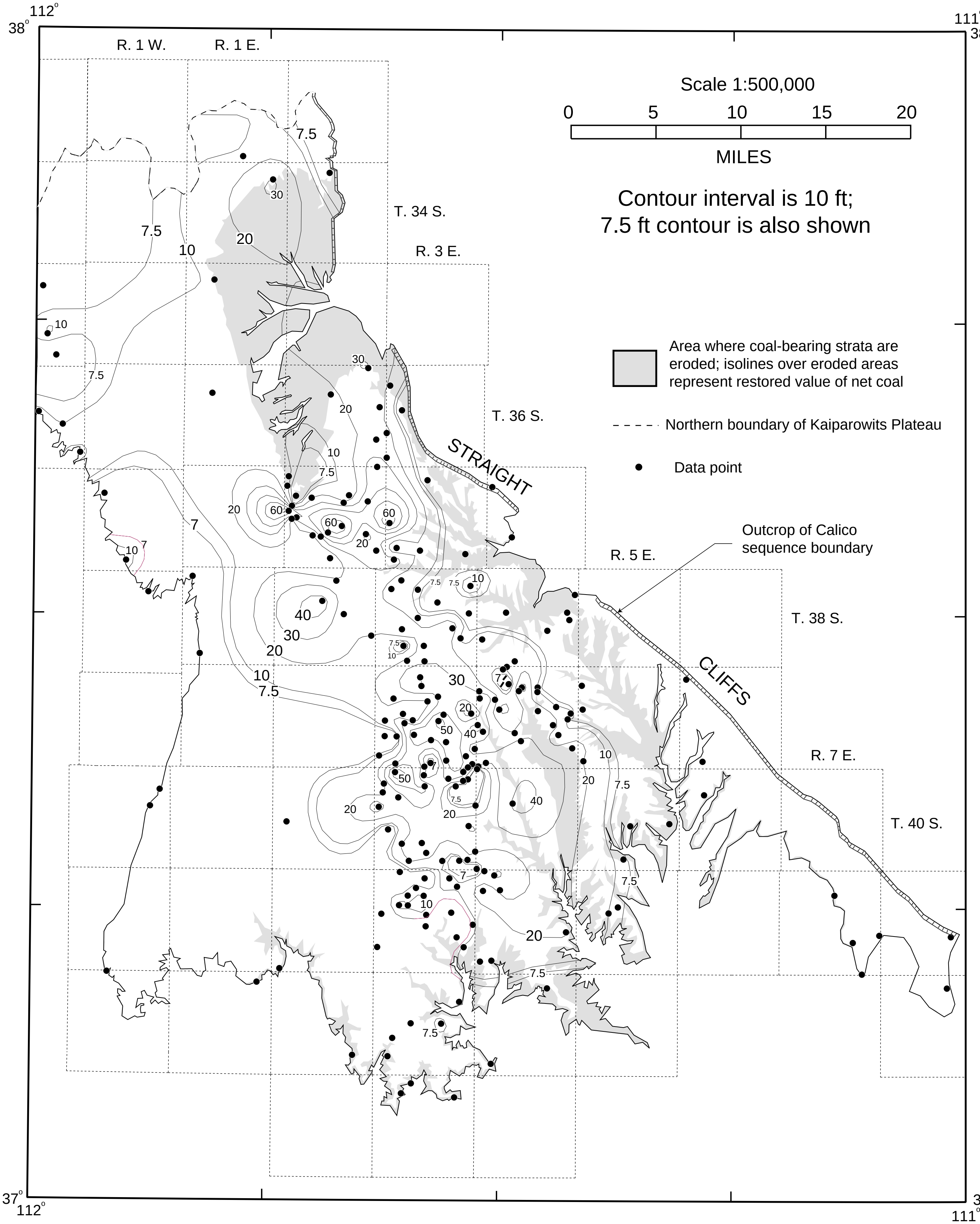

Figure 19*A*. -- Distribution of 7.5-14.0 foot thick coal beds in the Calico and A-sequences. Isopach map showing net coal in beds 7.5-14.0 feet thick.

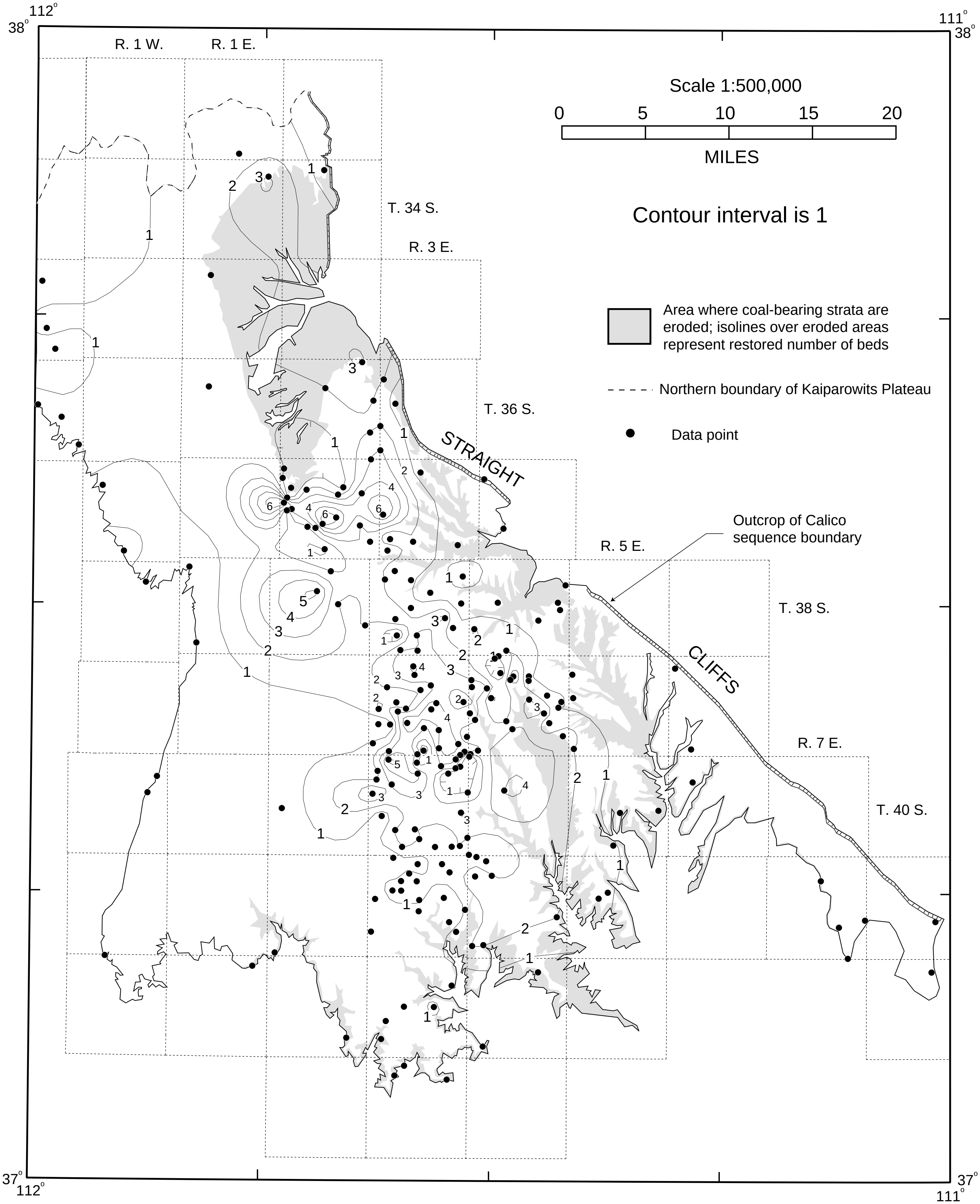

Figure 19*B*. -- Distribution of 7.5-14.0 foot thick coal beds in the Calico and A-sequences. Isopleth map showing the number of coal beds that are 7.5-14.0 feet thick.

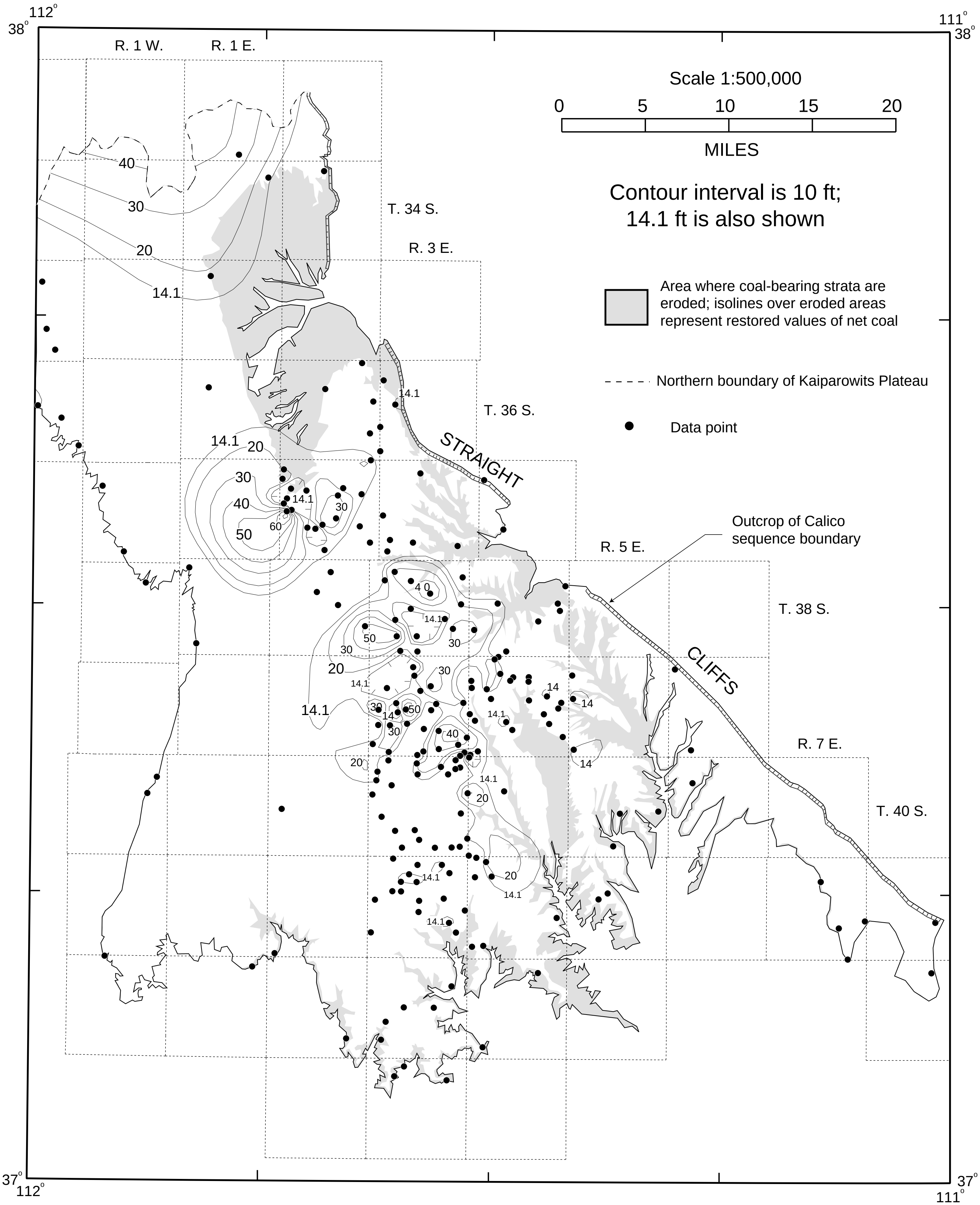

Figure 20*A*. -- Distribution of 14.1-20.0 foot thick coal beds in the Calico and A-sequences. Isopach map showing net coal in beds 14.1-20.0 feet thick.

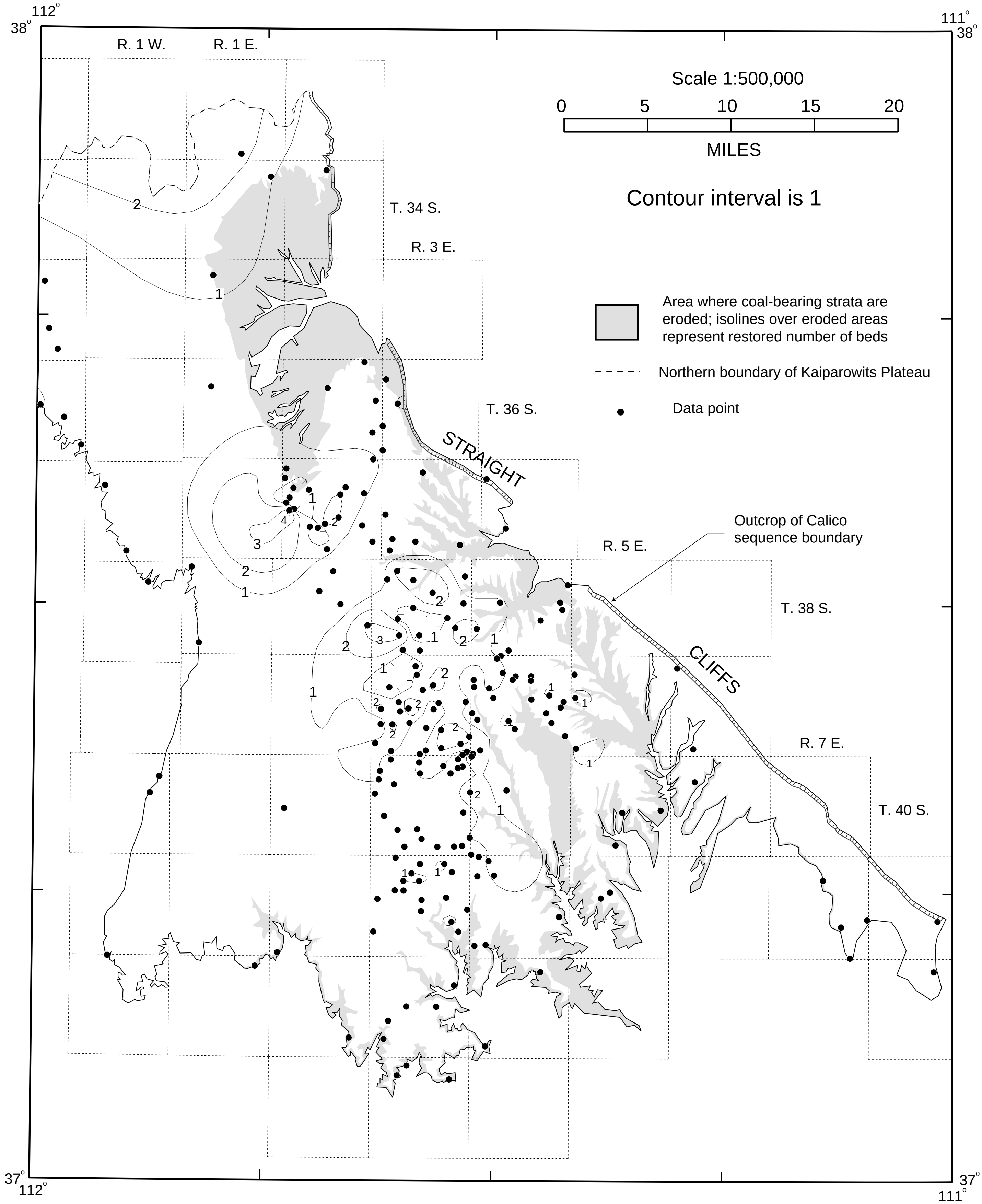

Figure 20*B*. -- Distribution of 14.1-20.0 foot thick coal beds in the Calico and A-sequences. Isopleth map showing the number of coal beds that are 14.1-20.0 feet thick.

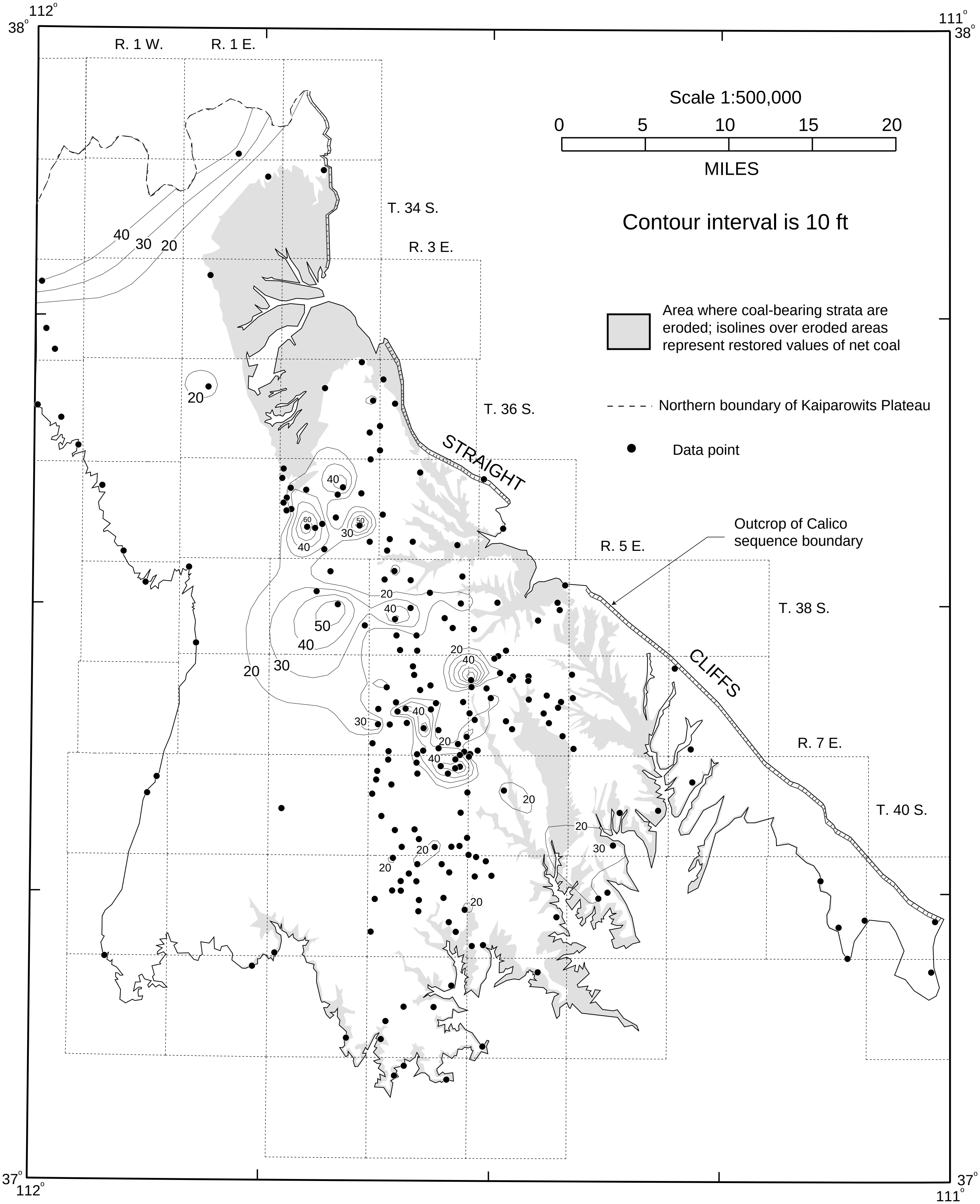

Figure 21*A*. -- Distribution of coal beds that are greater than 20.0 feet thick in the Calico and A-sequences. Isopach map showing net coal in beds that are greater than 20.0 feet thick.

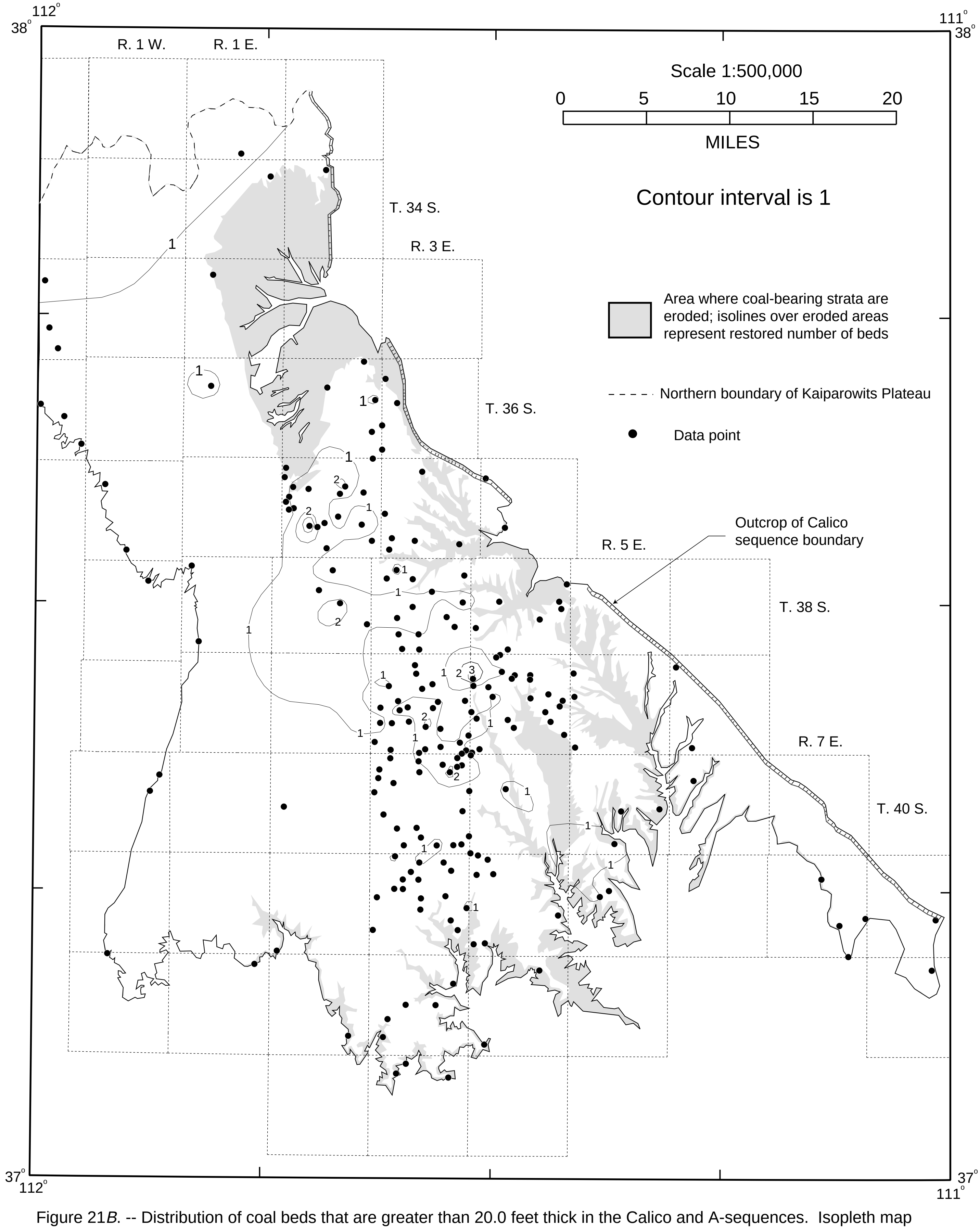

Figure 21*B*. -- Distribution of coal beds that are greater than 20.0 feet thick in the Calico and A-sequences. Isopleth map showing the number of coal beds that are greater than 20.0 feet thick.

Dip of strata

Based on studies conducted by the former U.S. Bureau of Mines between 1985 and 1993, underground mining is most efficient in areas where strata are inclined by less than 6°; underground mining is difficult where strata are inclined between 6° and 12° and it is not feasible where strata are inclined more than 12° (Timothy J. Rohrbacher, U.S. Geological Survey, oral commun., 1996). Inclinations of strata are shown in figure 9 for ranges of 0° to 6°, 6° to 12°, 12° to 25°, and greater than 25°. Coal resources within each category of inclination are calculated by integrating the dip-of-strata map (fig. 9) with the net coal isopach map (fig. 11). Approximately 49.8 billion short tons of coal are contained in strata that are inclined by less than 6°, 5.6 billion short tons are in strata that dip between 6° and 12°, and 6.9 billion short tons of coal are in strata that dip more than 12°. These tonnages comprise 80, 9, and 11 percent of the original resource, respectively.

COAL RESOURCE SUMMARY

Although the Calico and A-sequences contain an original coal resource of 62.3 billion short tons, this large resource figure must be regarded with caution, because it does not reflect economic, land-use, environmental, technological, and geologic restrictions that may affect its availability and recoverability. Peterson (1969a) estimated that only 10 percent of the coal in the Kaiparowits Plateau could be recovered with the technology of that time. Similar estimates for the Appalachian coal region (Rohrbacher and others, 1994) also indicate that less than 10 percent of an original coal resource can be mined and marketed at a profit.

Land-use and environmental considerations that may affect the economics or availability of coal in the Kaiparowits Plateau include the impact of mining and coal utilization on air and water quality in nearby National Parks and Recreational Areas, regional populations, grazing, and land subsidence above mined areas (Sargent, 1984). These issues may be significant; in 1976, several companies dropped their plans to construct a coal-burning power plant in the region due to Government actions and pending lawsuits over environmental issues (U.S. Bureau of Land Management, 1976; Sargent, 1984).

At least 32 billion short tons of coal are not likely to be mined in the foreseeable future because of geologic and technological restrictions that included overburden, dip of strata, and coal bed thickness. Physical and economic constraints generally limit current longwall and continuous mining to depths of less than 3,000 feet, to strata that are inclined by less than 12°, and to coal beds that are more than 3 feet thick; additionally, only 14 feet of coal can be mined from beds of any thickness (Timothy J. Rohrbacher, U.S. Geological Survey, oral commun., 1996). These overburden and bed thickness limits are supported by a summary given for 81 current longwalls operated in the United States by 30 companies (Merritt and Fiscor, 1995, p. 32-38). Approximately 18 billion short tons of coal are not likely to be mined because they are in areas where overburden is greater than 3,000 feet or where strata are inclined by more than 12°. Coal tonnages in these areas are calculated by integrating the dip of strata, net coal isopach, and overburden maps (figs. 9, 11, 15, respectively). An estimated additional 14 billion short tons of coal are not likely to be mined from the remaining areas of the Kaiparowits Plateau because they are in beds that are less than 3.4 feet thick (11 billion tons) or cannot be extracted from beds that are more than 14 feet thick (3 billion tons). These coal tonnages are determined by integrating the overburden and dip-of-strata maps with resources determined from coal isopach maps (figs. 16*A*, 17*A*) and bed maps (figs. 20*B*, 21*B*).

Approximately 30 billion short tons of coal are in areas of the Kaiparowits Plateau where geologic conditions are more favorable for current underground mining technology (fig. 22). These beds of coal are in areas where overburden is less than 3,000 feet thick and strata dip less than 12°. The coal tonnage is estimated for all beds of coal that are more than 3.5 feet thick, and coal tonnages in beds that are thicker than 14 feet thick are calculated as if they are only 14 feet thick. These coal tonnages do not reflect potential land-use or environmental restrictions, nor do they account for additional coal that cannot be mined due to the discontinuity of coal beds, coal that may be destroyed by the mining of adjacent strata, or coal that must be left in the ground for roof support.

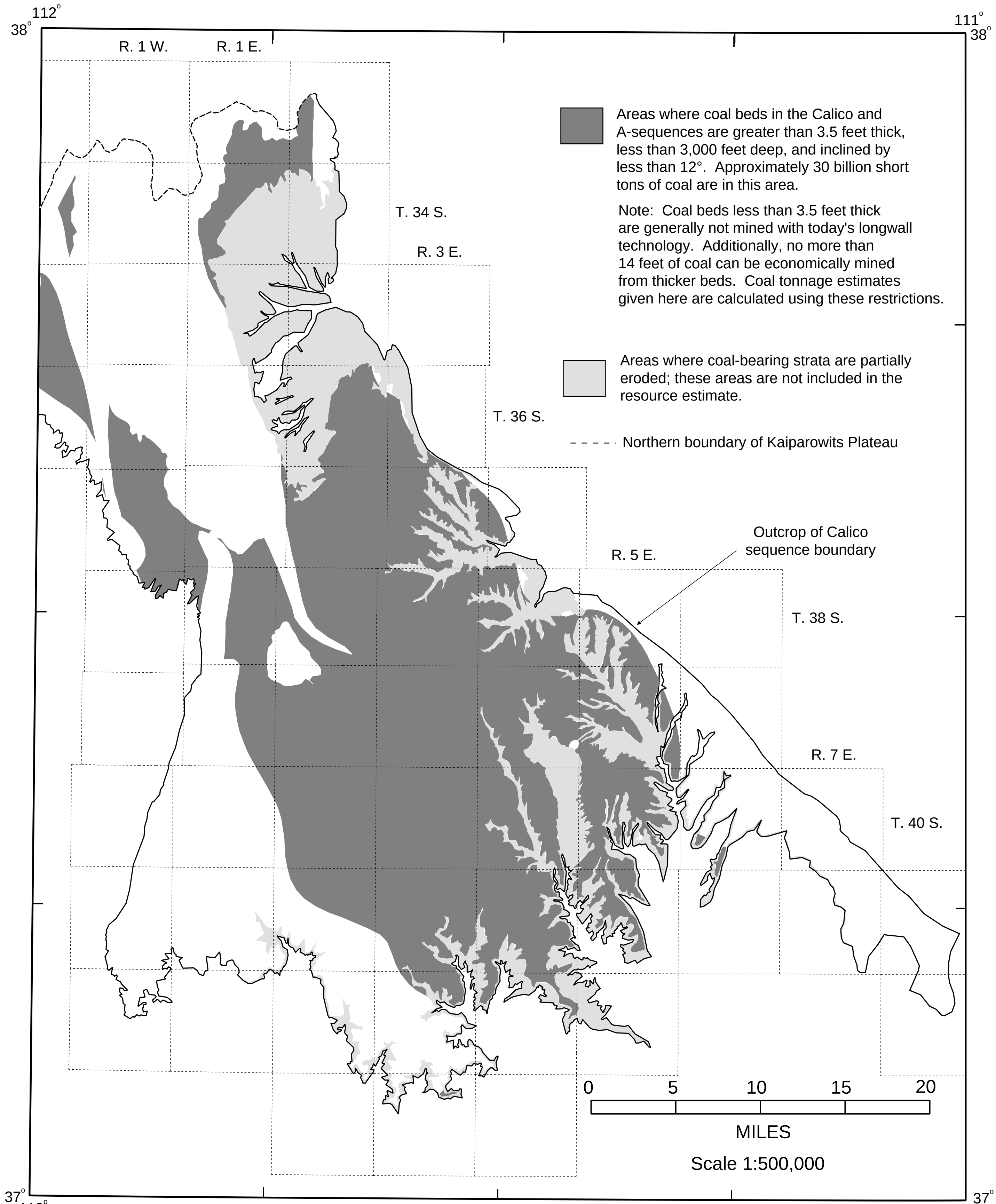

Figure 22. -- Map of the Kaiparowits Plateau showing areas (dark gray stipple) where coal beds are: 1) greater than 3.5 feet thick, 2) under less than 3,000 feet of overburden, and 3) inclined by less than 12° of dip. Areas where coal-bearing strata are partially eroded (light gray stipple) are not addressed in this investigation.