Contract Report

Calculation of Texas Lignite Resources Using the National Coal Resources Data System

by

W. R. Kaiser

Funded by the U.S. Geological Survey

Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

August 1996

CONTENTS

Figures

Tables

ABSTRACT

Calculation of Texas lignite resources, according to U.S. Geological Survey (USGS) methodology, using the National Coal Resources Data System (NCRDS) and software, began in 1979 and is now complete with reporting here of resources in three new regions—Jackson-Yegua east, Jackson south, and Wilcox south. In these regions, site files containing well locations and total lignite thicknesses were created using Ingres, a relational data base software. Resources were calculated using the Geographic Resources Analysis Support System (GRASS) GIS.

Texas lignite resources were calculated from a data base of 4,700 density and lithologic logs in terms of three USGS thickness categories (2.5 to 5 ft, >5 to 10 ft, and >10 ft) and one Bureau of Economic Geology (BEG) category (≥3 ft). NCRDS resources, calculated using USGS methodology, total 46,979 million tons, of which 15,767 million tons (34 percent) are demonstrated resources. Most of them are in beds 2.5 to 5 ft thick. Two-thirds of the resources are in the Wilcox trend and one-third in the Jackson-Yegua trend. The state's richest lignite regions are Jackson-Yegua east and Wilcox east-central.

In a comparison of NCRDS and BEG resource estimates, made using the same data base and thickness category (≥3 ft), the USGS inflated inferred resources, whereas the BEG, using geologic models, constrained inferred resources and maximized demonstrated resources, which are 13,691 and 20,383 million tons, respectively. The USGS method is highly data dependent and can make no allowance for demonstrated resources as defined and estimated by the BEG with moderate certainty using geologic models. The computerized and geologic methods could be combined to improve resource estimates from limited data.

INTRODUCTION

Calculation of Texas lignite resources, according to the methodology of the U.S. Geological Survey (USGS), using the National Coal Resources Data System (NCRDS) and software, began in 1979 and is now complete. Resources for the Wilcox Group in three East Texas regions were reported earlier by Tewalt and Jackson (1991). Resources reported here are for the Jackson Group and Yegua Formation of East Texas and Jackson and Wilcox Groups of South Texas (figs. 1 and 2). Resources calculated in both studies were combined and are summarized here as statewide totals. The statewide data base is that of Kaiser and others (1980), comprising 4,700 density and lithologic logs run in boreholes drilled for lignite exploration. The holes were commonly 150 to 200 ft deep but some were as deep as 300 ft.

In East Texas, resources in the Jackson Group and Yegua Formation are combined and termed Jackson-Yegua; they were calculated using 1,061 logs. Lignite occurs in the Manning and upper Wellborn Formations and in the middle two-thirds of the Yegua Formation (Kaiser and others, 1980) (fig. 2). The Manning Formation is the region's most important Jackson-Yegua lignite-bearing unit. In South Texas, Jackson lignite occurs in the lower Jackson above the Yegua Formation, which is lignite barren. Wilcox lignite occurs in the lower Wilcox just above the marine Midway Group (Kaiser and others, 1980) (fig. 2). Jackson resources were calculated using 398 logs and Wilcox 129 logs.

Following presentation of NCRDS resources, they and those defined and calculated by the Bureau of Economic Geology (BEG) are compared on the basis of the same data base and thickness category. A brief discussion of combining the USGS and BEG methods for improved resource estimates concludes this report.

METHODOLOGY

Near-surface resources were calculated by degree-of-certainty and thickness categories using a total-coal method, that is, by total thickness in the borehole rather than by individual bed (Tewalt and Jackson, 1991). Resources are classified by the USGS by decreasing degrees of geologic certainty based on increasing distances from coal-bearing boreholes. Three USGS degree-of-certainty categories are defined by concentric circles centered on a data point (borehole) (fig. 3). The most certain category is termed measured and is the coal within a 0.25-mi radius from a data

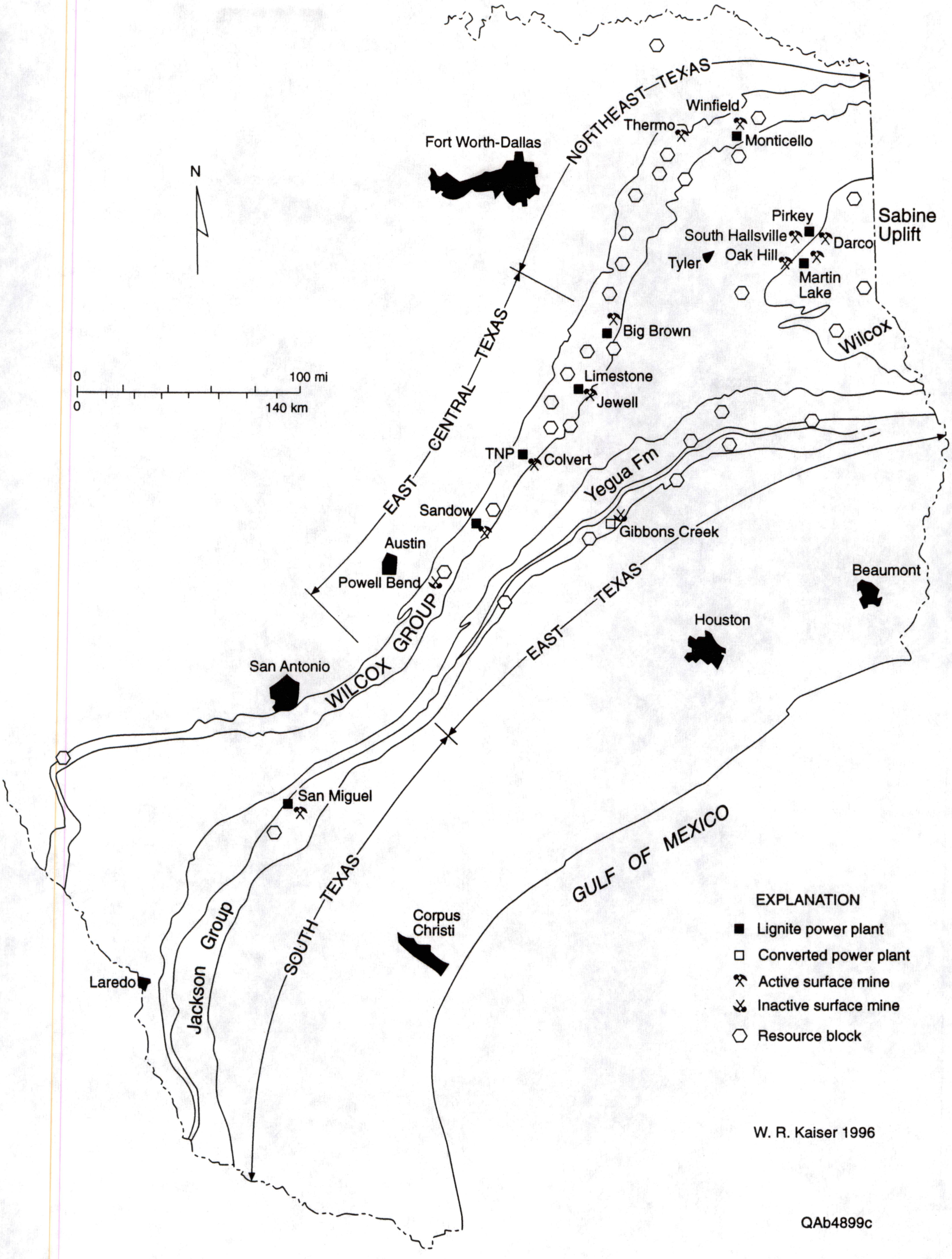

Figure 1. Lignite regions, mines, power plants, and resource blocks in Texas.

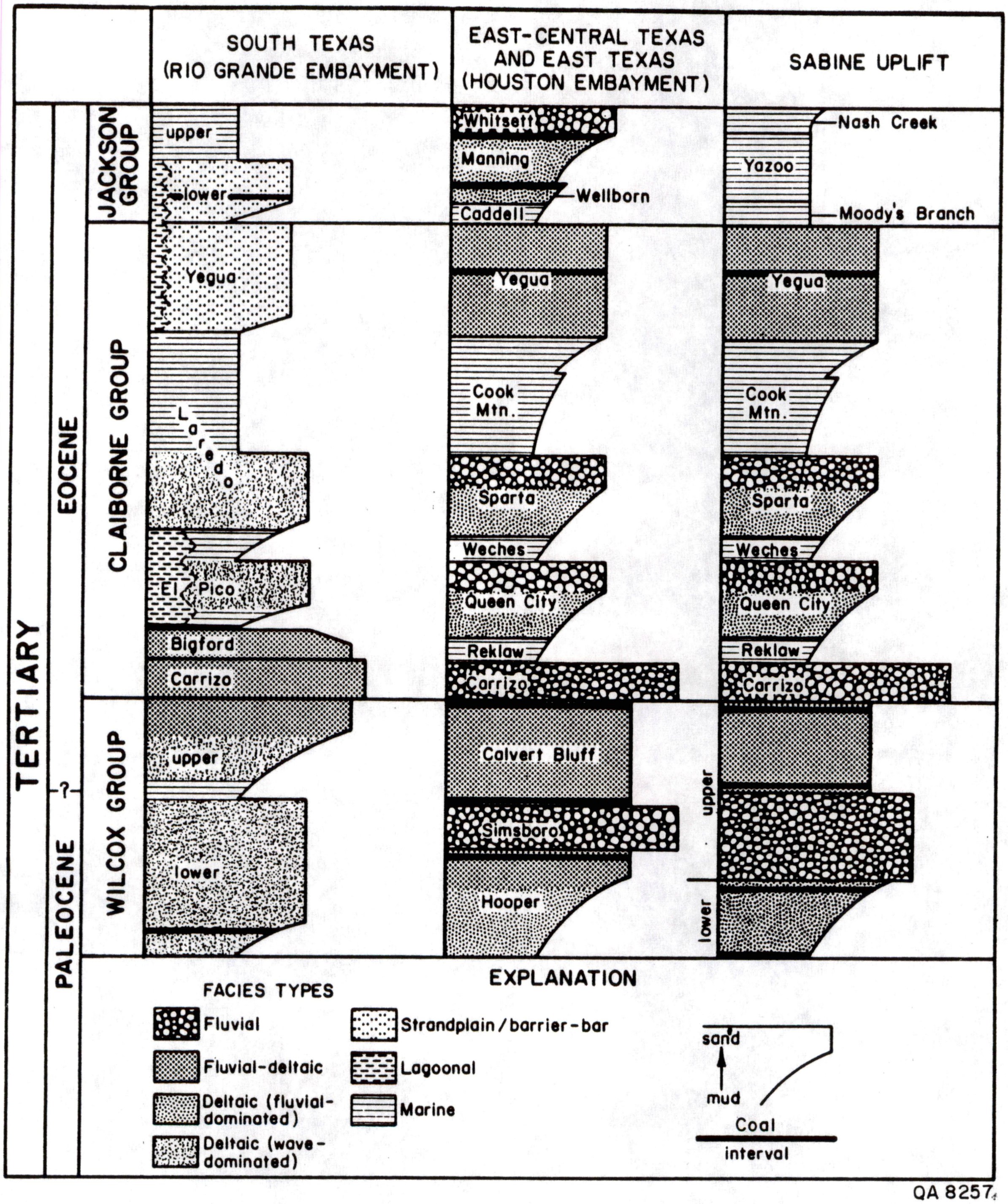

Figure 2. Lower Tertiary stratigraphy and the occurrence of lignite in Texas.

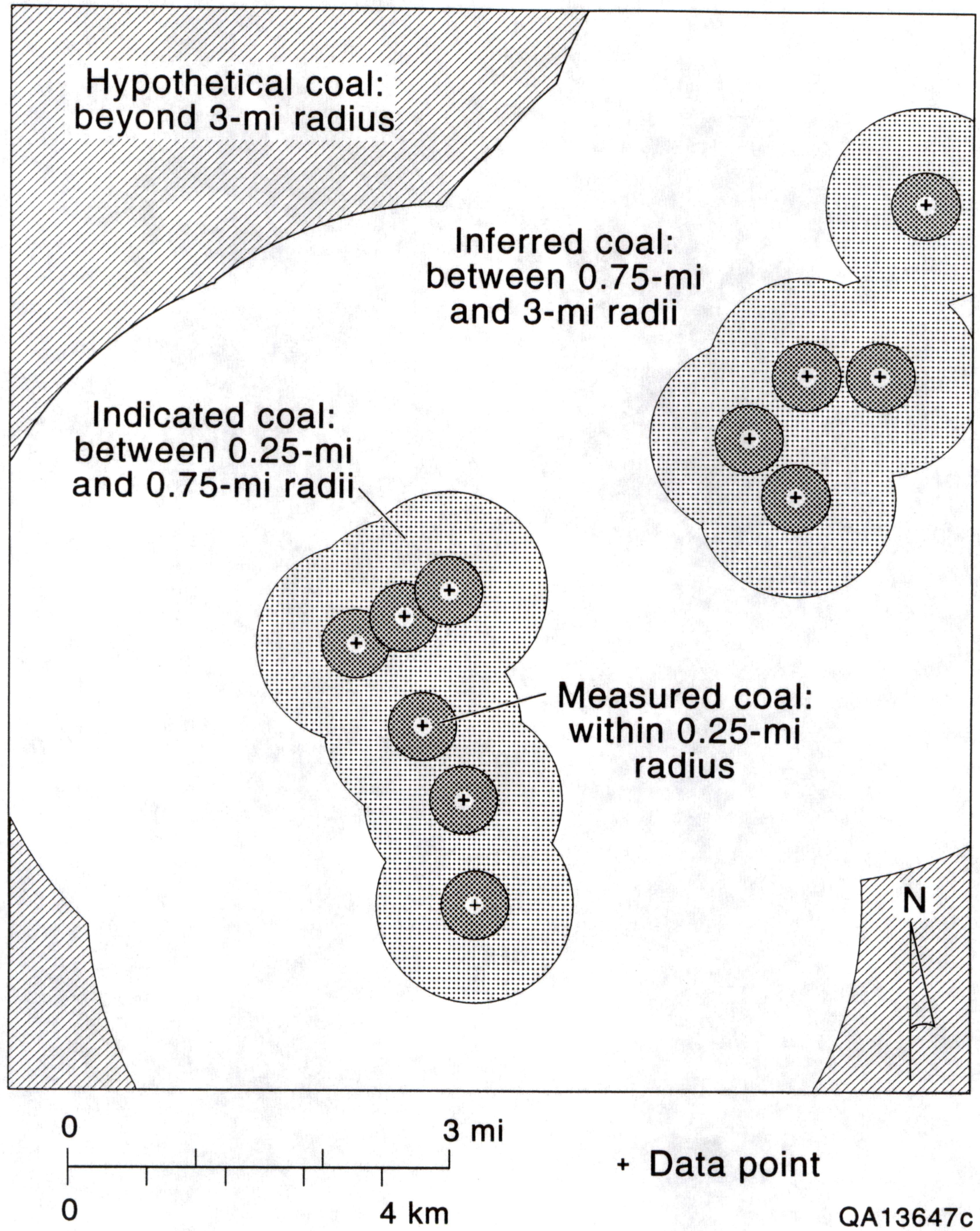

Figure 3. Definition of USGS degree-of-certainty categories (from Tewalt and Jackson, 1991).

point. Indicated coal is known with intermediate certainty and extends 0.5 mi from measured coal or that between 0.25-mi and 0.75-mi radius from a data point. The sum of measured and indicated resources is the demonstrated resources. Inferred coal is known with the least certainty and extends 2.25 mi beyond indicated coal or 3 mi from a data point.

Bed-thickness categories are rank dependent (Wood and others, 1983) and are consistent with thicknesses of Texas lignites. The following thickness categories are appropriate for Texas: 2.5 to 5 ft, >5 to 10 ft, and >10 ft and were used to calculate NCRDS resources under less than 500 ft of overburden. The 3-mi radius of the inferred resource circle was used as a downdip limit. In most cases, the resource circles do not extend beyond the 500-ft depth limit because of gentle dips. At a dip of 1.5°, 500 ft is reached in 3.62 mi and at 2° in 2.72 mi. The updip limit was the basal contact of the geologic unit in question. No other geologic constraints were placed on the areal extent of NCRDS resources.

Stratigraphic data obtained from geophysical logs are entered into USTRAT, the NCRDS data base. USTRAT files are queried, based on 7.5-minute quadrangles and coalbed thicknesses, to create site files containing well locations and total lignite thicknesses using Ingres, a relational data base software. The site files areally consist of scattered data points geographically grouped and interpolated into continuous grids of values from which resources are calculated using the Geographic Resources Analysis Support System (GRASS) GIS.

Borehole locations obtained in latitude and longitude from Ingres are converted to UTM locations and stored as a coverage of site files in GRASS. Geologic contacts on maps are digitized as vectors (lines) and converted to raster format to serve as the outcrop area. Thickness values in the site files are gridded to create rasters. Gridding, the process of creating an equally spaced network of thickness values from actual values, is perhaps the most important step in resource calculation and was accomplished using regularized spline with tension and smoothing (Mitasova, 1992). Degree-of-certainty circles are generated around site locations as vectors and are also converted to raster. A GRASS script or routine combines outcrop, overburden (if available), mined-out acreage (if any), thickness, and reliability into a new raster. Using this raster, the gridded thickness data are converted in GRASS to tons, using a tonnage factor of 1,750 tons per acre-ft.

Additional control from zero-lignite-thickness point files improved interpolation of lignite thicknesses between data points and in areas of sparse control and also resulted in more realistic estimates of inferred resources (Tewalt and Jackson, 1991). In order to reduce the number of gridding and resource computations, data files were grouped into five resource regions of contiguous quadrangles.

NCRDS RESOURCES

Jackson-Yegua East

NCRDS resources in the Jackson-Yegua trend of East Texas (fig. 1) extend from Fayette to Angelina County (figs. 4, 5, 6) and total 16,418 million tons, of which 4,570 million tons are demonstrated resources (table 1). In the Jackson, the area underlain by 2.5 to 5 ft and >5 to 10 ft beds is nearly identical and extends almost continuously from Fayette to Walker Counties (figs. 4 and 5). The area underlain by Jackson beds >10 ft thick is greatly diminished and essentially absent in the Yegua trend (fig. 6). Clearly, the great majority of Jackson-Yegua resources are in the Jackson Group.

Jackson South

NCRDS resources in the Jackson trend of South Texas (fig. 1) occur in the Rio Grande valley and San Miguel area (figs. 7, 8, 9) and total 1,990 million tons, of which 714 million tons are demonstrated resources (table 1). The area underlain by lignite in Zapata County decreases as bed thickness increases. In the San Miguel area, the area underlain by 2.5 to 5 ft and >5 to 10 ft beds is nearly identical. The area for 10 ft beds is smaller and mainly in the vicinity of the San Miguel mine.

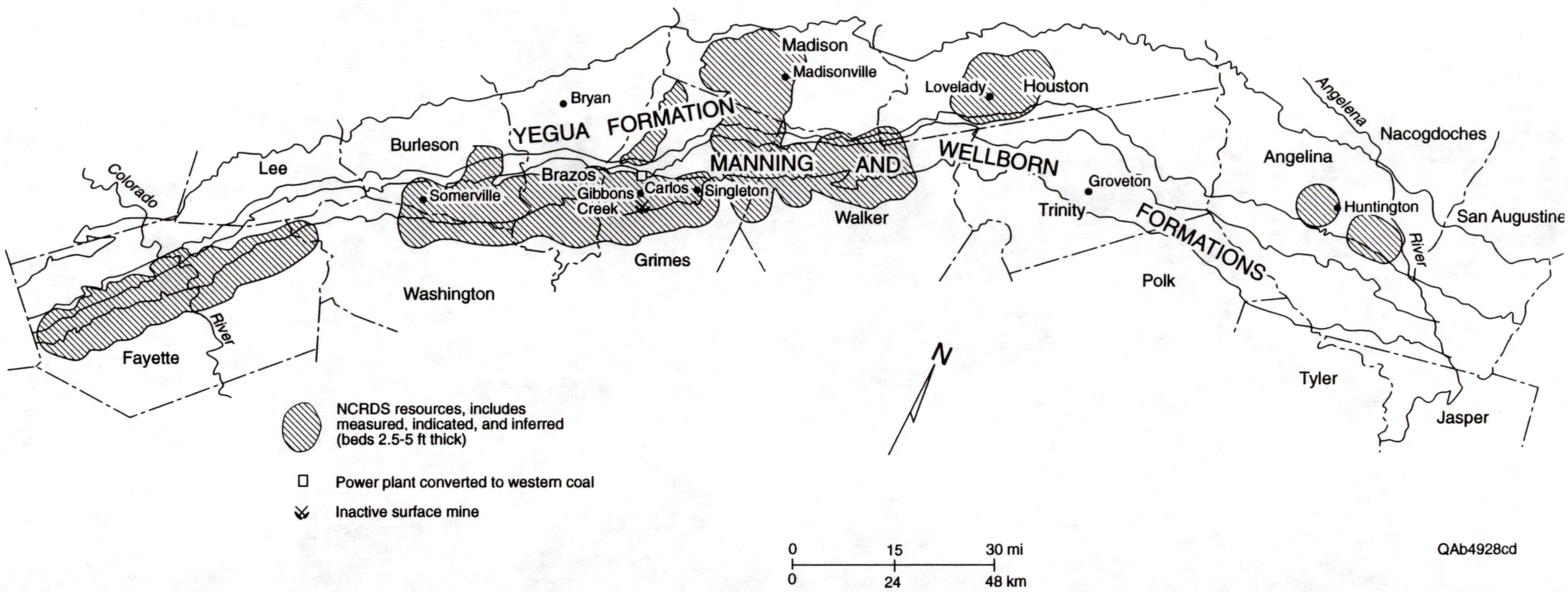

Figure 4. NCRDS resources in beds 2.5 to 5 ft thick, Jackson-Yegua east region.

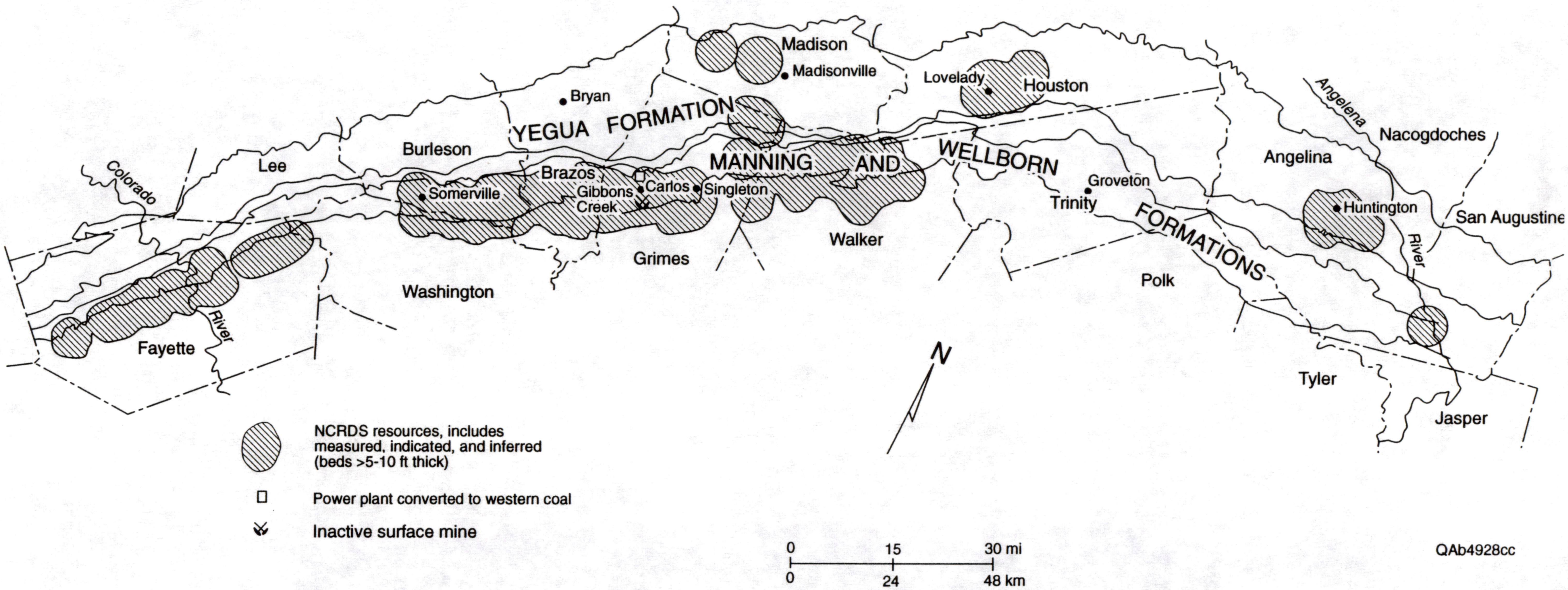

Figure 5. NCRDS resources in beds >5 to 10 ft thick, Jackson-Yegua east region.

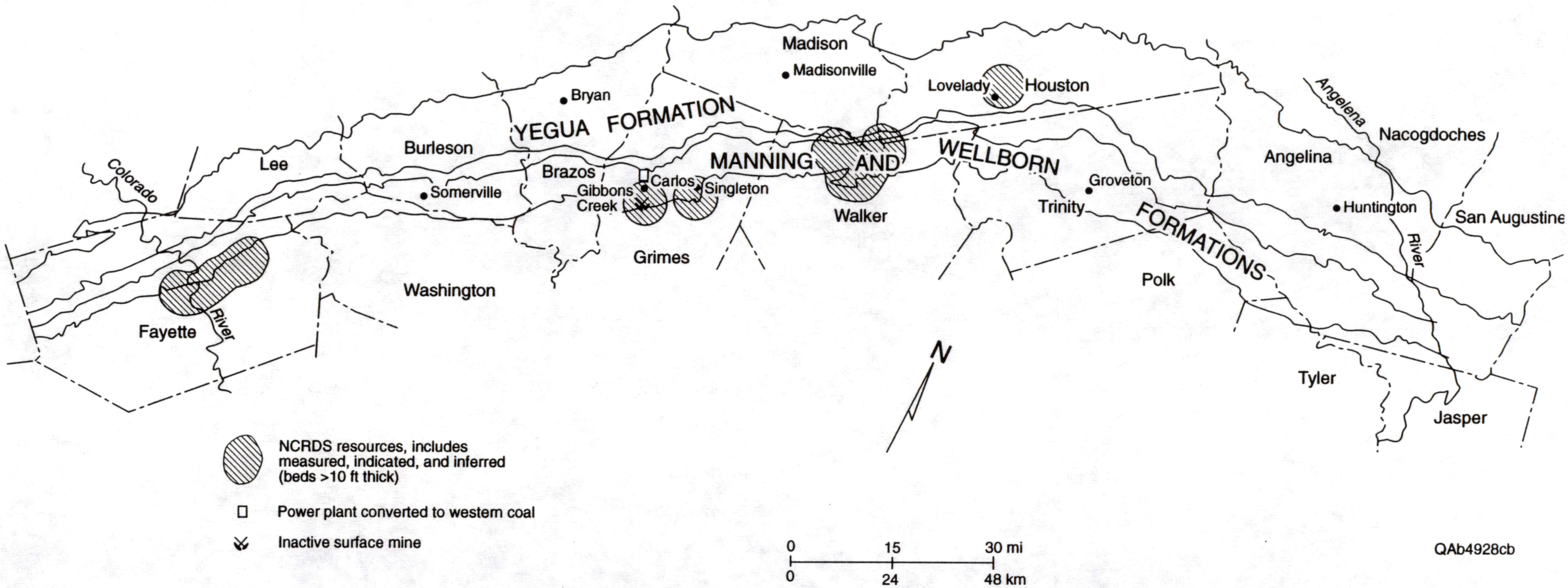

Figure 6. NCRDS resources in beds >10 ft thick, Jackson-Yegua east region.

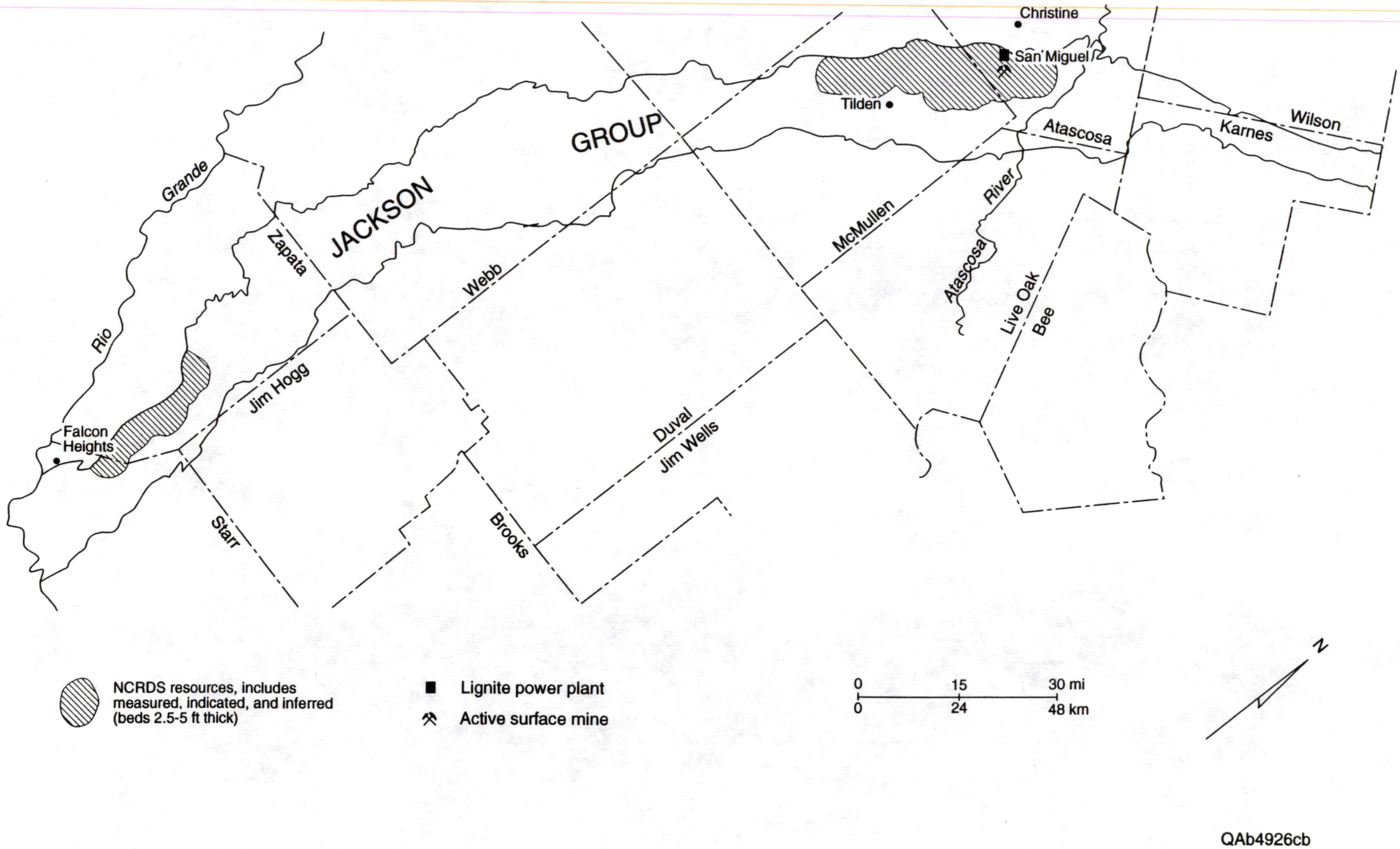

Figure 7. NCRDS resources in beds 2.5 to 5 ft thick, Jackson south region.

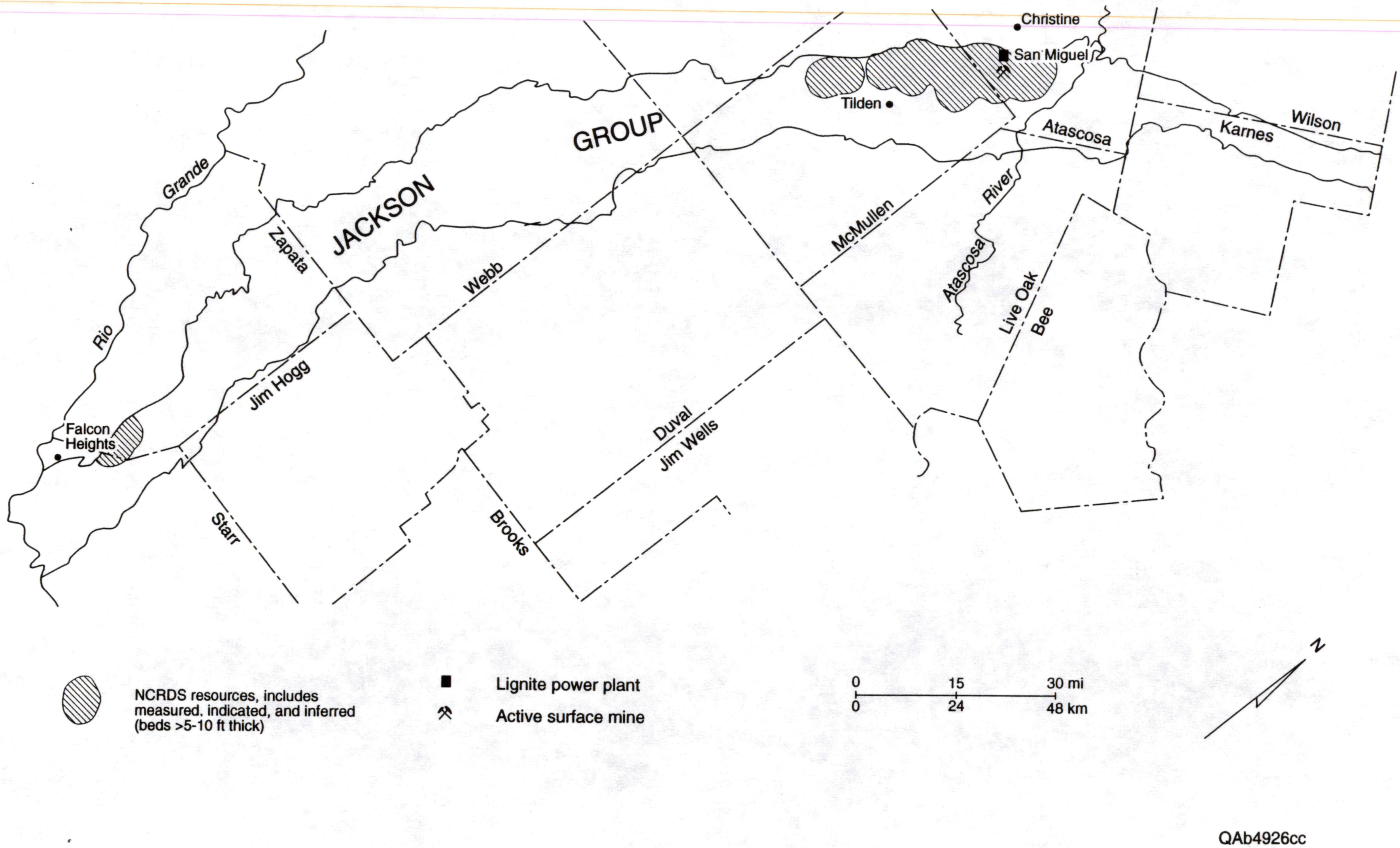

Figure 8. NCRDS resources in beds >5 to 10 ft thick, Jackson south region.

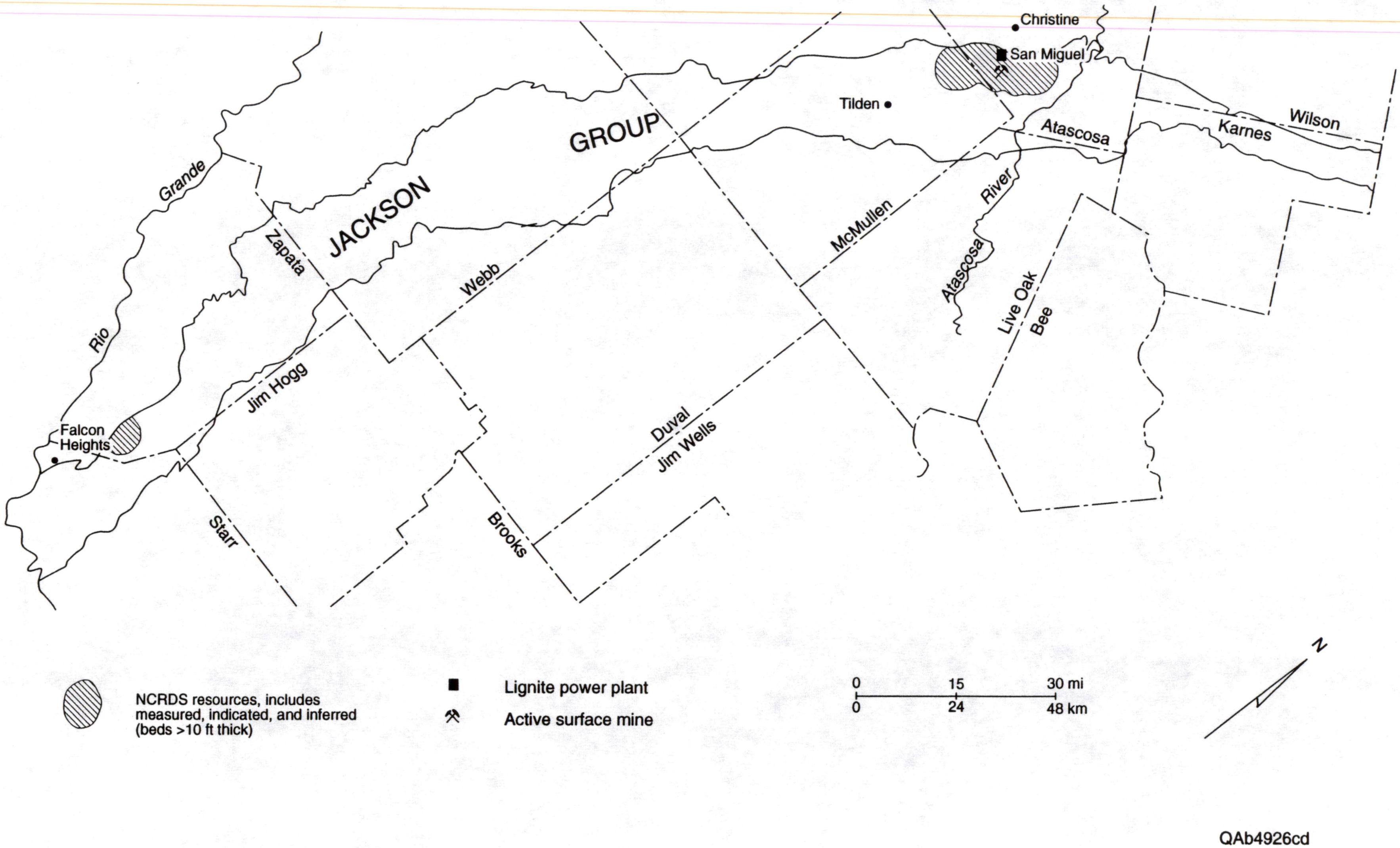

Figure 9. NCRDS resources in beds >10 ft thick, Jackson south region.

Table 1. NCRDS resources (millions of short tons) by USGS thickness category in three new regions.

Thickness category (ft)	Certainty Category			
	Measured	Indicated	Inferred	Total
		Jackson/Yegua East Texas		
2.5–5	557	1,684	5,234	7,475
>5–10	608	1,434	5,313	7,355
>10	81	206	1,301	1,588
Total	1,246	3,324	11,848	16,418
		Jackson South Texas		
2.5–5	173	290	768	1,231
>5–10	63	137	408	608
>10	19	32	100	151
Total	255	459	1,276	1,990
		Wilcox South Texas		
2.5–5	53	106	285	444
>5–10	23	42	92	157
>10	0	0	0	0
Total	76	148	377	601

Wilcox South

NCRDS resources in the Wilcox trend of South Texas (fig. 1) occur in three widely separated areas (Chacon, Pulliam Ranch, and Yancey) (figs. 10 and 11) and total 601 million tons, of which 224 million tons are demonstrated resources (table 1). The area underlain by >5 to 10 ft beds is reduced for Chacon and Pulliam Ranch areas and absent at Yancey. There are no beds >10 ft thick.

Texas Resources

NCRDS resources in Texas total 46,979 million tons, of which 15,767 million tons (34 percent) are demonstrated resources (table 2). Two-thirds (66 percent) of the resources are in the Wilcox trend and one-third (34 percent) in the Jackson-Yegua trend (table 3). Among regions, Jackson-Yegua east is richest in demonstrated resources (4,570 million tons or 29 percent) followed by Wilcox east-central with 4,162 million tons (26 percent). Most of the demonstrated resources (9,923 million tons or 63 percent) are in beds 2.5 to 5 ft thick, reflecting the thin-bed nature of Texas lignites. Note that only 5 percent of the resources are in beds greater than 10 ft thick, reflecting their rarity in Texas.

COMPARISON

To compare NCRDS resource estimates (Tewalt and Jackson, 1991; this report) with BEG estimates (Kaiser and others, 1980), NCRDS resources were calculated using the same data base and thickness category (≥3 ft) the BEG used. USGS methodology, as outlined above, is standardized for use nationally to allow resource comparison among the states. In contrast, the BEG relied on geologic models (depositional setting and coal occurrence) to calculate resources consistent with the geologic setting and Texas mining practice in an attempt to estimate reserves (Kaiser and others, 1980). Texas mines typically recover beds ≥3 ft thick to 200 ft. The USGS method, as implemented here, essentially disregards geologic setting.

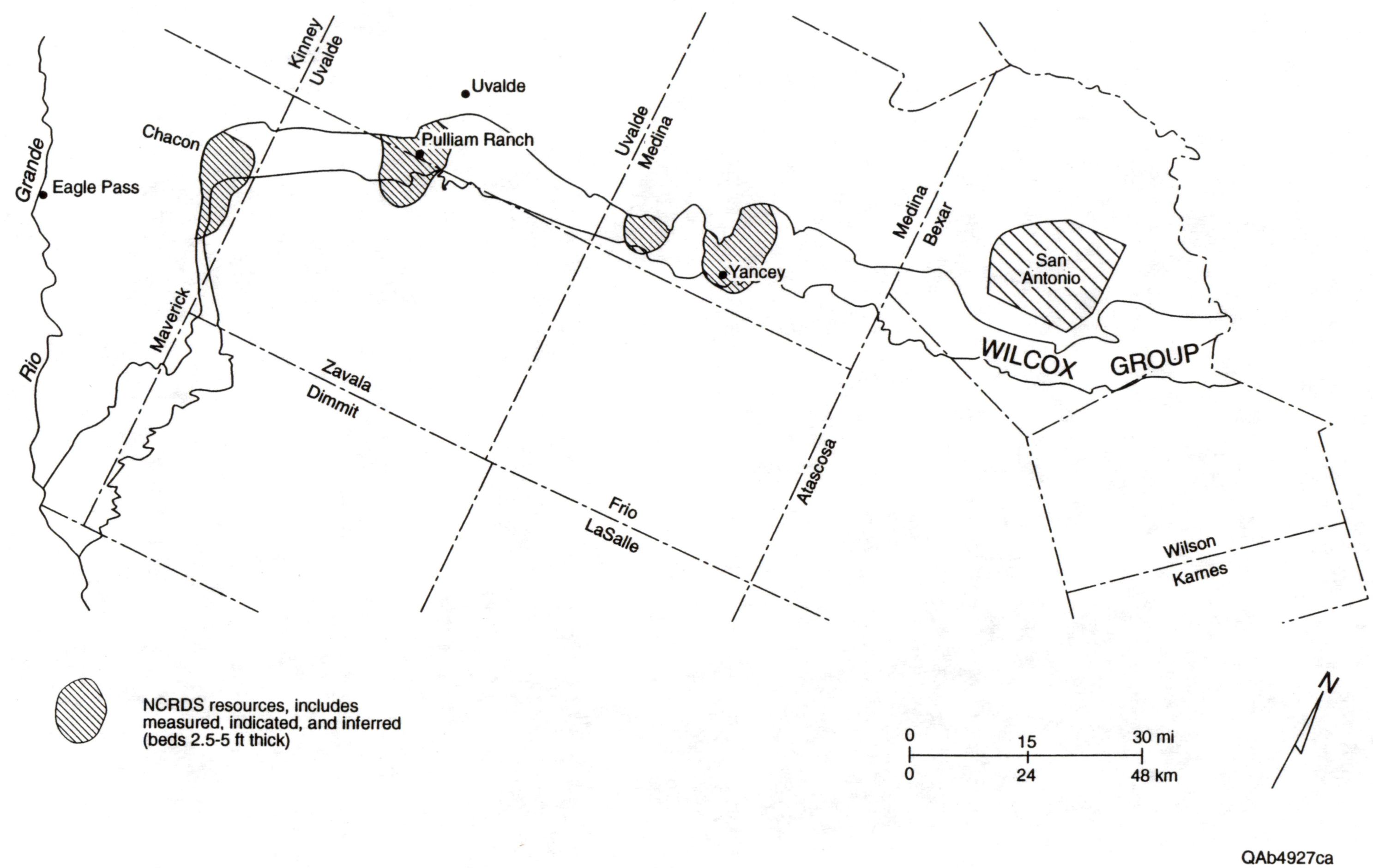

Figure 10. NCRDS resources in beds 2.5 to 5 ft thick, Wilcox south region.

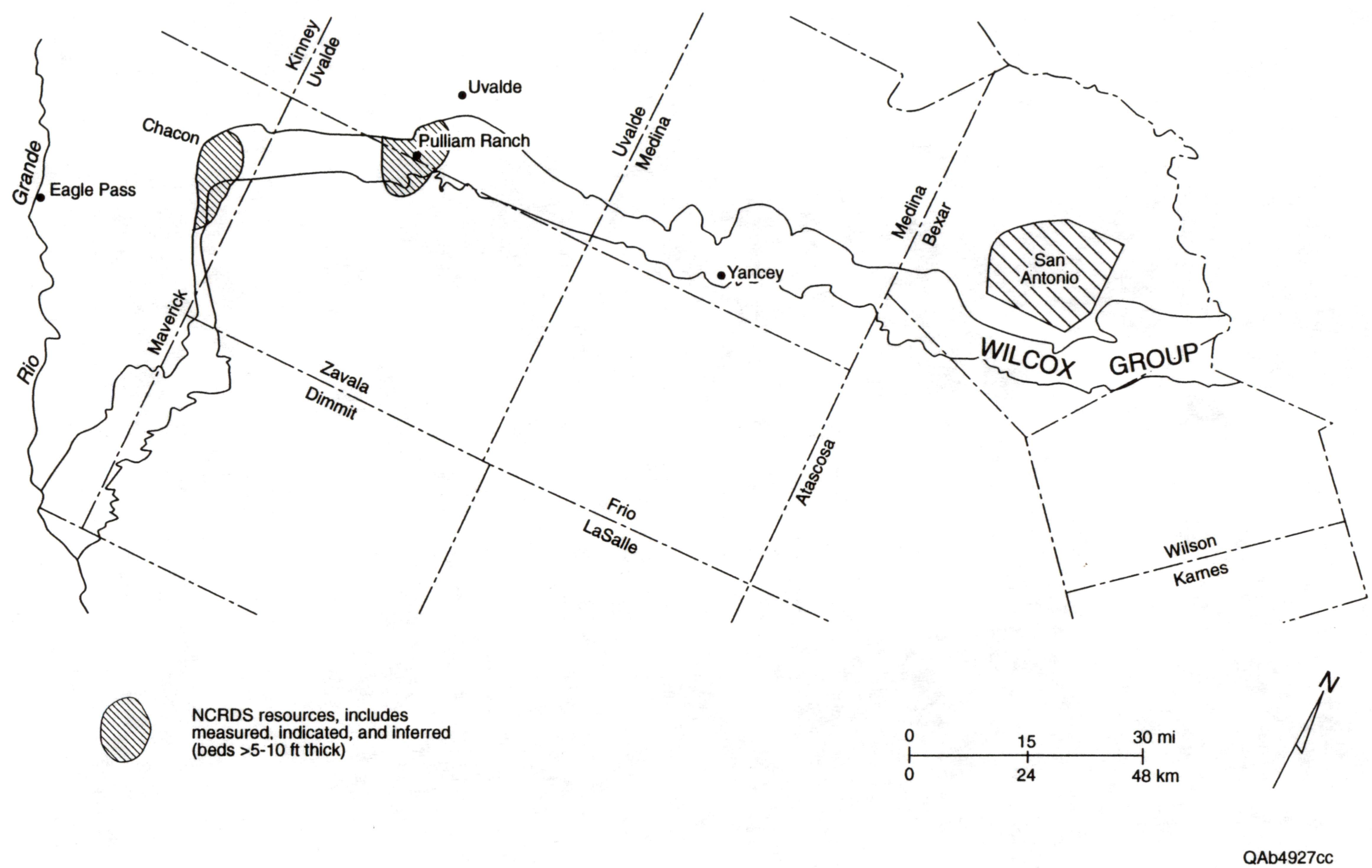

Figure 11. NCRDS resources in beds >5 to 10 ft thick, Wilcox south region.

Table 2. Texas NCRDS resources (millions of short tons) by region.

Region	Measured	Certainty Category Indicated	Inferred	Total
Wilcox Sabine Uplift[a]	835	2,672	7,209	10,716
Wilcox northeast[a]	600	1,990	5,912	8,502
Wilcox east-central[a]	1,282	2,880	4,590	8,752
Wilcox south[b]	76	148	377	601
Wilcox subtotal	2,793	7,690	18,088	28,571
Jackson/Yegua east[b]	1,246	3,324	11,848	16,418
Jackson south[b]	255	459	1,276	1,990
Jackson/Yegua subtotal	1,501	3,783	13,124	18,408
Total	4,294	11,473	31,212	46,979

[a]From Tewalt and Jackson, 1991.
[b]This report.

Table 3. Texas NCRDS demonstrated resources (millions of short tons) by thickness category and region.

	2.5–5 ft		>5–10 ft		>10 ft		Total	
Region	**tonnage**	**percent**	**tonnage**	**percent**	**tonnage**	**percent**	**tonnage**	**percent**
Wilcox Sabine Uplift[a]	2,409	15	1,070	7	28	<1	3,507	22
Wilcox northeast[a]	1,947	12	584	4	59	<1	2,590	17
Wilcox east-central[a]	2,704	17	1,083	7	375	2	4,162	26
Wilcox south[b]	159	1	65	<1	0	0	224	1
Wilcox subtotal	7,219	46	2,802	18	462	3	10,483	66
Jackson-Yegua east[b]	2,241	14	2,042	13	287	2	4,570	29
Jackson south[b]	463	3	200	1	51	<1	714	5
Jackson-Yegua subtotal	2,704	17	2,242	14	338	2	5,284	34
Total	9,923	63	5,044	32	800	5	15,767	100

[a]From Tewalt and Jackson, 1991.
[b]This report.

Definition of BEG Resources

The BEG calculated measured resources from data points (mainly boreholes with density logs) spaced in such a way that key geologic parameters, number of beds, bed thickness, and their lateral extent can be established and deposits outlined (Kaiser and others, 1980). For each deposit, data usually consisted of one strike cross section and two or three dip sections prepared from 50 to 200 logs typically on quarter-mile centers (figs. 12 and 13). To outline deposits, all beds were projected updip to 20 ft of cover and downdip to 200 ft of cover, thereby outlining the area underlain by near-surface lignite accessible to surface mining. Total lignite in beds ≥3 ft thick was plotted for each borehole, isopached, and planimetered for subsequent calculation of a tonnage factor determined by dividing resources by acreage. Resources were calculated by applying the appropriate tonnage factor to productive acreage synthesized from deposit and lease outlines (fig. 12).

Indicated resources are those computed on the basis of widely spaced boreholes, approximately 1 to 6 mi apart, and geologic setting. Productive acreage was determined by extension from measured deposits, geologic evidence (scattered density logs, old mine workings, stratigraphic occurrence), industry comment, leased acreage, and projection guided by geologic models (fig. 12). Resources were calculated by applying a tonnage factor consistent with measured deposits of a particular region.

Inferred resources are those computed only from geologic setting and projection; little proof of the presence of lignite exists, except for published reports of lignite outcrops. These resources lie in extensions beyond the boundaries of demonstrated resources and at the intersection with the outcrop of the updip projection of lignite mapped in the deep basin (fig. 12). For example, inferred resources of deltaic origin are separated along the outcrop by the updip projection of lignite-barren or lignite-poor interdeltaic areas. In fluvial settings, interchannel lignite is separated by channel sand belts.

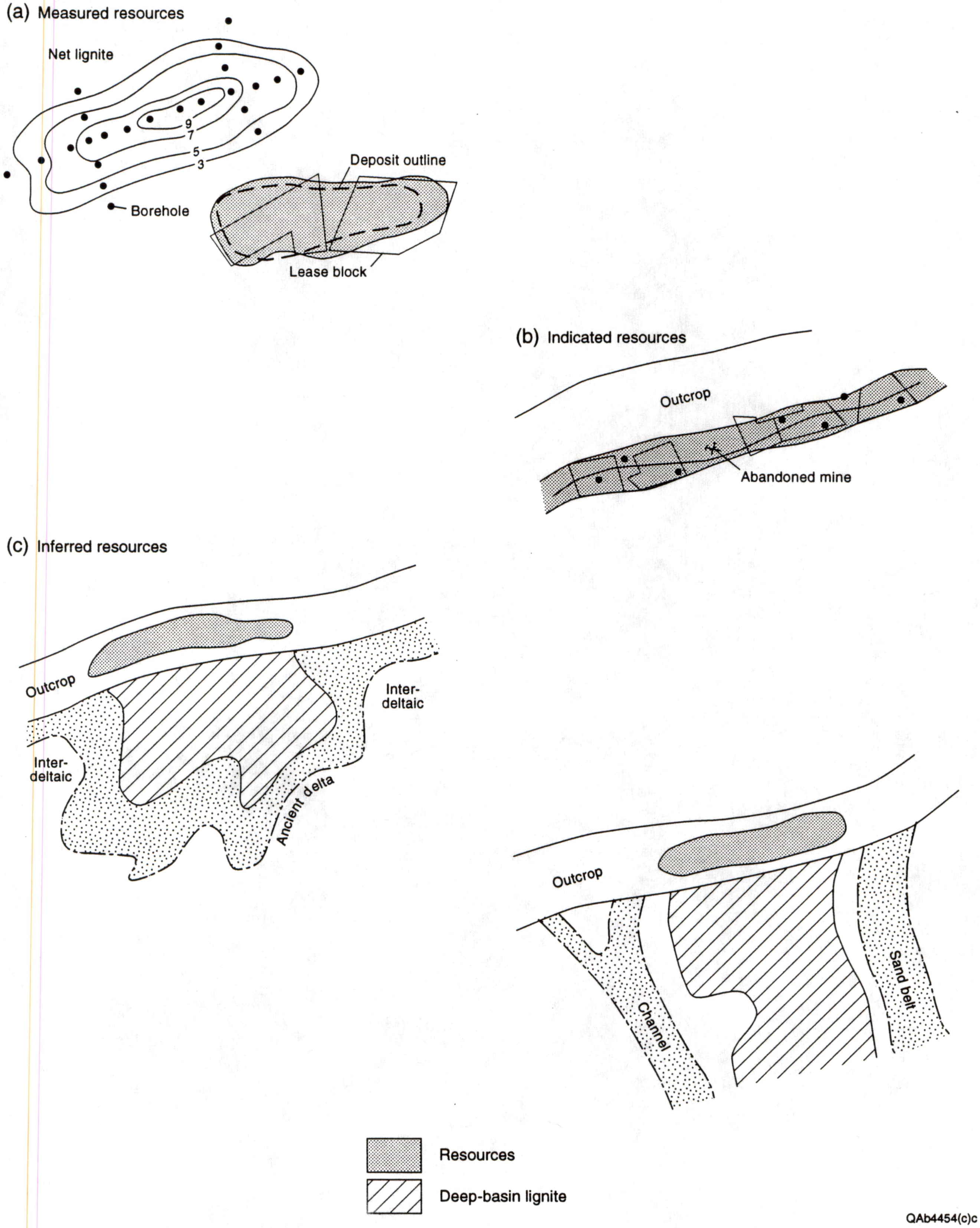

Figure 12. Definition of BEG resources. Measured and indicated resources incorporate leaseholder information. Inferred resources rely on deep-basin mapping and projection.

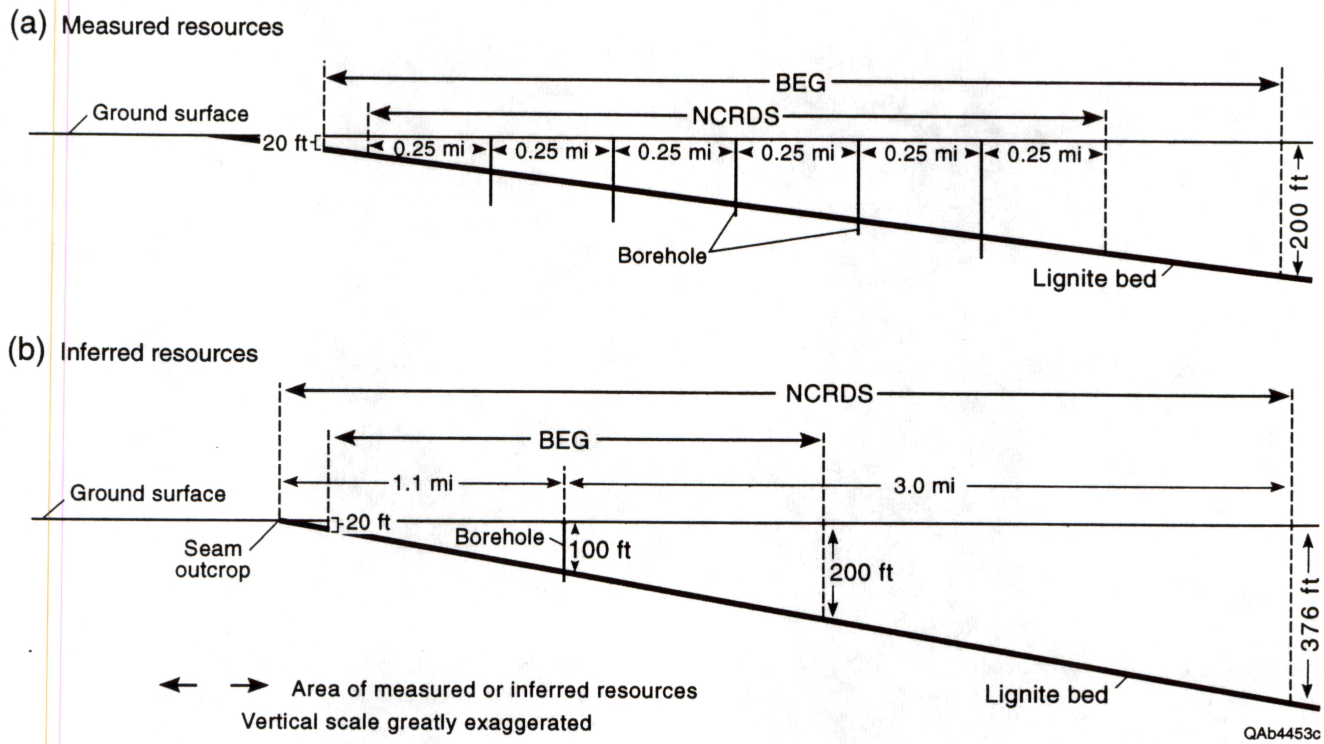

Figure 13. Schematic calculation of measured and inferred resources for a bed dipping at 1° (modified from Tewalt and Jackson, 1991). NCRDS measured resources require close-spaced data for definition. BEG inferred resources reflect mining depth parameters.

Region Comparisons

NCRDS resources in the Jackson-Yegua trend of East Texas (fig. 1) total 13,098 million tons (table 4), of which 3,910 million tons are demonstrated resources (table 5), whereas corresponding BEG resources are 6,050 and 4,839 million tons. Large inferred resources inflate the NCRDS total and reflect extension of inferred circles updip into the outcrop of stratigraphic units barren of lignite (e. g., Caddell Formation in Fayette County) and downdip into the deep basin (fig. 14). BEG demonstrated resources are large because of indicated resources in Trinity County defined from outcrop occurrences and projection of deltaic lignite from the deep basin (Kaiser and others, 1980). In the absence of borehole data, no NCRDS resources were calculated.

NCRDS resources in the Jackson trend of South Texas (fig. 1) total 1,847 million tons (table 4), of which 660 million tons are demonstrated resources (table 5), whereas corresponding BEG resources are 757 and 734 million tons. The large inferred category inflates the NCRDS total and reflects extension of inferred circles updip and downdip (fig. 15). BEG demonstrated resources account for 97 percent of its total resource and are defined by boreholes, stratigraphic occurrence in the lower Jackson Group, and projection north and south to outcrop of the Jackson linear clastic shoreline (Kaiser and others, 1980). The absence of lignite between the San Miguel and Rio Grande valley areas is attributed to the dominance of ancient lagoonal sediments and absence of suitable platforms for peat (lignite) accumulation.

NCRDS resources in the Wilcox trend of South Texas (fig. 1) total 607 million tons (table 4), of which 215 million tons are demonstrated resources (table 5), whereas corresponding BEG resources are 1,078 and 509 million tons. As in the other two regions, inferred resources is the largest NCRDS category. Small NCRDS and BEG resources reflect sparse drilling, restricted stratigraphic occurrence, and poorly understood geologic setting (Kaiser and others, 1980). This is particularly evident in the uncertainty about the position of the basal Wilcox contact in northeast Maverick, northwest Zavala, and southern Uvalde Counties (fig. 16). The contact of Kaiser and

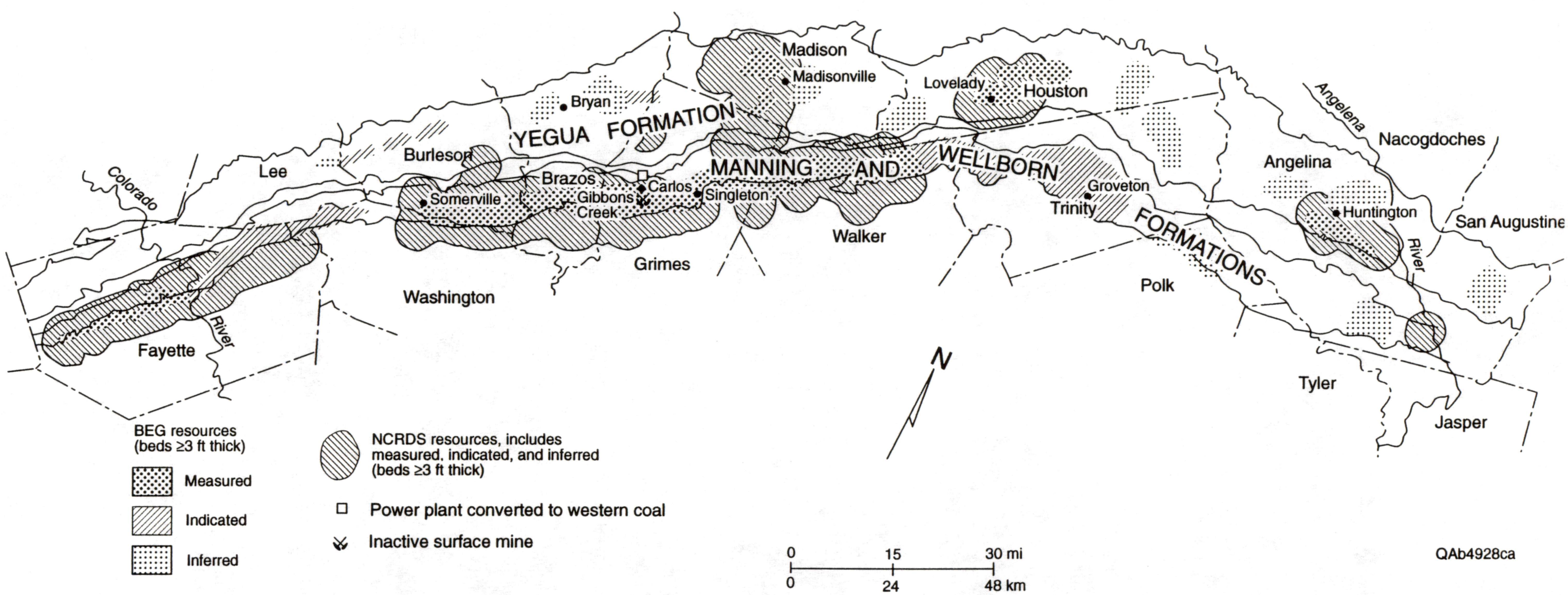

Figure 14. Comparison of NCRDS and BEG resources in beds ≥3 ft thick, Jackson-Yegua east region.

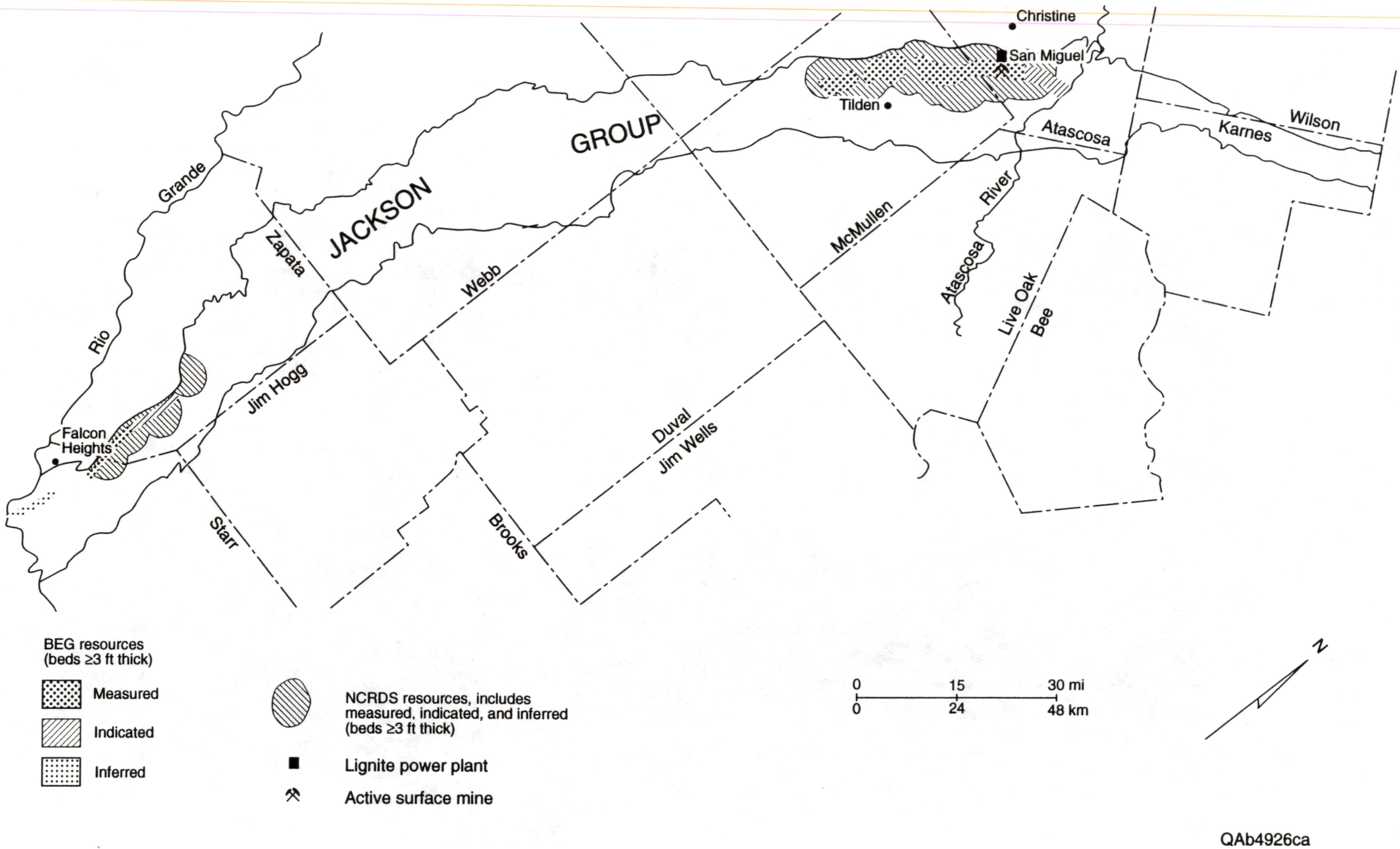

Figure 15. Comparison of NCRDS and BEG resources in beds ≥3 ft thick, Jackson south region.

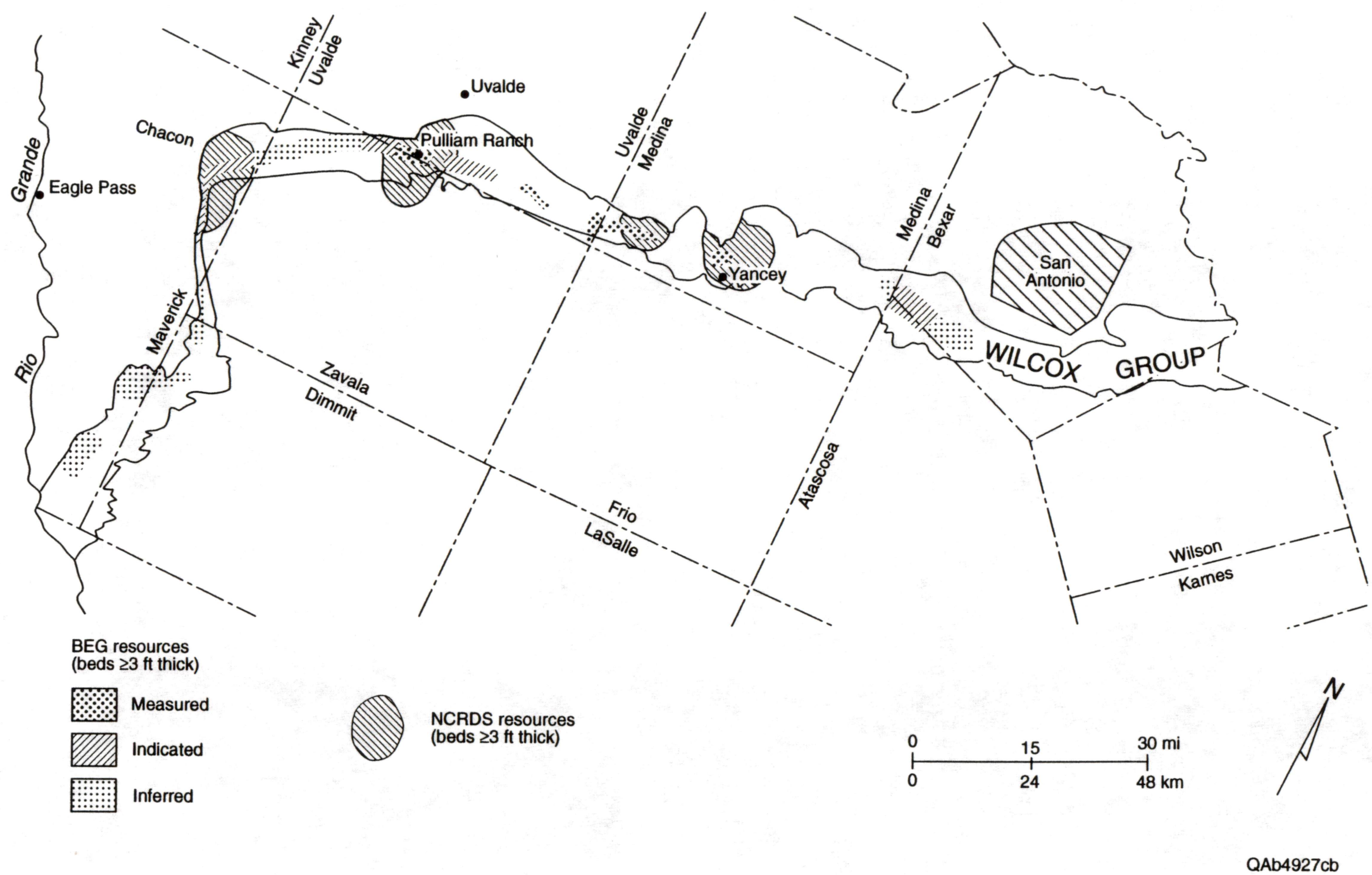

Figure 16. Comparison of NCRDS and BEG resources in beds ≥3 ft thick, Wilcox south region.

Table 4. Comparison of NCRDS and BEG resources (millions of short tons).[a]

Region	Measured		Indicated		Inferred		Total	
	NCRDS	BEG	NCRDS	BEG	NCRDS	BEG	NCRDS	BEG
Wilcox Sabine Uplift[b]	792	3,200	2,344	598	5,470	114	8,606	3,912
Wilcox northeast[b]	514	2,634	1,644	1,964	5,114	501	7,272	5,099
Wilcox east-central[b]	1,174	3,450	2,438	2,455	3,524	576	7,136	6,481
Wilcox south[c]	75	150	140	359	392	569	607	1,078
Wilcox subtotal	2,555	9,434	6,566	5,376	14,500	1,760	23,621	16,570
Jackson-Yegua east[c]	1,168	2,915	2,742	1,924	9,188	1,211	13,098	6,050
Jackson south[c]	248	567	412	167	1,187	23	1,847	757
Jackson-Yegua subtotal	1,416	3,482	3,154	2,091	10,375	1,234	14,945	6,807
Total	3,971	12,916	9,720	7,467	24,875	2,994	38,566	23,377

[a]Calculated in terms of beds ≥3 ft thick.
[b]NCRDS from Tewalt and Jackson, 1991; BEG from Kaiser and others, 1980.
[c]NCRDS this report; BEG from Kaiser and others, 1980.

Table 5. Comparison of NCRDS and BEG demonstrated resources (millions of short tons)[a]

Region	NCRDS	BEG
Wilcox Sabine Uplift[b]	3,136	3,798
Wilcox northeast[b]	2,158	4,598
Wilcox east-central[b]	3,612	5,905
Wilcox south[c]	215	509
Wilcox subtotal	9,121	14,810
Jackson-Yegua east[c]	3,910	4,839
Jackson south[c]	660	734
Jackson-Yegua subtotal	4,570	5,573
Total	13,691	20,383

[a]Calculated in terms of beds ≥3 ft thick.
[b]NCRDS from Tewalt and Jackson, 1991; BEG from Kaiser and others, 1980.
[c]NCRDS this report; BEG from Kaiser and others, 1980.

others (1980) may unduly restrict resources. Lignite distribution clearly shows it should lie farther north but with its exact position unknown because of Quaternary cover (Barnes, 1976).

Texas Comparison

NCRDS resources statewide total 38,566 million tons (table 4), of which 13,691 million tons (35 percent) are demonstrated resources (tables 5 and 6), whereas corresponding BEG resources are 23,377 million tons and 20,383 million tons (86 percent). Large inferred resources inflate the NCRDS total. In each region, NCRDS inferred resources exceed demonstrated resources, whereas only in the Wilcox south region is this true for BEG resources. The two lignite-richest regions are Wilcox east-central and Jackson-Yegua east.

The size of the USGS certainty categories will always cause the majority of NCRDS coal resources to be inferred, because the radius of the inferred circle is four times that for demonstrated resources (fig. 3). For example, the size of the USGS inferred circle causes the whole Jackson Group outcrop to be shown as lignite bearing (fig. 14), including areas barren of coal by reason of stratigraphy or depositional setting and with as much as 500 ft of overburden.

The BEG constrained inferred resources and maximized demonstrated resources using geologic models, which combine knowledge of depositional systems, stratigraphic occurrence, and regional dip to calculate resources from meager data (fig. 12). Depending on the geologic setting, a few data points may define measured resources, for example, deltaic Jackson in East Texas or strandplain Jackson in South Texas. In contrast, the USGS method is highly data dependent and in the absence of point-source data can make no allowance for demonstrated resources as defined and estimated with moderate certainty by the BEG using geologic models. This is true of Jackson BEG indicated resources in Trinity County (fig. 14) or upper Calvert Bluff BEG indicated resources north of the Brazos River in east-central Texas (Tewalt and Jackson, 1991). As a result, demonstrated resources are underestimated by the USGS in the absence of point-source data and inferred resources are inflated (fig. 13).

Table 6. Comparison of NCRDS and BEG resources by percent.[a]

Region	Measured		Indicated		Inferred		Total	
	NCRDS	BEG	NCRDS	BEG	NCRDS	BEG	NCRDS	BEG
Wilcox Sabine Uplift[b]	2	13	6	3	14	1	22	17
Wilcox northeast[b]	1	11	4	8	13	2	19	21
Wilcox east-central[b]	3	15	6	10	9	3	18	28
Wilcox south[c]	<1	1	<1	2	1	2	2	5
Wilcox subtotal	7	40	17	23	38	8	61	71
Jackson-Yegua east[c]	3	12	7	8	24	5	34	25
Jackson south[c]	<1	2	1	1	3	<1	5	4
Jackson-Yegua subtotal	4	14	8	9	27	6	39	29
Total	10	54	25	32	65	14	100	100

[a]Resources calculated in terms of beds ≥3 ft thick.
[b]NCRDS percent based on Tewalt and Jackson, 1991; BEG from Kaiser and others, 1980.
[c]NCRDS percent based on this report; BEG from Kaiser and others, 1980.

Combination of Methods

To develop better methods for calculating resources from limited data, the best features of the computerized and geologic methods must be combined. The NCRDS works best in the presence of abundant borehole data. As these data become fewer, geologic methods must be increasingly relied upon. USGS methodology could be modified to include geologic boundaries determined by depositional setting and by using information from lease holders, thereby eliminating much of the inferred resource area (Tewalt and Jackson, 1991). Within a geologically defined domain, radii of circles-of-certainty could be adjusted to reflect coalbed continuity appropriate to the depositional setting. For example, the demonstrated circles could be enlarged in areas where beds are continuous such as in the lower Calvert Bluff Formation of east-central Texas (Kaiser and others, 1980). Where beds are less continuous (Wilcox Group of northeast Texas) circles would be reduced in size. Furthermore, the radii of inferred circles, depending on dip, could be adjusted such that all regions have equal depths of overburden. Finally, tonnage factors calculated using GRASS could be used to calculate inferred resources delineated geologically (fig. 12).

CONCLUSIONS

1. Calculation of Texas lignite resources, according to USGS methodology, using the National Coal Resources Data System (NCRDS) and software, is now complete. NCRDS resources total 46,979 million tons, of which 15,767 million tons (34 percent) are demonstrated resources. Most of the resources are in beds 2.5 to 5 ft thick; beds 10 ft or more thick are rare. Two-thirds of the resources are in the Wilcox trend and one-third in the Jackson-Yegua trend. The state's richest lignite regions are Jackson-Yegua east and Wilcox east-central.

2. NCRDS and BEG resources were compared on the basis of the same data base and thickness category. The USGS method is geologically unsophisticated but standardized and applicable throughout the United States, whereas the BEG method relied on geologic models, requiring considerable geologic expertise to extrapolate resources beyond known deposits.

NCRDS resources statewide total 38,566 million tons, of which 13,691 million tons (35 percent) are demonstrated resources, whereas corresponding BEG resources are 23,377 million tons and 20,383 tons (86 percent).

3. The USGS method, as implemented here, underestimates demonstrated resources and inflates inferred resources. The BEG, using geologic models, constrained inferred resources and maximized demonstrated resources. The USGS method is highly data dependent and can make no allowance for demonstrated resources as defined and estimated by the BEG with moderate certainty from limited data using geologic models.

4. Improved resource estimates from limited data will require combining the computerized and geologic methods. This could be done by geologically defining resource areas, by using information from lease holders, by adjusting resource circles to reflect coalbed continuity and dip, and by using GRASS calculated tonnage factors.

ACKNOWLEDGMENTS

This work was funded by the U.S. Geological Survey under cooperative agreements nos. 14-08-0001-A0848, 1434-92-A-0953, 1434-93-A-1114, 1434-94-A-1211, 1434-95-A-01333 and Bureau of Economic Geology matching funds. Mary L. W. Jackson coordinated data input and resource calculation. Scott Goode created data files for use in GRASS. Susan J. Tewalt (USGS) made the resource calculations.

REFERENCES

Barnes, V. E., project director, 1976, Crystal City—Eagle Pass Sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

Kaiser, W. R., Ayers, W. B., Jr., and La Brie, L. W., 1980, Lignite resources in Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 104, 52 p.

Mitasova, Helena, 1992, Surfaces and modeling: U.S. Army Construction Engineering Research Laboratory, Grassclippings Winter 1992, p. 16-18.

Tewalt, S. J., and Jackson, M. L. W., 1991, Estimation of lignite resources in the Wilcox Group of central and East Texas using the National Coal Resources Data System: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 91-1, 44 p.

Wood, G. H., Jr., Kehn, T. M., Carter, M. D., and Culbertson, W. C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.