Availability of Coal Resources in the Fruitland Formation, San Juan Basin, Northwest New Mexico

By

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Introduction

Coal is an important part of New Mexico's economy and contributes substantially to New Mexico's Permanent Fund. The state ranked 16th in the nation in coal production (24.07 million st, 1996) and almost two-thirds of this product is used for electrical generation. Coal-fired power plants are close to mine mouths because of the high cost ($24.66/st, 1996) of New Mexico coal. Coal prices are high because the seams are lenticular, relatively thin (less than 20 ft), and multiple seams are mined. Compared to other western states, in particular Wyoming, New Mexico coal is expensive to mine, which prohibits transporting the product over long distances. Lack of rail transportation also plays a part in limiting markets for New Mexico coal, particularly for the San Juan Basin (SJB) in northwestern New Mexico. Economics dictate transmitting electricity from the SJB to other western and Pacific Coast states rather than shipping coal there.

Approximately 60% of New Mexico's coal production is from the Late Cretaceous Fruitland Formation. This coal-bearing unit has some of the thickest coals mined in the SJB, and they are less discontinuous over short distances than other coal-bearing sequences in the basin. Three of the six mines in New Mexico are operated by BHP Minerals: the San Juan, La Plata and Navajo mines; and produce coal from this formation. The Navajo mine is the 21st largest mine in the nation, producing over 7 million st in 1996. This mine has been operating for 34 years with total output of over 217 million st.

With the economic and geologic factors mentioned above in mind, four quadrangles on the northeast edge of the Bisti field were chosen for this study (Fig. 1). This area along the Fruitland outcrop has economic potential because of its proximity to the existing power plants and for the relative continuity of the coal seams. The southern extent of BHP Minerals Navajo mine is approximately 16

miles northwest of the study area and the recently relinquished leases of the Conpaso mine (El Paso Natural Gas Navajo Lease) are immediately west of the study area. Within this area, two small mines, the De-Na-Zin and Gateway, were in production during the 1980s.

Background and purpose

In the continuing effort to estimate better the coal resources available in New Mexico, the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) participated in a one-year study funded by the Department of Energy to reevaluate coal reserves in the SJB, New Mexico. From this study, the updated demonstrated reserve base (DRB) estimate is 11.24 billion short tons (st) of surface and deep coal. This updated total compares with 4.43 billion st in the Energy Information Administration's DRB for all of New Mexico, and 2.81 billion st for the SJB, as of January 1, 1993. These new estimates of "remaining" coal resources include significant adjustments for past production and recovery rates (through 1994). The updated estimates also incorporate analyses of available sulfur, heat, and ash content for characterizing New Mexico's remaining coal resources. Coal quality data (sulfur, ash, and Btu content) are examined along with coal resource data. The preliminary remaining, minable DRB estimate for the Bisti field is 2,040.76 million st of subbituminous low-sulfur coal (Hoffman, 1996a).

This study, funded by the US Geological Survey as part of the Coal Availability Program, looks at a small area (238 sq. mi.) of the westernmost Bisti field. The purpose of this study is to calculate the available resources by coal zone in a small area of the Fruitland Bisti field using the Geographic Information System (GIS) Arc Info. By applying the technological and land use restrictions, a more realistic available resource is obtained. Differences between this study and the DRB include:

(1) Use of GIS for resource calculations rather than hand calculation of reliability categories and drawing of coal thickness and overburden maps.

(2) Grouping the Fruitland coals by zones for quality analyses and resource calculations

(3) Recoverability of the available resource is not calculated. Recoverability involves calculating the resource that is economically minable with today's mining techniques. USGS personnel will do this.

(4) Although coal quality is considered, the available resource is not categorized by quality categories the same way as in the DRB study.

Geologic setting

Fruitland Formation exposures (Fig. 1) within the Bisti field trend southeast from the eastern boundary of the Navajo Indian Reservation, more or less parallel to the Late Cretaceous shoreline (N55°W). The Bisti field is about 35 mi long, and arbitrarily separated from the Star Lake field at the boundary between R9W and R8W. The entire coal field is within San Juan County and on the Toadlena and Chaco Canyon 1:100,000 quadrangles. The project area is at the western edge of the Bisti coal field and is entirely on the Toadlena quadrangle.

The Bisti field lies within the Chaco Slope physiographic area (Fig. 2), in gently dipping strata (3–5^{o}NNE). The study area encompasses a four-quadrangle area including Bisti, located on Fig. 2 at the western edge of this field. Significant faulting and high–angle dips are lacking, making surface mining more economical in the Bisti field. Erosion of the Fruitland Formation and overlying Kirtland Formation lithologies result in badlands topography and clinker (naturally burned coal) deposits. Overburden and interburden lithology of the Fruitland coals is largely mudstone, siltstone, and fine–grained friable sandstone.

Coal geology

The Fruitland Formation has four recognizable coal zones in the study area. Exploration projects, such as the El Paso Natural Gas Navajo Lease (Conpaso-Burnham) and the Bisti project by Public Service Co. of New Mexico, defined these four zones. The zones are from top to bottom: Yellow, Blue,

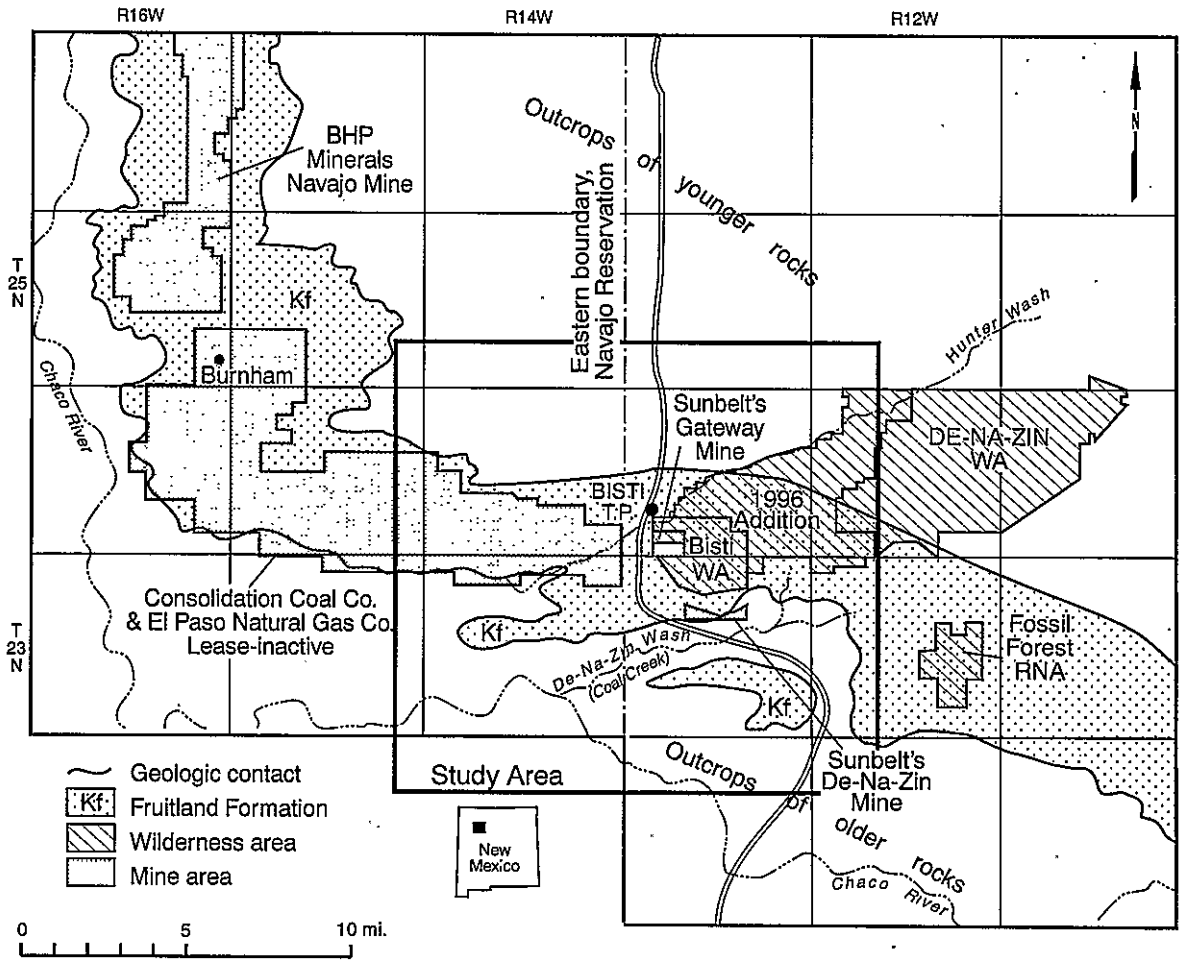


Figure 1. Location map for Bisti study area.

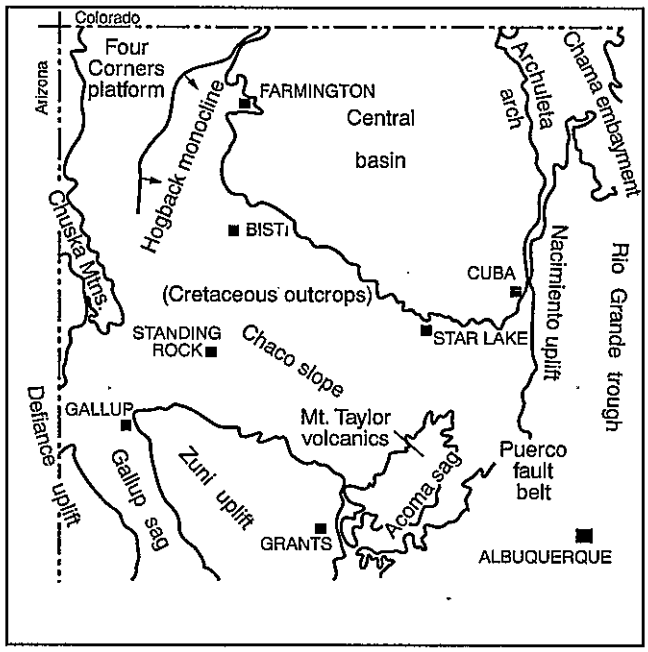


Figure 2. Tectonic map of San Juan Basin, New Mexico (from Beaumont, 1982, fig. 3; reprinted by permission of the American Association of Petroleum Geologists courtesy of E.C. Beaumont).

Green, and Red, using El Paso's terminology. In the study area, the average thickness of the coal-bearing Fruitland Formation is 102 ft, when the presence or absence of the Yellow zone is not considered. In wells where the Yellow zone is present, the average thickness of the Fruitland is 172 ft. A generalized stratigraphic column (Fig. 3) shows the general relationship of the zones.

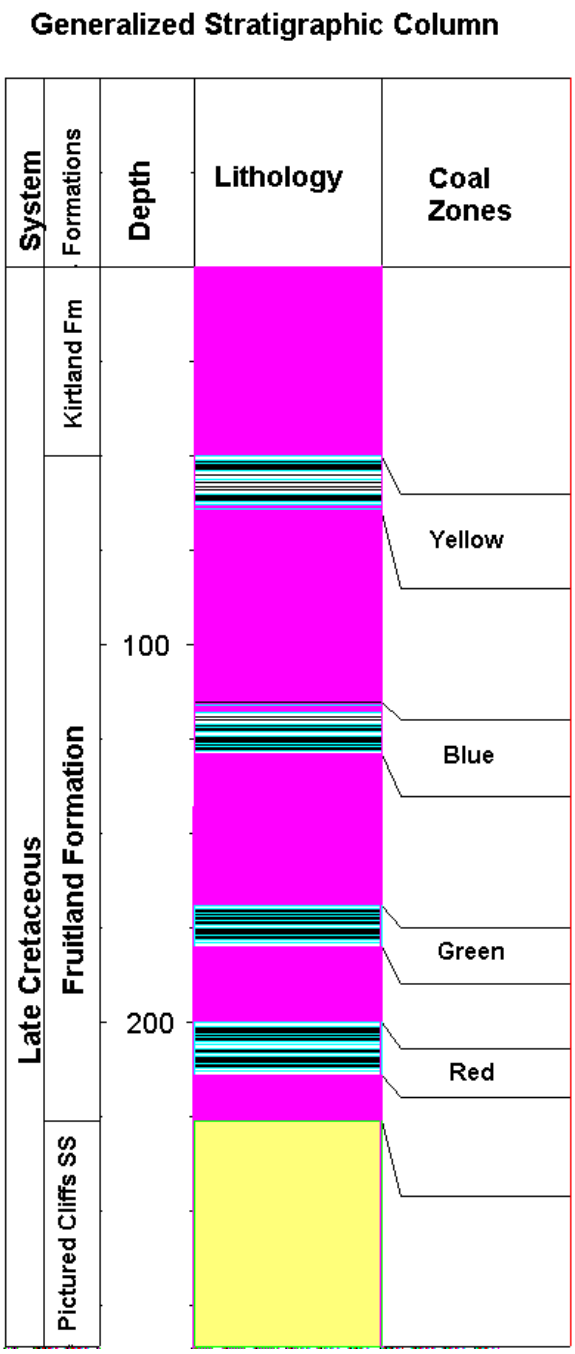


Figure 3. Generalized stratigraphic column of Fruitland Formation with coal zones in Bisti study area.

Other characteristics of the zones are in the following table:

Table 1. Coal zone characteristics

Zone (no. of data points)	Yellow (167)			Blue (263)			Green (280)			Red (438)		
(In ft.)	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Coal Seam Thickness (>=2.5 ft)	5.88	19.50	2.50	5.89	28.00	2.50	7.92	30.00	2.50	5.97	21.00	2.50
Total Coal Thickness in Zone	7.66	29.00	2.50	8.19	30.00	2.50	9.04	40.00	2.50	8.52	45.50	2.50
Zone Thickness	14.48	205.00	1.00	13.88	106.00	1.00	10.97	84.00	0.60	13.69	78.50	1.00
Number of Seams in Zone	1	4	1	1	4	1	1	3	1	2	3	1
Interburden Thickness	14.12	120.00	0.10	10.24	94.00	0.03	5.52	24.00	0.40	7.34	52.00	0
Included Parting Thickness	0.53	2.00	0	0.95	2.00	0	1.11	2.00	0	0.78	2.70	0

From Table 1, it is apparent that there is great variability within and between the zones. Zone thickness averages 11 to 14.5 ft. The Red zone averages two seams, but the remaining zones average one seam. Individual seam thickness averages from 6 to 8 ft, with the thickest being in the Green zone. The maximum interburden and zone thickness for the Yellow is misleading. Presumably, there is a zone above the Yellow with a few thin coals, which was not recognized in this study. The lenticularity of these zones is illustrated in cross sections (Fig. 4) along strike (Fig. 5., A-A') and down dip (Fig. 6, 7, - B-B', C-C'). Correlation of seams on these cross sections and for resource calculation is by zone rather than by bed, meaning that one coal does not necessarily represent the same bed in the adjacent section but rather the same zone.

Coal quality

The western Bisti field was considered suitable for the coal availability project in part because of the sulfur quality characteristics that indicated a potential compliance coal resource (0.41-0.60 Lbs of Sulfur/Mbtu, EIA, 1993). Weighted averages of Fruitland coal in the Bisti field (Hoffman, 1996b) are:

	Average	Std. Dev.	No. of Samples
Moisture (%)	13.93	3.33	44
Ash (%)	19.29	5.42	44
Volatile matter (%)	31.13	2.85	44
Fixed carbon (%)	35.60	4.46	44
Sulfur (%)	0.52	0.09	44
Calorific value (Btu/lb)	8754	883	44
Lbs of Sulfur/MBtu	0.61	0.12	48

When the available coal analyses for the study area are weighted by zone within each drill hole, the average sulfur values (Table 2) are within the same range as those from the entire field. However, the number of weighted samples for each zone is quite low therefore, the values are less statistically valid, particularly for the Green zone. The values derived suggest these coals would meet the New Source Performance Standards of the Clean Air Act of 1.2 pounds of sulfur dioxide emissions per million Btu of coal burned. About 0.1% of the total sulfur in these samples is pyritic sulfur, which might be removed by washing. The minimum sulfur values indicate that with blending, these coals could meet compliance standards.

Coals in the study area are nonagglomerating Subbituminous A, with relatively high ash yield, a common characteristic of Fruitland Formation coals. An average of the few oxide analyses available reveal the major constituent of the ash is SiO_2 (58%), followed by AlO_2 (25%), Fe_2O_3 (4%), CaO (3.5%), and Na_2O (1.9%). The remaining oxides are less than 1%.

Table 2. Weighted Average Analyses by Coal Zone from Fruitland Formation Bisti area.

Zone (no. of Samples)	Yellow (22)			Blue (24)			Green (9)			Red (26)		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Moisture (%)	14.88	19.09	10.60	15.19	25.28	9.00	15.99	20.43	12.70	15.91	20.75	12.60
Ash (%)	21.52	29.80	12.20	17.00	28.50	8.24	15.30	31.40	9.21	18.91	30.80	12.30
Volatile Matter (%)	29.89	33.40	20.70	30.49	34.70	22.90	32.41	35.40	28.80	30.22	34.30	23.50
Fixed Carbon (%)	32.77	43.80	23.00	35.67	45.70	28.70	36.24	40.60	25.60	35.02	47.80	26.30
Sulfur (%)	0.55	0.80	0.35	0.52	0.70	0.35	0.49	0.62	0.40	0.67	0.34	1.80
Btu/lb	8307	9621	6852	8932	10075	7710	9228	7170	10336	8745	9851	6909
MMFBtu /lb	10817	11569	8957	10956	11473	9878	11051	11898	10287	10996	10165	11412
Lbs Sulfur/MM Btu	0.66	0.92	0.46	0.58	0.82	0.35	0.53	0.63	0.45	0.79	2.31	0.36

Available data

The database for this study is a subset of the data collected and entered by the NMBMMR into the National Coal Resource Data System (NCRDS) as part of a long-term (19 years) cooperative grant with the USGS. Several exploration projects in the study area have resulted in a clustered data set (Fig. 4). Many of the drill holes are concentrated in the surface-minable area so less data is available for the deep coal area except where oil and gas logs are available. Other sources of drill hole data are mine plans, coal resource occurrence and coal development potential maps (CROCDP), NMBMMR drilling, and USGS investigations. Additional data were entered into the database after the project had begun in part to help fill in gaps. These data were obtained from the Bureau of Land Management (BLM) offices

in Farmington, New Mexico. The additional data were from recently relinquished leases and Preference Right Lease Applications on Federal lands.

The four quadrangles (and the number of data points) involved in this study are:

Alamo Mesa West: 67
Bisti Trading Post: 101
Tanner Lake: 64
The Pillar 3 NE: 7
TOTAL 238

The surrounding quadrangles with point data are:

Alamo Mesa East: 15
Burnham Trading Post: 75
Carson Trading Post: 48
Moncisco Wash: 64
Newcomb SE: 2
Pretty Rock: 95
The Pillar: 17
TOTAL 316

Methodology

Fruitland coals in the Bisti area are subbituminous (Table 2); therefore, resource calculations are based on a minimum thickness of 2.5 ft and 1770 tons/ac ft. The following parameters, which conform to USGS Circular 891 (Wood, et al., 1983), were used to calculate resources for each zone. Because of the lenticularity of the coals, resource calculations are based on total coal (≥2.5 ft) within a zone instead of individual seams. Coals that are less than 2.5 ft and above or below coals meeting the thickness criteria and are separated by a parting less than the thickness of the thinner coal are included in the calculation. The following are the resource criteria used in this study:

Thickness (ft):	**Depth (ft):**	**Reliability**
2.5-5	15:1 stripping ratio	Measured (1/4 mi)
5-10	0-250	Indicated (1/4-3/4 mi)
10-20	250-500	Inferred (3/4-3 mi)
>20	500-1000	
	>1000	

The reliability categories are limited to measured, indicated and inferred. Because of the lenticularity of these coal beds, the hypothetical category was not used in this study.

Line data for the Pictured Cliffs-Fruitland contact was digitized from USGS maps by O'Sullivan, Mytton, and, Strobell, 1986; O'Sullivan, Scott, and Heller, 1979; and Scott, O'Sullivan, and Mytton, 1979. Additional Fruitland crop line data were digitized from Beaumont, 1998. These line data form a boundary mask between areas of coal and no coal. Data files with elevations for tops of coal zones were gridded in Arc Info and overlain with a grid from the 1:100,000 Toadlena Digital Elevation Model (DEM). From this combined layer, the overburden maps for each zone were generated. The zero depth line for each zone is determined from the overburden layer.

From the original database, files for each zone with latitude, longitude, total thickness, and point identification were created. These files included data from quadrangles surrounding the four-quadrangle study area. By using data from surrounding quadrangles, reliability categories that overlap into the study area were included in the resource calculations. The data files were used to produce coal thickness grids and polygon files for the reliability categories. The reliability polygons were gridded and each cell assigned a thickness from the thickness grid. By overlaying the overburden layer onto the reliability layers, the total area (in m^2- converted to ac) for each thickness, depth, and reliability category were determined for the four-quadrangle area. Volumes (ac ft) were calculated using the thickness attribute of the cells, and finally multiplied by 1770 tons/ac ft to result in original resource tonnage (Tables 3-6) for each zone.

Land use restrictions were digitized from the 1:100,000 Toadlena quadrangle Digital Line Grid (DLG). The De-Na-Zin and Gateway mines were digitized from mine plan outlines drawn onto the 1:100,000 quadrangle. The mined-out-area layer was applied to the original resource layers to obtain remaining resources. Technical restriction filters were applied to the remaining resource layers for each zone. Appropriate buffers, as discussed under "Land Use Restrictions", were assigned to the digitized

land use restrictions. These restriction layers were consecutively overlain on the combined overburden, reliability, and thickness layers with the mined-out areas and technical restrictions to calculate the resource tonnage removed by these different restrictions (Tables 3-7, Fig. 8).

Factors Affecting Availability of Coal Resources

Previous mining

The De-Na-Zin and Gateway mines, operated by Sunbelt Mining are within the study area (Figs1, 8). These small mines produced 1.8 million tons from 1980 through 1988. These areas are subtracted from the original resources for the 0-250 ft depths and 15:1 stripping ratio to a depth of 250 ft to obtain remaining resources. It is difficult to know what beds/zones were mined at these two operations, but it is assumed that all zones were mined within 250 ft of the surface.

Technical restrictions

Technical parameters that influence the resources of this study are:

1) Coal too close to the surface.

   Coal with less than 20 ft of overburden is subtracted from the remaining resource estimate. Coal with less than 20 ft of overburden is removed because SJB coal within this interval is generally weathered or sometimes burned and can not be used for energy production. Most operating mines in the SJB use the greater-than-20-ft depth guideline for calculating mine reserves

2) Coal too thin at depth.

   Coal beds 2.5ft to 5 ft thick are not considered minable at depths greater than 250 ft. The original resources are calculated for this depth category but these results are removed under the technical restrictions.

Land use restrictions

Restrictions to mining in the project area are few, but some are significant. The restrictions considered are those listed in the New Mexico Coal Surface Mining Regulations 19 NMAC 8.2. The Bisti Wilderness area is 3,946 ac, entirely within the study area, removing a significant area of surface-minable coal. A small part of the De-Na-Zin Wilderness area is within the study area. In 1996, the area linking the Bisti and De-Na-Zin Wilderness Areas was officially made a wilderness area. This addition to the Wilderness Area withdrew 16,000 ac from the resource evaluation (Fig. 1). The De-Na-Zin and Hunter washes cut across the study area. These are intermittent streams, but are major washes in the area. These streams are not considered Alluvial Valley Floors because they do not support agriculture. However, during certain times of the year, significant water flows in these washes. A major highway from Farmington, State Highway 371, a few county roads, a pipeline, and powerline transect the eastern side of the area (Fig. 8). These restrictions were digitized from the 1:100,000 Toadlena DLG. The Bisti Trading Post and a few hogans are the only buildings in the area. The buildings were digitized from the 7½' quadrangles. Although archeological sites are within the study area, they would likely be mitigated, and were not considered.

The following is a list of restrictions that were considered for this area. The buffers applied to these restrictions adhere to the New Mexico Coal Surface Mining Regulations 19 NMAC 8.2, which follow the Federal regulations.

Restrictions	**Buffer**
County Roads	200 ft
State Highway 371	200 ft
Pipelines, Powerlines	100 ft
Buildings, Public or Private	300 ft
Wilderness Areas	(entire area)
Streams	100 ft

The areas covered by these restrictions along with the mined-out areas and Fruitland outcrop are shown on Fig. 8.

Results

Coal availability calculations- likely restrictions to mining

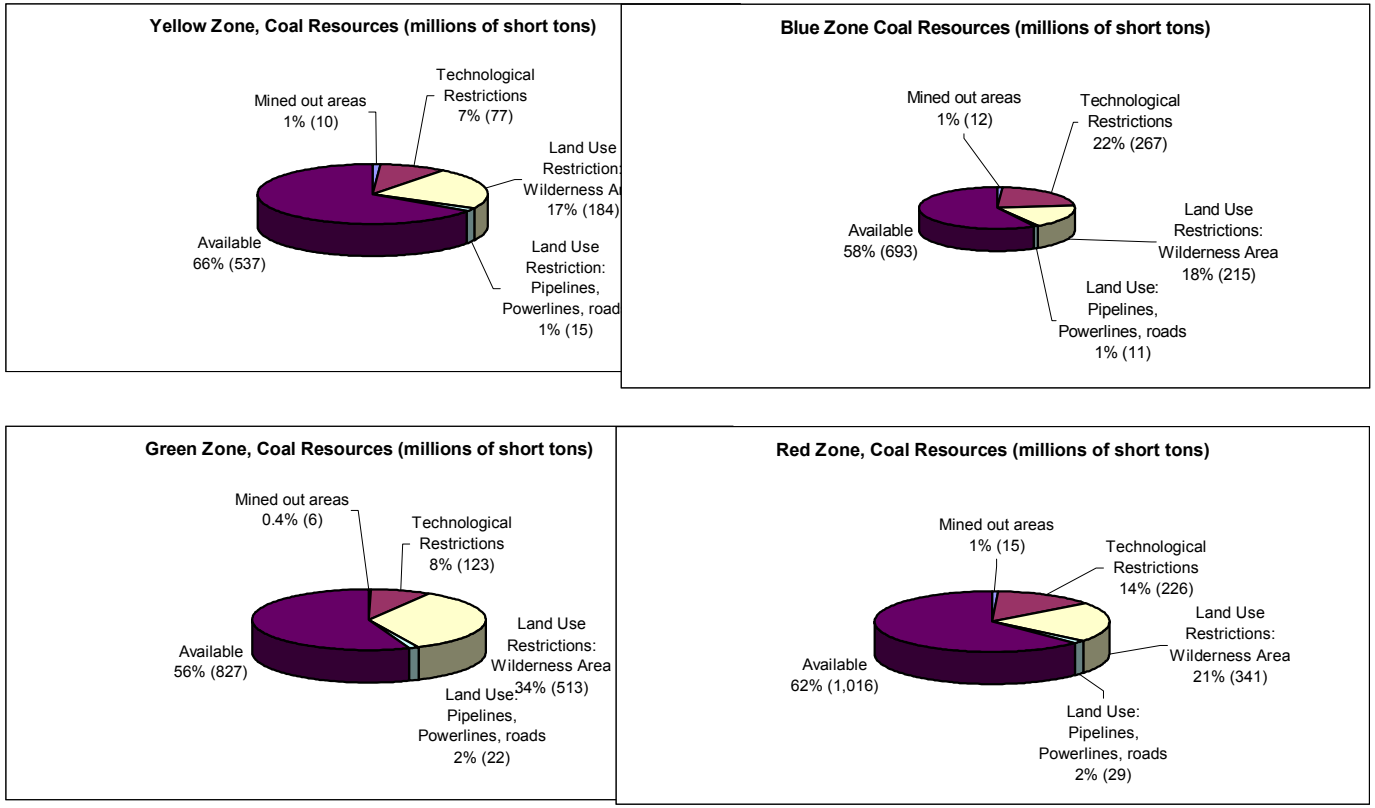
The original resources for the Bisti study area are 5.14 billion tons (Table 7). Production at the surface Gateway and De-Na-Zin mines totaled 1.8 million st. Removing the mine plan areas for these two mines from the 0-250 ft-depth category decreased the original resource by 43 million st. Calculating the 15:1 stripping ratio category for the mined area (Table 3-6), for coal within 250 ft of the surface subtracted 35 million st from the original resource. Both of these figures are much larger than the actual production, but as was stated, it is hard to determine the actual coal zones mined in the area.

The technological restrictions, removing near surface coal (0-20 ft) and thin coal (>=2.5-5 ft) at depths greater than 250 ft, removed 693 million st from the total resource. The largest depletion of remaining resources is the Bisti-De-Na-Zin Wilderness Area. This restriction removes 1.25 billion st or 28.5 % from the remaining resource. Of this total, the 1996 addition to the wilderness area removes 1.1 billion st. The wilderness area removes the greatest tonnage from the Green zone, which has on average the thickest seams. The pipeline, powerline, and major roads in the study area remove 77 million st. It is unlikely that State Highway 371 would be mitigated, although some of the county roads might be considered. Fig. 9a-d shows the proportion of coal removed by these restrictions and the available resource for each of the zones.

Table 7. Summary of coal resources and available coal, by zone in millions of short tons for the Bisti study area.

Coal zone Name	Original Resources	Mined-out areas	Likely restrictions to Mining						Restrictions with potential for mitigation		
			Technological Restrictions	Land Use Restrictions: Wilderness Area	Land Use: Pipelines, Powerlines, roads	Total Restrictions	Available	%Available	Buildings	Land Use Restrictions: Streams	Total Land Use Restriction
Yellow	823	10	77	184	15	285	537	65%	3	1	202
Blue	1,199	12	267	215	11	506	693	58%	3	17	247
Green	1,490	6	123	513	22	663	827	55%	4	14	552
Red	1,628	15	226	341	29	611	1,016	62%	5	19	394
Overall	**5,139**	**43**	**693**	**1,253**	**77**	**2,066**	**3,073**	**60%**	**15**	**51**	**1,395**

Figure 9a-d. Coal resources removed by likely restrictions to mining and available resources



Coal availability calculations- restrictions with potential for mitigation

The restrictions applied to the remaining resource with potential for mitigation are buildings, perhaps with the exception of the Bisti Trading Post, and the drainage areas. Buildings remove 15 million st from the remaining resource. If mining were to take place these buildings, which are Navajo hogans, would be moved and the owners compensated. The De-Na-Zin and Hunter washes remove 51 million st from the remaining resources. These washes are not Alluvial Valley Floors and lack flow except during rainy seasons, consequently mining might not be restricted in the wash areas.

Comparison with other resource studies

The DRB study estimate of 2 billion st for the entire Bisti field is difficult to compare to the available resource for the four-quadrangle area (1.4 billion st). The DRB did not include calculations for inferred reliability, and for depths greater than 1000 ft. For this study, large amounts of point source data were added from BLM files, increasing the accuracy and filling in areas of no data. The impact of the wilderness area to the entire Bisti field was significantly greater for this study in part because the addition between the Bisti and De-Na-Zin Wilderness areas did not exist at the time of the DRB study. Consequently, land use restrictions have a greater influence on the available coal for this study.

Summary

Four coal zones were recognized in the study area. These zones, Yellow, Blue, Green, and Red are highly variable, but the average seam is 6 to 8 ft thick. The Fruitland Formation in the Bisti study area contains high-ash, low-sulfur, Subbituminous A-rank coals. This resource does meet compliance coal standards of less than 0.6 lbs sulfur/million Btu, except for the Red Zone, with blending or washing all these coals potentially could meet this guideline.

Using Arc Info facilitates calculating resources for areas with many restrictions and allows for faster recalculation of resources with new data. Original resources for this study area are 5.14 billion st and are greater than previous studies because the inferred category is included. Significant amounts of point-source data were added, also increasing the resource. Technical restrictions and previous mining removed about 0.7 billion tons from the original resource. The Bisti-De-Na-Zin Wilderness area is the largest land use restriction, removing 28.5% of the remaining resource, about 1.3 billion st. The 1996 addition linking the two wilderness areas is significant, removing 1.1 billion st of the total 1.3 billion st. The available resource is 3 billion st for this study area. Of this available resource, 0.7 billion st is within the 15:1 stripping ratio category.

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Table 3. Estimated Resources of the Fruitland Formation, Red zone, (Bisti Trading Post, Alamo Mesa West, Tanner Lake, The Pillar 3 NE quadrangles)
In Thousands of short tons)

		Measured					Indicated					Inferred					Total				
Original		2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total
	15:01	6,795	55,836	67,056	20,975	150,662	13,638	53,596	45,027	30,079	142,340	4,498	48,917	3,715	4,418	61,548	24,930	158,350	115,799	55,472	354,550
	0-250	20,435	115,360	83,432	17,771	236,998	26,699	101,122	62,812	4,632	195,265	7,707	51,149	4,469	0	63,325	54,840	267,631	150,714	22,403	495,588
	250-500	6,057	20,998	13,687	13,728	54,470	26,235	55,274	35,216	90,093	206,817	20,980	51,011	5,611	63,095	140,697	53,272	127,282	54,514	166,916	401,985
	500-1000	1,715	0	4,653	7,958	14,326	18,461	3,363	26,874	68,745	117,443	103,074	61,568	111,452	259,707	535,800	123,250	64,931	142,979	336,410	667,570
	>1000	0	87	115	0	202	126	5,931	13,266	0	19,323	14	9,770	33,221	0	43,006	140	15,788	46,602	0	62,531
																					1,627,673 Total
Mined Out																					
Surface	15:01	0	4,145	1,860	0	6,006	478	1,883	2,696	0	5,057	0	0	0	0	0	478	6,029	4,556	0	11,063
	0-250	0	6,177	1,860	0	8,038	561	3,804	2,733	0	7,098	0	0	0	0	0	561	9,981	4,593	0	15,135
Remaining	15:01	6,795	51,691	65,196	20,975	144,657	13,160	51,712	42,331	30,079	137,283	4,498	48,917	3,715	4,418	61,548	24,453	152,321	111,243	55,472	343,488
	20-250	20,435	109,182	81,572	17,771	228,960	26,138	97,318	60,079	4,632	188,167	7,707	51,149	4,469	0	63,325	54,279	257,650	146,121	22,403	480,452
Restrictions																					
Technological- >20 ft and >250 for 2.5-5 ft																					
	15:01	775	5,491	3,062	0	9,328	4,547	12,972	6,774	0	24,293	2462.07	11577.57	1,435	0	15,475	7,784	30,040	11,271	0	49,096
	20-250	749	5,538	3,027	418	9,731	4,059	12,898	6,202	536	23,695	2,520	12,061	1,612	0	16,194	7,328	30,497	10,841	954	49,620
	250-500	6,057	0	0	0	6,057	26,235	0	0	0	26,235	20,980	0	0	0	20,980	53,272	0	0	0	53,272
	500-1000	1,715	0	0	0	1,715	18,461	0	0	0	18,461	103,074	0	0	0	103,074	123,250	0	0	0	123,250
	>1000	0	0	0	0	0	126	0	0	0	126	14	0	0	0	14	140	0	0	0	140
																					275,378
Land-Use																					
Wilderness	15:01	65	3,745	1,766	11,933	17,511	536	6,505	3,444	27,706	38,191	0	0	0	4,418	4,418	602	10,250	5,211	44,057	60,120
	20-250	4,588	19,387	6,645	8,312	38,931	6,758	24,430	9,737	1,722	42,646	0	11	41	0	51	11,346	43,827	16,422	10,034	81,629
	250-500		10,100	7,572	13,323	30,994		22,424	29,026	79,969	131,419		2,949	2,588	62,210	67,747	0	35,473	39,186	155,502	230,160
	500-1000		0	1,221	0	1,221		1,257	6,740	0	7,997		80	17,622	2,664	20,366	0	1,336	25,584	2,664	29,584
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Buildings	15:01	0	158	76	0	234	96	142	349	0	586	28	427	0	0	455	124	726	425	0	1,274
	20-250	0	425	76	0	501	143	398	457	0	998	32	395	126	0	552	175	1,218	658	0	2,051
	250-500		53	0	0	53		409	35	0	444		23	0	0	23	0	485	35	0	520
	500-1000		0	0	395	395		0	80	0	80		198	244	1,299	1,742	0	198	324	1,694	2,216
	>1000		0	0	0	0		96	143	0	239		0	0	0	0	0	96	143	0	239
																					5,027
Pipelines, Powerlines,																					
roads	15:01	327	1,057	827	0	2,211	365	361	386	0	1,112	53	3,742	27	0	3,821	745	5,160	1,239	0	7,144
	20-250	724	1,816	862	0	3,402	690	568	421	0	1,680	60	3,756	27	0	3,843	1,474	6,140	1,310	0	8,924
	250-500		1,104	466	0	1,570		1,112	96	0	1,207		248	0	0	248	0	2,464	561	0	3,025
	500-1000		0	301	0	301		244	329	0	573		2,901	1,956	10,755	15,611	0	3,145	2,586	10,755	16,486
	>1000		0	0	0	0		0	129	0	129		0	0	0	0	0	0	129	0	129
																					28,564
Hydro	15:01	566	3,724	6,915	0	11,206	358	614	637	0	1,609	0	0	0	0	0	924	4,338	7,553	0	12,815
	20-250	3,096	6,556	7,526	0	17,178	467	936	710	0	2,113	0	0	0	0	0	3,563	7,492	8,236	0	19,291
	250-500		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	500-1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Available	15:01	5,060	37,517	52,550	9,041	104,168	7,259	31,118	30,741	2,374	71,492	1,954	33,172	2,253	0	37,379	14,273	101,807	85,544	11,415	213,039
	20-250	11,278	75,460	63,437	9,041	159,217	14,020	58,088	42,553	2,374	117,034	5,094	34,927	2,664	0	42,685	30,393	168,476	108,653	11,415	318,936
	250-500	0	9,740	5,650	405	15,795	0	31,329	6,059	10,124	47,512	0	47,792	3,023	885	51,700	0	88,861	14,732	11,415	115,008
	500-1000	0	0	3,131	7,563	10,694	0	1,862	19,725	68,745	90,332	0	58,389	91,629	244,989	395,007	0	60,251	114,485	321,297	496,034
	>1000	0	87	115	0	202	0	5,836	12,994	0	18,829	0	9,770	33,221	0	42,992	0	15,693	46,330	0	62,023
																					992,000 Total

Table 4. Estimated Resources of the Fruitland Formation, Green zone, (Bisti Trading Post, Alamo Mesa West, Tanner Lake, The Pillar 3 NE quadrangles)
In Thousands of short tons)

		Measured					Indicated					Inferred					Total				
Original		2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total
	15:01	6,080	18,098	12,381	22,300	58,860	14,941	21,918	47,907	111,391	196,157	25,888	33,973	41,452	43,708	145,021	46,909	73,990	101,740	177,400	400,038
	0-250	18,847	38,542	13,294	9,832	80,516	49,004	56,914	47,870	28,281	182,069	51,780	38,181	39,597	1,648	131,205	119,631	133,637	100,761	39,761	393,790
	250-500	1,216	13,459	8,625	16,068	39,368	7,836	60,805	72,938	112,317	253,896	10,604	62,391	59,137	72,388	204,520	19,656	136,655	140,701	200,773	497,784
	500-1000	466	3,625	4,940	0	9,031	3,434	28,968	33,386	0	65,787	29,805	231,183	203,594	2,890	467,473	33,704	263,776	241,920	2,890	542,291
	>1000	0	108	119	0	227	0	6,629	11,491	0	18,119	11	8,854	29,040	0	37,905	11	15,590	40,650	0	56,251
																					1,490,115
Mined Out																					
Surface	15:01	506	0	0	0	506	982	32	0	0	1,014	1,558	0	0	0	1,558	3,046	32	0	0	3,078
	0-250	699	0	0	122	821	2,577	558	0	87	3,221	1,885	0	0	28	1,913	5,161	558	0	237	5,956
Remaining	15:01	5,574	18,098	12,381	22,300	58,353	13,958	21,886	47,907	111,391	195,143	24,330	33,973	41,452	43,708	143,464	43,862	73,958	101,740	177,400	396,960
	20-250	18,148	38,542	13,294	9,710	79,694	46,427	56,357	47,870	28,194	178,848	49,895	38,181	39,597	1,620	129,291	114,469	133,079	100,761	39,524	387,834
Restrictions																					
Technological- >20 ft and >250 for 2.5-5 ft																					
	15:01	1,696	2,420	3,112	0	7,227	6,321	9,156	16,796	0	32,272	10324.41	7839.33	11,378	0	29,541	18,341	19,415	31,285	0	69,041
	20-250	1,566	2,444	3,220	0	7,230	6,627	9,429	17,447	0	33,503	10,310	7,639	10,907	0	28,856	18,504	19,512	31,573	0	69,589
	250-500	1,216	0	0	0	1,216	7,836	0	0	0	7,836	10,604	0	0	0	10,604	19,656	0	0	0	19,656
	500-1000	466	0	0	0	466	3,434	0	0	0	3,434	29,805	0	0	0	29,805	33,704	0	0	0	33,704
	>1000	0	0	0	0	0	0	0	0	0	0	11	0	0	0	11	11	0	0	0	11
																					192,001
Land-Use																					
Wildernes	15:01	115	839	5,799	18,920	25,672	1,508	248	23,994	109,271	135,021	662	0	4,896	43,708	49,266	2,285	1,087	34,688	171,899	209,959
	20-250	858	2,820	6,636	6,330	16,643	7,738	6,515	23,373	26,074	63,701	8,084	0	3,161	1,620	12,864	16,680	9,335	33,170	34,023	93,208
	250-500		6,907	8,558	16,068	31,533		29,424	72,938	112,317	214,680		10,098	58,575	72,388	141,060	0	46,429	140,071	200,773	387,272
	500-1000		0	0	0	0		3,572	382	0	3,954		6,284	19,004	2,890	28,178	0	9,855	19,387	2,890	32,133
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Buildings	15:01	0	0	0	0	0	0	404	358	0	761	21	227	228	0	476	21	630	586	0	1,237
	20-250	161	0	0	0	161	140	504	358	0	1,002	122	191	191	0	504	423	696	549	0	1,667
	250-500		0	0	0	0		250	0	0	250		32	0	0	32	0	281	0	0	281
	500-1000		65	0	0	65		200	156	0	356		713	970	0	1,683	0	979	1,126	0	2,105
	>1000		0	0	0	0		106	131	0	237		0	0	0	0	0	106	131	0	237
																					4,290
Pipelines, Powerlines																					
, roads	15:01	297	292	0	0	589	296	418	274	0	988	673	2,768	2,768	0	6,209	1,266	3,478	3,043	0	7,786
	20-250	349	372	0	0	720	481	1,064	347	0	1,892	1,545	3,037	2,936	0	7,519	2,375	4,473	3,283	0	10,131
	250-500		641	0	0	641		466	0	0	466		237	0	0	237	0	1,343	0	0	1,343
	500-1000		0	478	0	478		0	756	0	756		5,142	3,990	0	9,131	0	5,142	5,223	0	10,365
	>1000		0	0	0	0		0	14	0	14		0	0	0	0	0	0	14	0	14
																					21,854
Hydro	15:01	345	3,657	1,193	0	5,195	324	2,611	37	0	2,972	0	0	0	0	0	669	6,268	1,230	0	8,167
	20-250	1,234	5,075	1,195	0	7,503	1,556	4,607	35	0	6,199	0	0	0	0	0	2,790	9,682	1,230	0	13,702
	250-500		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	500-1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Available	15:01	3,121	10,891	2,278	3,381	19,670	5,510	9,050	6,448	2,120	23,129	12,650	23,139	22,182	0	57,971	21,281	43,080	30,908	5,501	100,770
	20-250	13,979	27,831	2,244	3,381	47,436	29,885	34,237	6,310	2,120	72,552	29,833	27,313	22,401	0	79,547	73,697	89,381	30,956	5,501	199,536
	250-500	0	5,912	67	0	5,979	0	30,665	0	0	30,665	0	52,024	563	0	52,587	0	88,601	630	0	89,231
	500-1000	0	3,559	4,462	0	8,022	0	25,196	32,092	0	57,288	0	219,045	179,630	0	398,675	0	247,800	216,184	0	463,984
	>1000	0	108	119	0	227	0	6,522	11,346	0	17,868	0	8,854	29,040	0	37,894	0	15,484	40,505	0	55,989
																					808,740 Total

Table 5. Estimated Resources of the Fruitland Formation, Blue zone, (Bisti Trading Post, Alamo Mesa West, Tanner Lake, The Pillar 3 NE quadrangles)
In Thousands of short tons)

		Measured					Indicated					Inferred					Total					
Original		2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	
	15:01	6,682	31,361	79,436	24,095	141,573	11,232	38,430	92,005	49,987	191,654	5,508	11,501	67,979	17,514	102,502	23,422	81,293	239,419	91,596	435,730	
	0-250	17,891	52,650	81,353	22,304	174,198	30,232	75,836	101,495	29,120	236,683	6,429	12,926	69,848	1,007	90,210	54,551	141,412	252,696	52,431	501,091	
	250-500	6,620	1,228	7,869	1,712	17,429	29,890	22,612	43,638	20,950	117,089	43,333	55,373	16,574	47,156	162,436	79,843	79,213	68,081	69,818	296,955	
	500-1000	1,212	2,459	0	0	3,671	7,790	15,870	0	0	23,660	94,334	178,281	52,289	22,546	347,451	103,336	196,610	52,289	22,546	374,782	
	>1000	0	0	0	0	0	0	0	0	0	0	7,641	18,130	0	0	25,771	7,641	18,130	0	0	25,771	
																					1,198,598	Subtotal
Mined Out																						
Surface	15:01	5	2,749	1,092	0	3,846	27	3,949	2,225	0	6,200	0	1,274	85	0	1,359	32	7,972	3,402	0	11,406	
	0-250	18	3,119	1,030	0	4,167	27	4,441	2,253	0	6,721	0	1,306	200	0	1,506	44	8,866	3,483	0	12,394	
Remaining	15:01	6,676	28,612	78,344	24,095	137,727	11,206	34,481	89,780	49,987	185,454	5,508	10,227	67,894	17,514	101,143	23,391	73,320	236,017	91,596	424,324	
	20-250	17,873	49,532	80,323	22,304	170,032	30,205	71,395	99,242	29,120	229,962	6,429	11,620	69,648	1,007	88,704	54,507	132,546	249,212	52,431	488,697	
Restrictions																						
Technological- >20 ft and >250 for 2.5-5 ft																						
	15:01	1,952	3,064	4,211	0	9,227	4,827	5,140	21,196	0	31,163	3646.2	3357.69	29,587	0	36,591	10,425	11,562	54,994	0	76,981	
	20-250	1,828	2,974	4,098	0	8,900	4,696	5,064	20,865	0	30,625	3,653	3,416	29,347	0	36,416	10,178	11,454	54,309	0	75,940	
	250-500	6,620	0	0	0	6,620	29,890	0	0	0	29,890	43,333	0	0	0	43,333	79,843	0	0	0	79,843	
	500-1000	1,212	0	0	0	1,212	7,790	0	0	0	7,790	94,334	0	0	0	94,334	103,336	0	0	0	103,336	
	>1000	0	0	0	0	0	0	0	0	0	0	7,641	0	0	0	7,641	7,641	0	0	0	7,641	
																					343,741	Subtotal
Land-Use																						
Wildernes	15:01	446	6,634	11,510	979	19,569	296	7,381	29,888	18,426	55,990	0	329	1,949	6,071	8,349	742	14,344	43,347	25,476	83,909	
	20-250	4,616	14,217	11,716	979	31,527	8,268	19,316	35,090	5,285	67,959	795	1,644	4,561	779	7,779	13,679	35,177	51,367	7,043	107,266	
	250-500		0	7,128	0	7,128		4,434	30,455	13,346	48,234		14,422	9,142	10,834	34,398	0	18,856	46,724	24,180	89,760	
	500-1000		0	0	0	0		807	0	0	807		17,127	0	301	17,427	0	17,934	0	301	18,235	
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	
Buildings	15:01	0	182	202	0	384	0	35	373	0	409	0	0	143	0	143	0	218	719	0	936	
	20-250	48	324	202	0	573	32	239	342	0	612	0	0	143	0	143	80	563	687	0	1,329	
	250-500		0	0	0	0		99	0	0	99		200	0	0	200	0	299	0	0	299	
	500-1000		55	0	0	55		188	0	0	188		347	462	0	809	0	589	462	0	1,051	
	>1000		0	0	0	0		0	0	0	0		96	0	0	96	0	96	0	0	96	
																					2,775	Subtotal
Pipelines, Powerlines																						
, roads	15:01	73	198	736	0	1,007	143	860	1,053	0	2,057	60	809	2,299	0	3,168	276	1,867	4,089	0	6,232	
	20-250	377	99	630	0	1,106	492	926	878	0	2,296	35	766	1,351	0	2,152	904	1,791	2,859	0	5,554	
	250-500		19	0	0	19		276	0	0	276		749	0	0	749	0	1,044	0	0	1,044	
	500-1000		0	0	0	0		0	0	0	0		3,544	1,181	0	4,724	0	3,544	1,181	0	4,724	
	>1000		0	0	0	0		0	0	0	0		11	0	0	11	0	11	0	0	11	
																					11,333	Subtotal
Hydro	15:01	908	5,259	7,307	513	13,987	280	2,062	722	0	3,064	0	0	0	0	0	1,188	7,321	8,029	513	17,050	
	20-250	977	5,255	7,317	513	14,063	381	2,066	722	0	3,168	0	0	0	0	0	1,358	7,321	8,039	513	17,231	
	250-500		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	
	500-1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0	
Available	15:01	3,298	13,275	54,378	22,603	93,553	5,660	19,003	36,547	31,561	92,771	1,802	5,731	33,915	11,443	52,891	10,760	38,009	124,840	65,607	239,216	
	20-250	10,027	26,663	56,360	20,812	113,862	16,337	43,784	41,345	23,835	125,302	1,945	5,793	34,246	228	42,213	28,309	76,241	131,952	44,875	281,377	
	250-500	0	1,209	742	1,712	3,662	0	17,803	13,183	7,604	38,590	0	40,002	7,432	36,322	83,756	0	59,014	21,357	45,638	126,008	
	500-1000	0	2,404	0	0	2,404	0	14,875	0	0	14,875	0	157,265	50,647	22,245	230,157	0	174,543	50,647	22,245	247,435	
	>1000	0	0	0	0	0	0	0	0	0	0	0	18,024	0	0	18,024	0	18,024	0	0	18,024	
																					672,844	Total

Table 6. Estimated Resources of the Fruitland Formation, Yellow zone, (Bisti Trading Post, Alamo Mesa West, Tanner Lake, The Pillar 3 NE quadrangles)
In Thousands of short tons)

		Measured					Indicated					Inferred					Total				
Original		2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total	2.5-5	5-10	10-20	>20	Total
	15:01	8,753	45,470	38,046	2,407	94,676	10,255	57,367	38,556	0	106,179	4,044	22,056	4,931	0	31,032	23,052	124,893	81,533	2,407	231,886
	0-250	17,684	58,688	43,184	2,407	121,964	35,347	92,837	48,192	0	176,375	34,883	51,234	13,567	0	99,685	87,914	202,759	104,943	2,407	398,023
	250-500	0	4,671	6,122	0	10,793	292	28,182	19,596	0	48,070	7,151	140,338	69,650	0	217,138	7,443	173,191	95,368	0	276,001
	500-1000	0	0	0	0	0	0	0	0	0	0	17,509	112,260	2,154	0	131,923	17,509	112,260	2,154	0	131,923
	>1000	0	0	0	0	0	0	0	0	0	0	16,604	0	0	0	16,604	16,604	0	0	0	16,604
																					822,553 Subtotal
Mined Out																					
Surface	15:01	375	1,159	1,975	0	3,510	839	2,308	1,612	0	4,760	228	1,228	0	0	1,457	1,443	4,696	3,588	0	9,726
	0-250	292	1,112	2,028	0	3,432	830	2,292	1,646	0	4,768	225	1,184	136	0	1,545	1,347	4,588	3,811	0	9,746
Remaining	15:01	8,377	44,310	36,071	2,407	91,166	9,416	55,059	36,943	0	101,419	3,816	20,828	4,931	0	29,575	21,610	120,197	77,945	2,407	222,160
	20-250	17,392	57,576	41,156	2,407	118,532	34,517	90,544	46,546	0	171,607	34,658	50,050	13,431	0	98,139	86,567	198,171	101,132	2,407	388,278
Restrictions																					
Technological- >20 ft and >250 for 2.5-5 ft																					
	15:01	2,351	5,602	3,712	0	11,664	4,108	12,323	2,963	0	19,394	1835.49	4846.26	60	0	6,742	8,294	22,771	6,735	0	37,800
	20-250	2,368	6,041	2,880	0	11,289	4,319	12,409	1,745	0	18,473	1,283	4,324	0	0	5,607	7,970	22,775	4,625	0	35,370
	250-500	0	0	0	0	0	292	0	0	0	292	7,151	0	0	0	7,151	7,443	0	0	0	7,443
	500-1000	0	0	0	0	0	0	0	0	0	0	17,509	0	0	0	17,509	17,509	0	0	0	17,509
	>1000	0	0	0	0	0	0	0	0	0	0	16,604	0	0	0	16,604	16,604	0	0	0	16,604
																					76,926 Subtotal
Land-Use																					
Wildernes	15:01	1,846	8,517	3,544	0	13,907	1,517	9,723	7,926	0	19,166	48	0	4,537	0	4,584	3,411	18,240	16,006	0	37,657
	20-250	6,930	13,776	2,830	0	23,536	20,727	22,504	6,353	0	49,583	22,787	11,231	3,582	0	37,600	50,443	47,510	12,765	0	110,719
	250-500		2,490	2,981	0	5,471		17,758	4,275	0	22,033		32,887	3,289	0	36,175	0	53,135	10,544	0	63,679
	500-1000		0	0	0	0		0	0	0	0		9,192	0	0	9,192	0	9,192	0	0	9,192
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Buildings	15:01	89	39	131	0	258	21	266	142	0	428	0	16	0	0	16	110	320	273	0	703
	20-250	80	81	131	0	292	7	271	372	0	650	170	0	0	0	170	257	352	503	0	1,112
	250-500		96	0	0	96		53	359	0	412		281	281	0	563	0	430	641	0	1,071
	500-1000		0	0	0	0		0	0	0	0		577	0	0	577	0	577	0	0	577
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
																					2,759 Subtotal
Pipelines, Powerlines																					
, roads	15:01	64	715	430	0	1,209	34	947	202	0	1,182	115	1,435	0	0	1,551	212	3,098	632	0	3,942
	20-250	28	1,241	1,299	0	2,568	21	1,142	589	0	1,752	637	1,729	0	0	2,366	687	4,112	1,889	0	6,687
	250-500		0	94	0	94		892	504	0	1,397		2,398	1,742	0	4,140	0	3,290	2,340	0	5,630
	500-1000		0	0	0	0		0	0	0	0		2,602	0	0	2,602	0	2,602	0	0	2,602
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
																					14,919 Subtotal
Hydro	15:01	281	60	0	0	342	296	21	0	0	317	0	0	0	0	0	577	81	0	0	658
	20-250	504	60	0	0	565	333	11	0	0	343	0	0	0	0	0	837	71	0	0	908
	250-500		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	500-1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
	>1000		0	0	0	0		0	0	0	0		0	0	0	0	0	0	0	0	0
Available	15:01	3,747	29,377	28,255	2,407	63,785	3,441	31,780	25,711	0	60,932	1,818	14,530	335	0	16,682	9,006	75,687	54,300	2,407	141,400
	20-250	7,482	36,377	34,016	2,407	80,282	9,110	54,208	37,487	0	100,805	9,781	32,766	9,848	0	52,396	26,373	123,351	81,351	2,407	233,482
	250-500	0	2,085	3,048	0	5,133	0	9,478	14,457	0	23,936	0	104,772	64,338	0	169,109	0	116,335	81,843	0	198,178
	500-1000	0	0	0	0	0	0	0	0	0	0	0	99,890	2,154	0	102,044	0	99,890	2,154	0	102,044
	>1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
																					533,705 Total

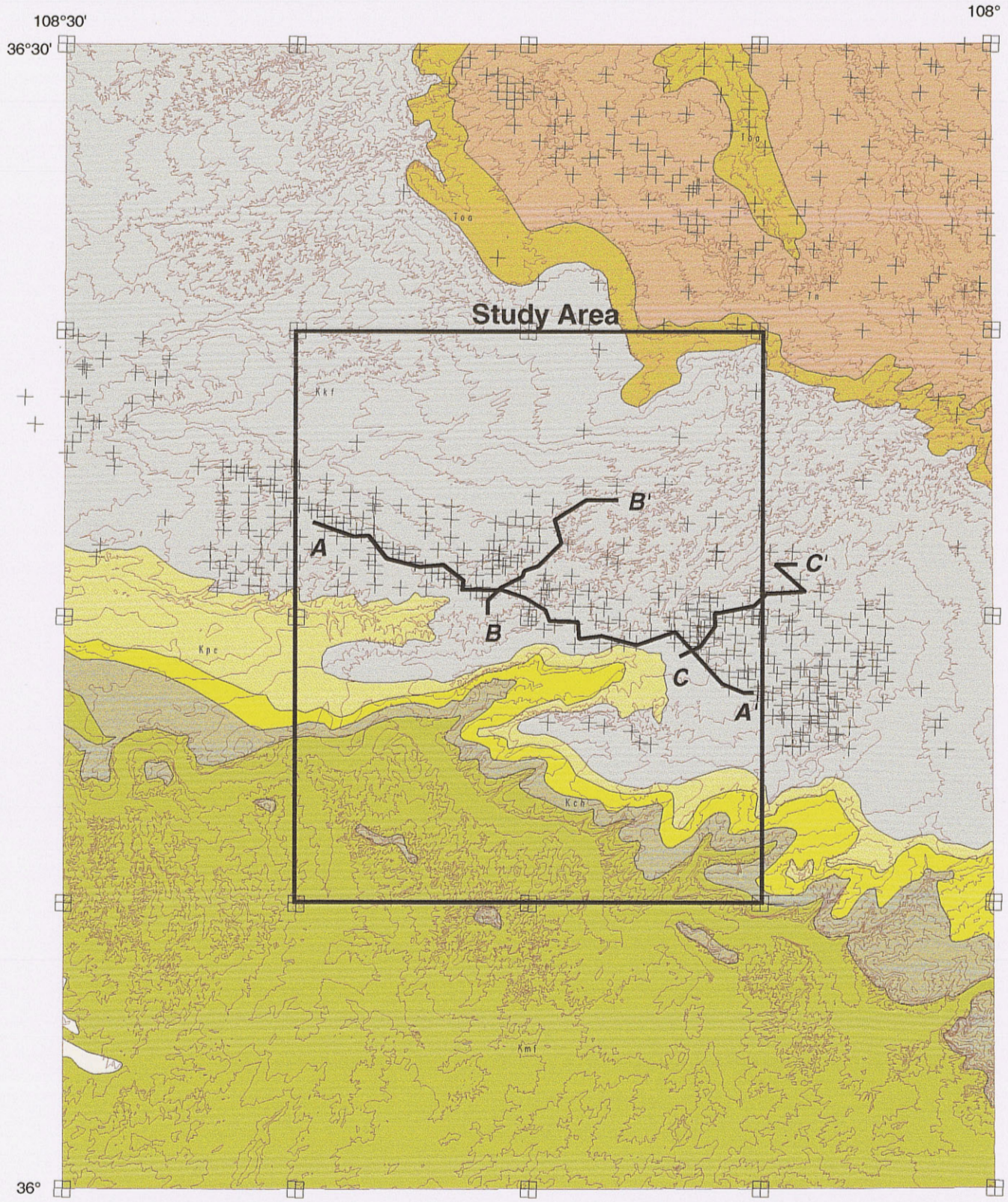

Figure 4. Geologic map of study area with drill hole data and cross sections. Geology from Anderson, Jones, and Green, 1997. Scale 1:300,000

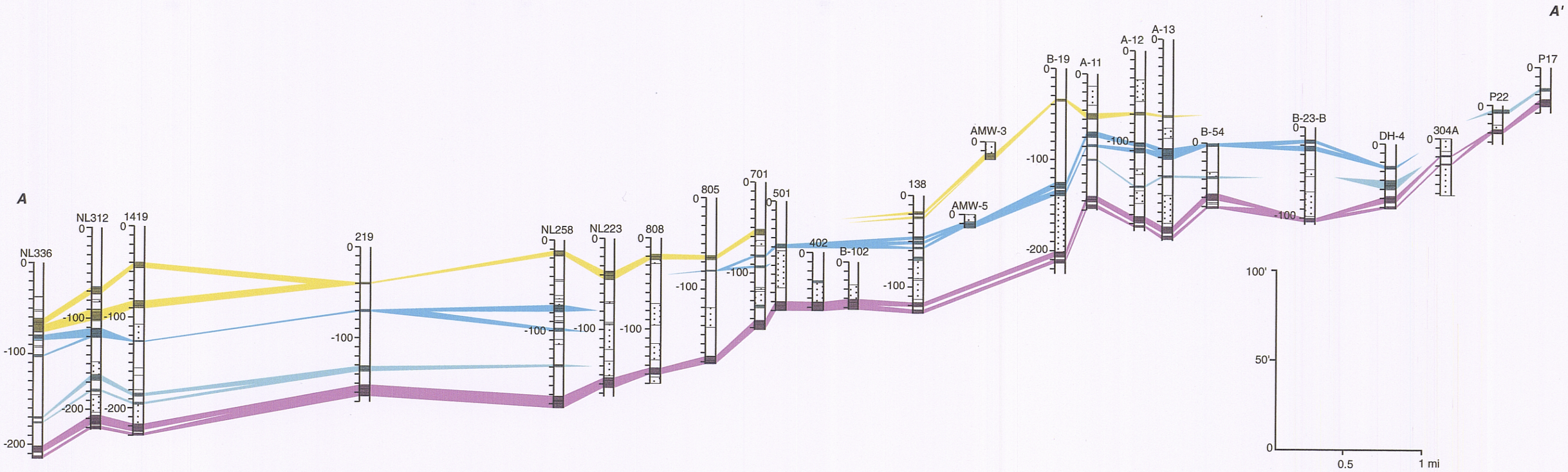

Figure 5. Cross section along strike in Bisti study area. See Figure 9 for location.

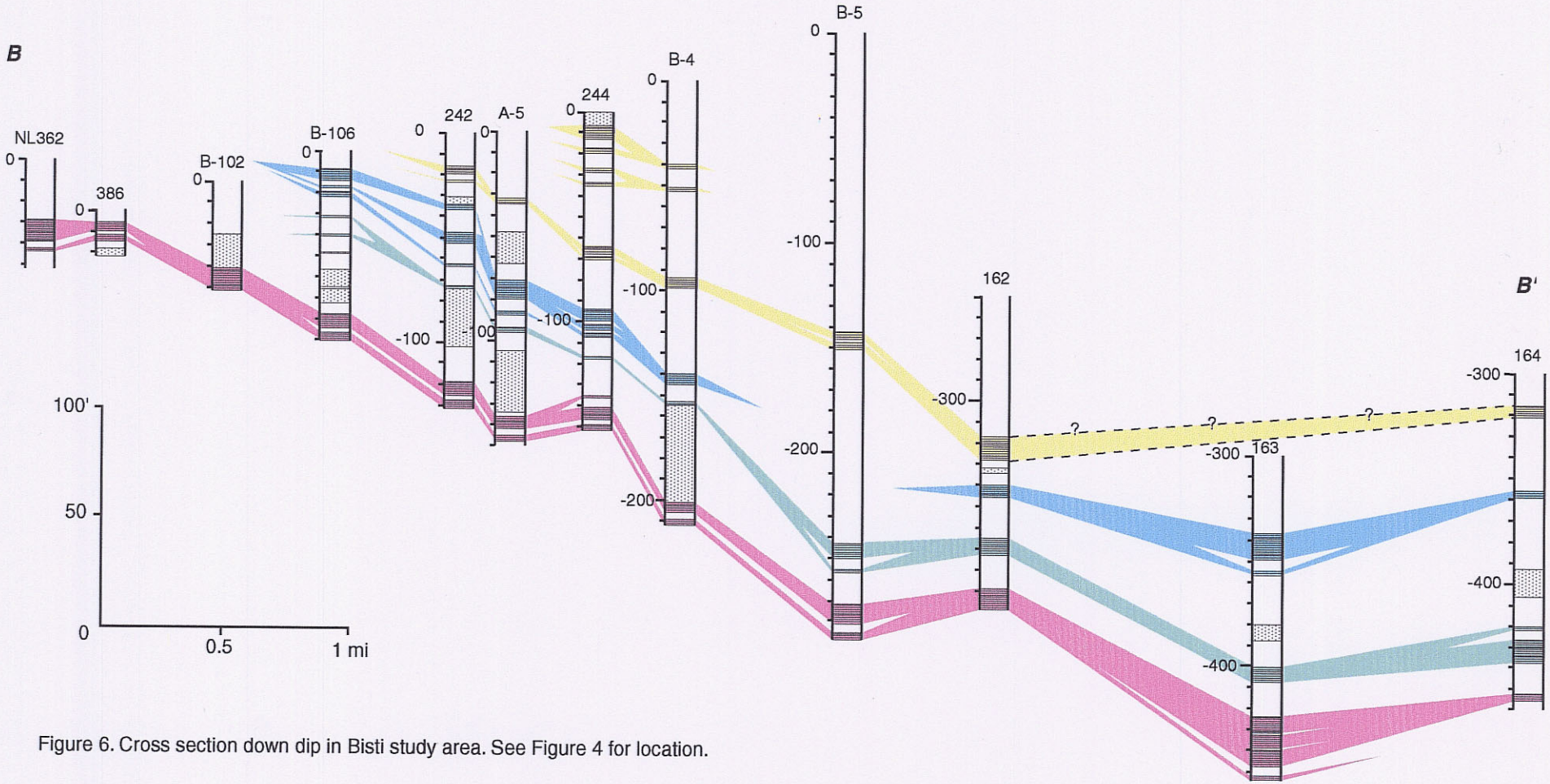

Figure 6. Cross section down dip in Bisti study area. See Figure 4 for location.

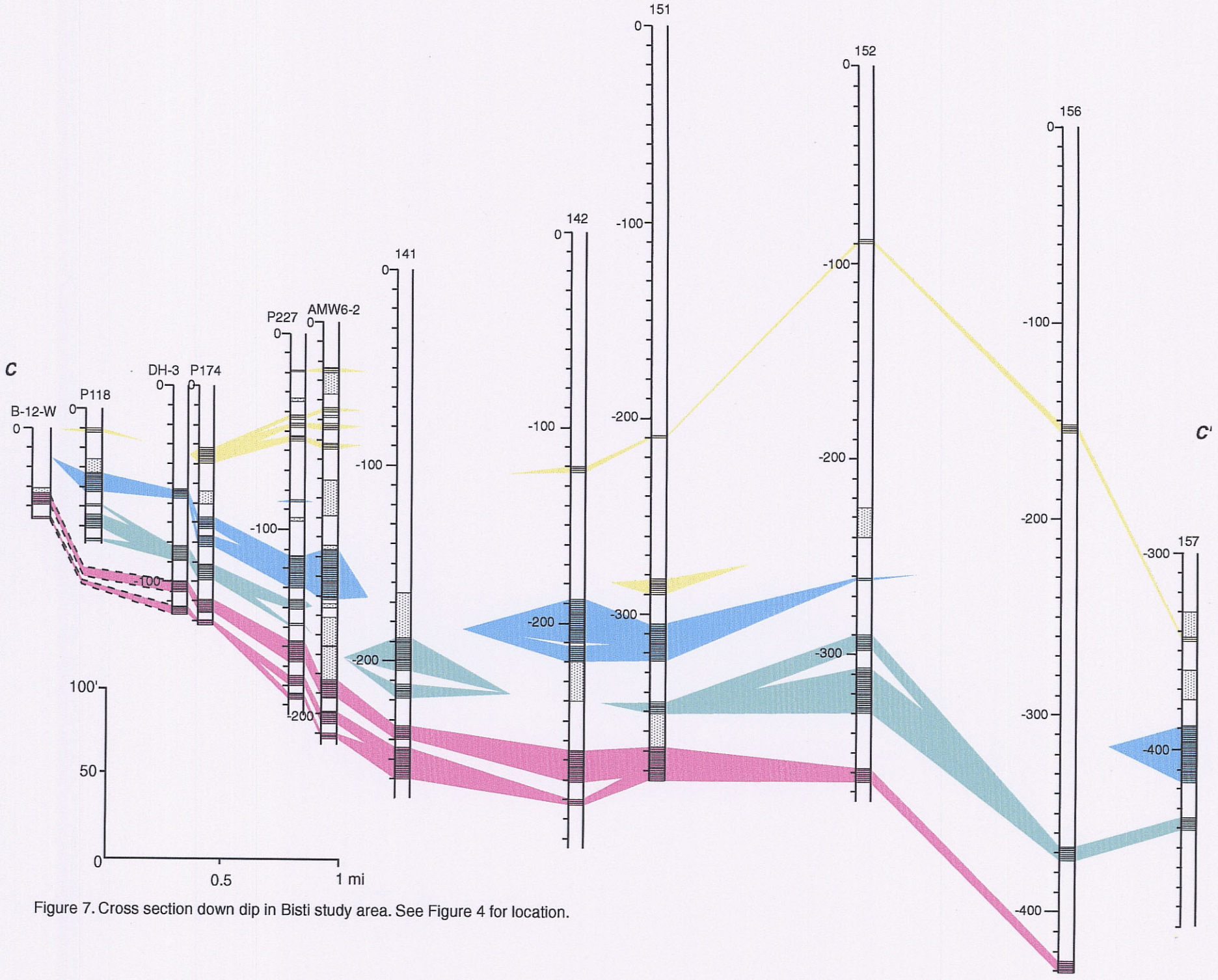

Figure 7. Cross section down dip in Bisti study area. See Figure 4 for location.

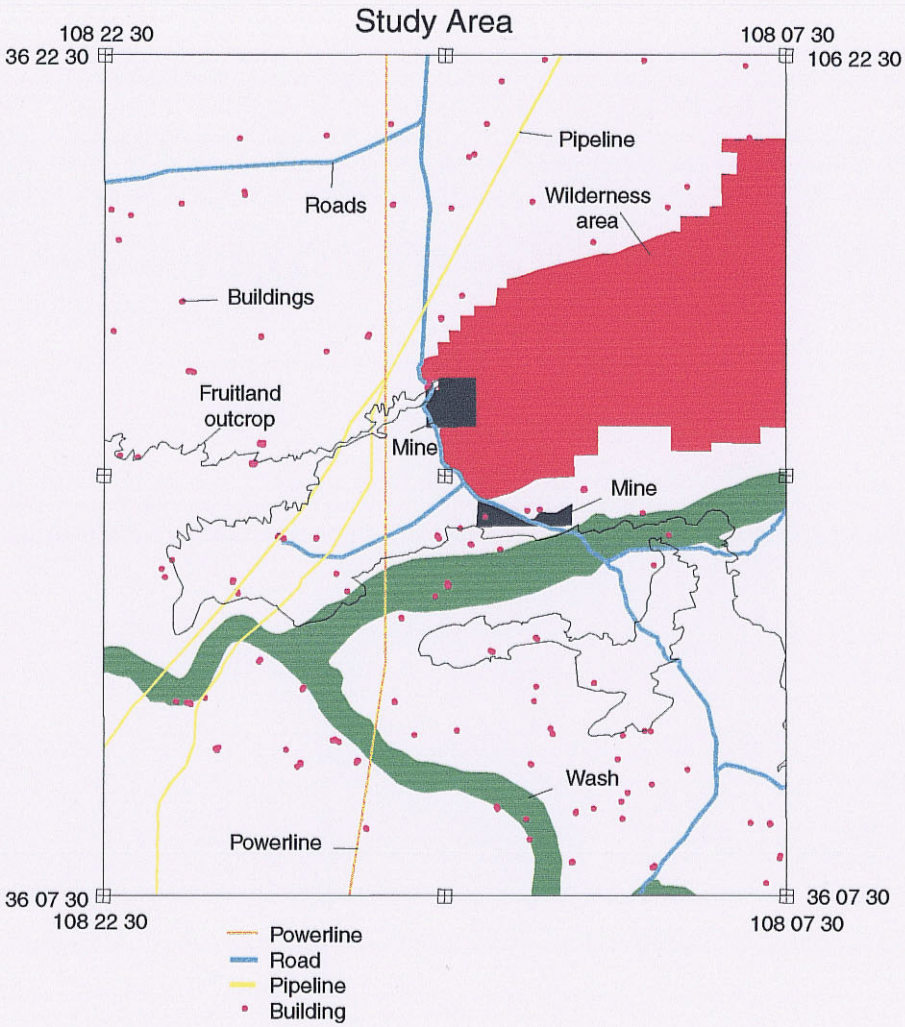

Figure 8. Mined out and land use restrictions in Bisti study area.
Scale 1:250,000