

Chapter 2

Methodology for Calculating Oil Shale Resources for the Green River and Washakie Basins, Southwestern Wyoming



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Volume Title Page*

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Chapter 2 of 6

Oil Shale Resources of the Eocene Green River Formation, Greater Green River Basin, Wyoming, Colorado, and Utah

By U.S. Geological Survey Oil Shale Assessment Team

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Methodology for Calculating Oil Shale Resources for the Green River and Washakie Basins, Southwestern Wyoming

By Tracey J. Mercier, Michael E. Brownfield, and Ronald C. Johnson

Abstract

Advancements in computer and database technology since the 1989 assessment of the in-place oil shale resources for the Piceance Basin, Colorado, have provided the U.S. Geological Survey with tools to convert legacy data, store and manipulate new data, perform calculations, and quantify, report, and display assessment results. Relational database and geographic information systems (GIS) software were used to streamline the storage and manipulation of data. A deterministic spatial interpolation method, the Radial Basis Function, was used to generate isopach and isoresource models with the GIS software, which provided a spatial statistics function to summarize the prediction models and determine the volume of in-place oil shale resources.

Introduction

This report presents the methodology used by the U.S. Geological Survey (USGS) in the geology-based assessment of the in-place oil resources in three oil shale zones of the Eocene Green River Formation in the Green River and Washakie Basins, southwestern Wyoming (fig. 1). The focus is on the methodology used to: (1) convert legacy data; (2) analyze the data through application of current computer techniques; and (3) ultimately quantify the resultant data using spreadsheet, database, and geographic information systems (GIS) software. The methods used are similar to those used in the 2010 USGS Piceance Basin assessment (Mercier and others, 2010), but vary due to the complicated nature of the stratigraphy and the need to use rotary holes in the Greater Green River Basin assessment.

After converting, combining, and loading individual legacy Fischer assay (American Society for Testing and Materials, 1980) data files into a relational database (Dyini, 1998), custom scripts and queries were written to filter records and perform various calculations using a database form. The legacy data also contained location information for each oil

shale borehole that was converted to spatial data and then linked to its associated Fischer assay data.

After performing calculations in the database, the resultant data were migrated to a GIS software package and a cell-based modeling technique was used to calculate total barrels of oil yield per oil shale zone. Through this process, all data were updated to a contemporary relational database format and new spatial data models were created for use in GIS software. Detailed technical descriptions of the methodology and the tools employed in the assessment from a software-centric perspective are presented in a case study following this report.

Oil Shale Assessment

Data Preparation, Capture, and Conversion

In order to calculate in-place oil shale resources using relational database and GIS software, it was necessary to collect data points with accompanying oil-yield data, create digital outcrop boundary lines to constrain resource calculations, and correlate the three oil shale zones within the Eocene Green River Formation in the Green River and Washakie Basins.

Spatial Data

The legacy Fischer assay data files contain header information detailing the locations of boreholes, but not all of the files contain latitude and longitude coordinates. To maintain consistency, the borehole locations were digitized in GIS software based on footage measurements north, south, east, and west of Public Land Survey System (PLSS) section corners (Bureau of Land Management, 2002), or by using the best available location information presented in the header, such as the section centerpoint. In addition to placing the boreholes in real-world coordinates and plotting their locations on maps, three oil shale zones within the Eocene Green River Formation—LaCleda Bed of Laney Member, Wilkins Peak Member, and Tipton Shale Member (Roehler, 1991) were defined and



Figure 1. Green River and Washakie Basins, southwestern Wyoming, showing area underlain by oil shale-bearing rocks. Outcrops and lateral extent of the Laney and Tipton Shale Members of the Green River Formation and staff geologist's interpretations shown in brown.

correlated between holes in the subsurface using oil-yield histograms generated from the Fischer assay data files (fig. 2).

Two different resource polygon files were needed to perform resource calculations for the three oil shale zones. Boundary files for this purpose (fig. 3) were created by downloading mapped outlines of the top of the Laney Member and the top of the Tipton Shale Member of the Green River Formation (Green and Drouillard, 1994). The top of the Laney Member outcrop was used to delineate a resource-polygon file for the two uppermost zones: the LaCledde Bed of the Laney Member, and the Wilkins Peak Member (figs. 2, 3). The top of the Tipton Shale Member outcrop was used to delineate a resource-polygon file for that unit. The outcrops thus served as the basis for bounding polygons, but were adjusted in some areas based on interpretations of the field relations. These files were then intersected spatially with a PLSS land grid for the Green River and Washakie Basins to allow resource calculation on a per-township basis. Some township polygons were deleted from the intersected resource files owing to a lack of control points.

Tabular Fischer Assay Data

Source ASCII text data were obtained from published Fischer assays (Dyni, 1998) and from previously unpublished Fischer assay data stored by the USGS. These files were stored as individual ASCII-formatted text files (fig. 4) for each borehole that contained the header location information and the column-delimited Fischer assay records. Each borehole was assigned a unique four-digit number, with the prefix “W” for Wyoming. To expedite the querying of the Fischer assay data, a file-conversion software package was used to convert and combine all of the Fischer assay records into one relational database table that allowed detailed queries on one large table (some 40,000 records) instead of hundreds of different files.

Some legacy Fischer assay records were incomplete; especially those associated with rotary drill cuttings; those boreholes contain the character “R” in their USGS identifier (USGSID). Almost all boreholes contain missing intervals that represent samples that were not recovered during the drilling/coring process. Missing records in the original data files were labeled as “0.0B” or “0.00B” in all columns except for the top and base of the interval fields (Dyni, 1998). During the initial data import and conversion process (table 1), it was necessary to remove the “B” for those values to be imported as a numeric field, which were then considered to be missing intervals in the assay table. This step allowed calculations to be made on any given field, as those values were converted from characters to numeric values. Four other fields were added to the master Fischer assays table: (1) the “USGSID” field, the unique borehole identifier, or primary key, was added to each record in the Import Wizard 9 conversion process by using the original text filename; (2) the “INTVL” field, an abbreviation for thickness of the sampled interval, was calculated in Microsoft Access 2007 by using an update query (base of the sampled interval minus the top of the sampled

interval); (3) the “INTXOIL” field (thickness of interval times shale oil in gallons per short ton of rock) was also calculated by using an update query, which was necessary to perform weighted-average calculations; and (4) the “ROCKTYPE” field was added to denote beds of halite and (or) trona (“NH”), or sandstone (“NO”). Although such beds were commonly assayed, the assay results typically produced zero oil and thus are listed as containing zero oil in the assay tables. However, these legitimate zero-oil-yield values then needed to be distinguished from actual missing intervals that are also listed as zero oil yield in the assay tables in order to correctly calculate an average gallon per ton (GPT) for the zone in which they were contained. To distinguish the two, a minimum oil-yield value of 0.00001 GPT was assigned to these zero-value sandstone beds.

Overview of Assessment Methodology

The column-delimited ASCII text Fischer assay records were converted using Import Wizard 9 (Beside Software, 2006) and then stored in a Microsoft Access (Microsoft Corporation, 2006) table (fig. 5). Additionally, the oil shale zone “tops” file with correlation data for Wyoming was converted from a Microsoft Excel 2007 spreadsheet and then stored in the Access database (WY_TOPS_090318). A one-to-many relation was established between formation tops and the Fischer assay data (WY_Assays_INTV), providing access to many assay records for each borehole. By establishing this link, Structured Query Language (SQL) queries and Visual Basic formulas were developed to calculate resource estimates for each borehole by oil shale zone. Derivative maps were then constructed, including: (1) oil shale zone thickness, (2) average oil yield in gallons per ton (GPT), (3) oil yield in barrels per acre (BPA), (4) barrels of oil yield per township, and (5) percentage of missing intervals determined from the core sample.

The header information from the legacy borehole files was used to digitize the spatial location for each hole using GIS software. The point location and its unique USGSID were stored in a point feature class in a GIS geodatabase. Each borehole was also assigned a unique USGSID that was used in correlation data and resource-estimate tabular relationships. Geostatistical modeling software was then used to model the resource data for each zone using a RBF method. After comparing and testing several modeling techniques, it was determined that the RBF-Multiquadric function (ESRI, 2006) produced the most geologically reasonable models.

Once satisfied with a particular model, raster datasets were generated for further analysis, including the ability to generate summary statistics based on the BPA models. Zonal statistics functions were applied to quantify resources, using the defined resource polygons intersected with townships as the limiting zones to count each raster cell’s estimated BPA value. As the analysis cell size was one acre, no mathematical conversions were necessary, as the software simply counted each cell’s BPA value contained within each individual

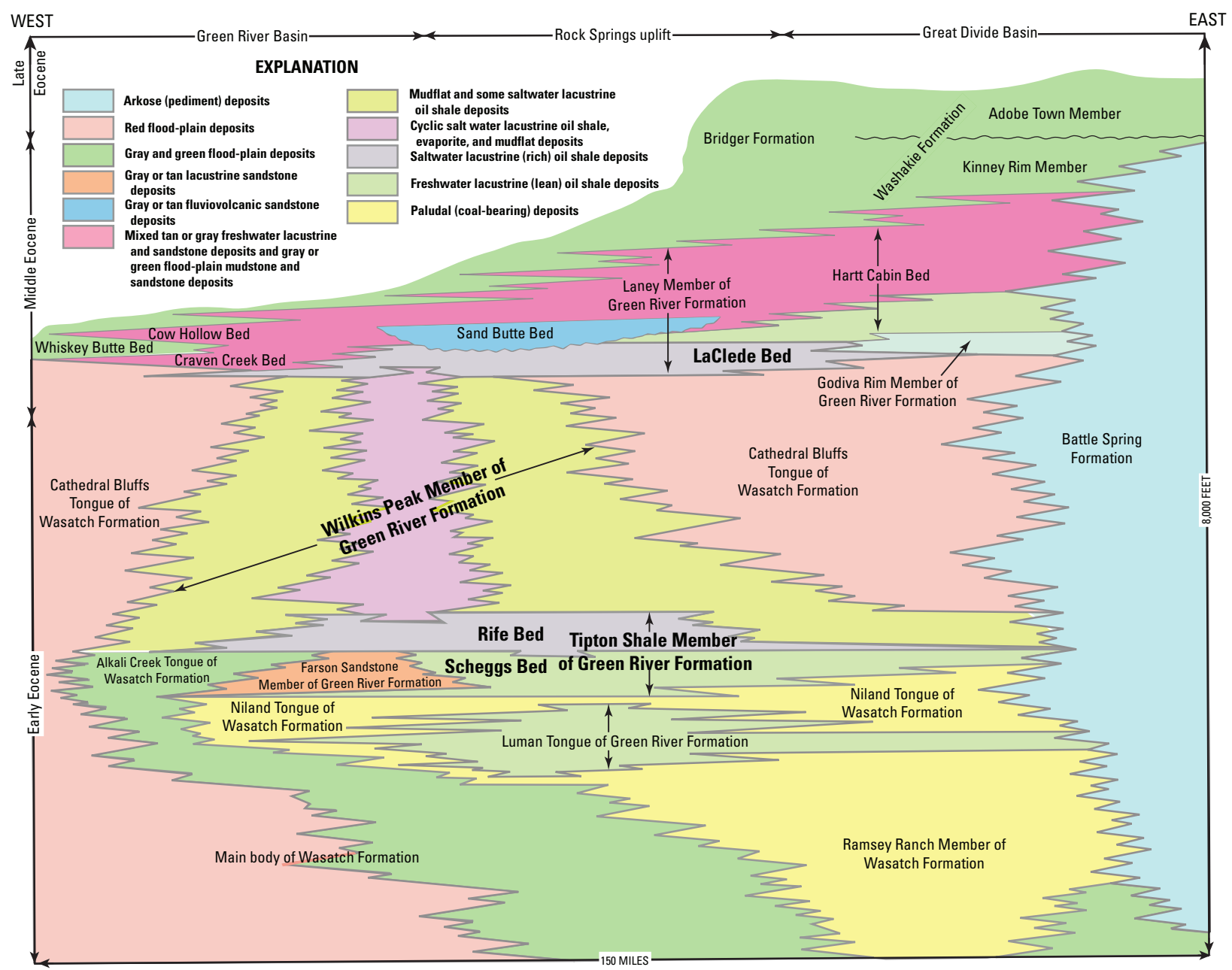


Figure 2. Generalized east-west cross section of Eocene rocks in the Green River Basin, Wyoming, Colorado, and Utah showing stratigraphic units and environments of deposition. Modified from Roehler (1991).

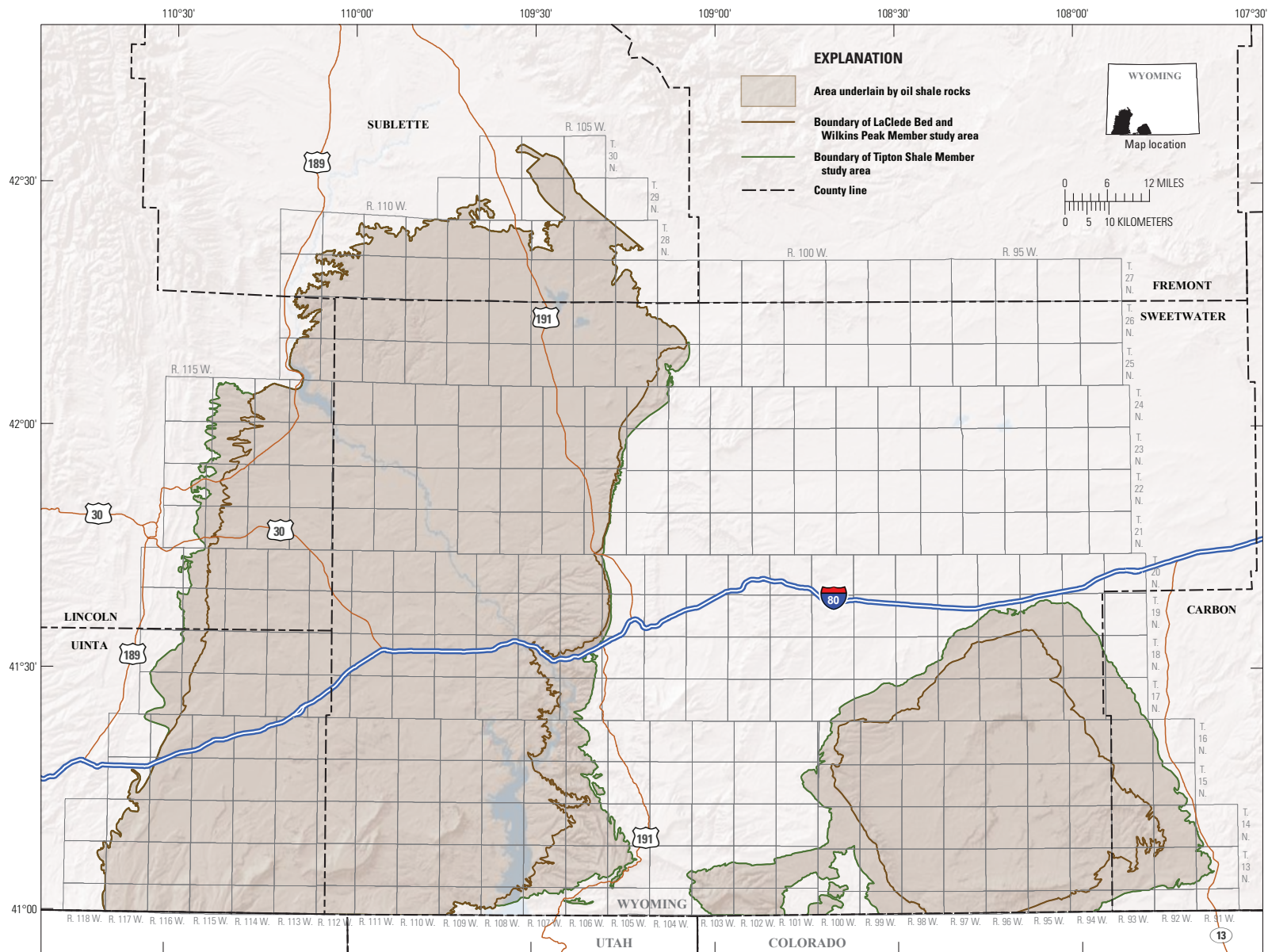


Figure 3. Green River and Washakie Basins, southwestern Wyoming, showing the two resource polygons used to limit in-place oil shale resource calculations: (1) LaCiede Bed of the Laney Member, and Wilkins Peak Member of the Green River Formation, and (2) the Tipton Shale Member of the Green River Formation. Laney Member of the Green River Formation outcrop shown in brown. Tipton Shale Member of the Green River Formation outcrop shown in green.

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File Edit Format View Help

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661601	0.0	85.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661618	85.0	90.0	0.0B	0.0B	0.0B	0.0B	0.5	0.0B	0.000B	0.0B
661619	90.0	95.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661620	95.0	105.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661622	105.0	120.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661625	120.0	125.0	0.0B	0.0B	0.0B	0.0B	0.5	0.0B	0.000B	0.0B
661626	125.0	130.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661627	130.0	135.0	0.0B	0.0B	0.0B	0.0B	0.5	0.0B	0.000B	0.0B
661628	135.0	185.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661638	185.0	190.0	0.0B	0.0B	0.0B	0.0B	0.5	0.0B	0.000B	0.0B
661639	190.0	290.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661659	290.0	295.0	0.0B	0.0B	0.0B	0.0B	0.5	0.0B	0.000B	0.0B
661660	295.0	365.0	0.0B	0.0B	0.0B	0.0B	0.0	0.0B	0.000B	0.0B
661674	365.0	375.0	0.0B	0.0B	0.0B	0.0B	2.0	0.0B	0.000B	0.0B
66484	375.0	376.0	0.0	2.5	97.0	0.5	0.0	5.9	0.000B	1.0
66485	376.0	378.0	0.0	2.1	97.7	0.2	0.0	5.0	0.000B	1.0
66486	378.0	380.0	0.0	1.9	97.8	0.3	0.0	4.6	0.000B	1.0
66487	380.0	381.9	0.0	1.9	97.9	0.2	0.0	4.6	0.000B	1.0
66488	381.9	383.7	0.0	2.3	97.4	0.3	0.0	5.5	0.000B	1.0
66489	383.7	384.4	0.0	1.8	97.9	0.3	0.0	4.2	0.000B	1.0
66490	384.4	385.5	0.0	2.5	97.1	0.4	0.0	6.0	0.000B	1.0
66491	385.5	387.0	0.0	2.0	97.8	0.2	0.0	4.8	0.000B	1.0
66492	387.0	389.0	0.0	2.1	97.5	0.4	0.0	5.1	0.000B	1.0
66493	389.0	391.0	0.0	1.8	97.2	1.0	0.0	4.4	0.000B	1.0
66494	391.0	393.0	0.0	2.6	97.0	0.4	0.0	6.2	0.000B	1.0
66495	393.0	395.0	0.0	1.9	97.4	0.7	0.0	4.6	0.000B	1.0

Column 1 2 3 4 5 6 7 8 9 10 11

Figure 4. Image clip of a portion of the original Fischer assay laboratory records in ASCII-text format (Dyni, 1998) for the U.S. Bureau of Mines Wyoming 1 borehole showing header data (first row). Header data include operator name, borehole name, and location. Columns (see table 1 for explanation of abbreviations): 1, LABNO; 2, TOPFT; 3, BOTFT; 4, SHLOILPCT; 5, WATERPCT; 6, SHLRSDPCT; 7, GASPLSPCT; 8, OILGPT; 9, WATERGPT; 10, SPCFGRAV; 11, COKETEND. Values of 0.00B and 0.000B denote missing records.

Table 1. Column names and definitions in the Microsoft Access table after converting the original Fischer assay laboratory data and adding additional columns needed for resource calculations.

Column name	Column definition
OBJECTID	Software-calculated identifier
LABNO	Six-digit USBM Laramie laboratory number
TOPFT	Depth, in ft, measured from the surface datum to the top of the sampled interval
BOTFT	Depth, in ft, measured from the surface datum to the base of the sampled interval
SHLOILPCT	Amount of shale oil, in weight percent
WATERPCT	Amount of water, in weight percent
SHLRSDPCT	Amount of shale residue, in weight percent
GASPLSPCT	Amount of "gas plus loss," in weight percent
OILGPT	Shale oil, in U.S. gallons per short ton of rock
WATERGPT	Water, in U.S. gallons per short ton of rock
SPCFGRAV	Specific gravity of the shale oil
COKETEND	Tendency for spent shale to coke
USGSID	Unique ID assigned by staff geologist
INTVL	Thickness of interval, in ft (BOTFT-TOPFT)
INTXOIL	Column used for weighted-average gallons per ton calculation (INTVL * OILGPT)
ROCKTYPE	Column added to denote intervals that were edited to distinguish between missing records and records found in core descriptions to be halite and (or) trona ("NH"), or sandstone ("NO").

Oil Shale Resource Methodology Overview

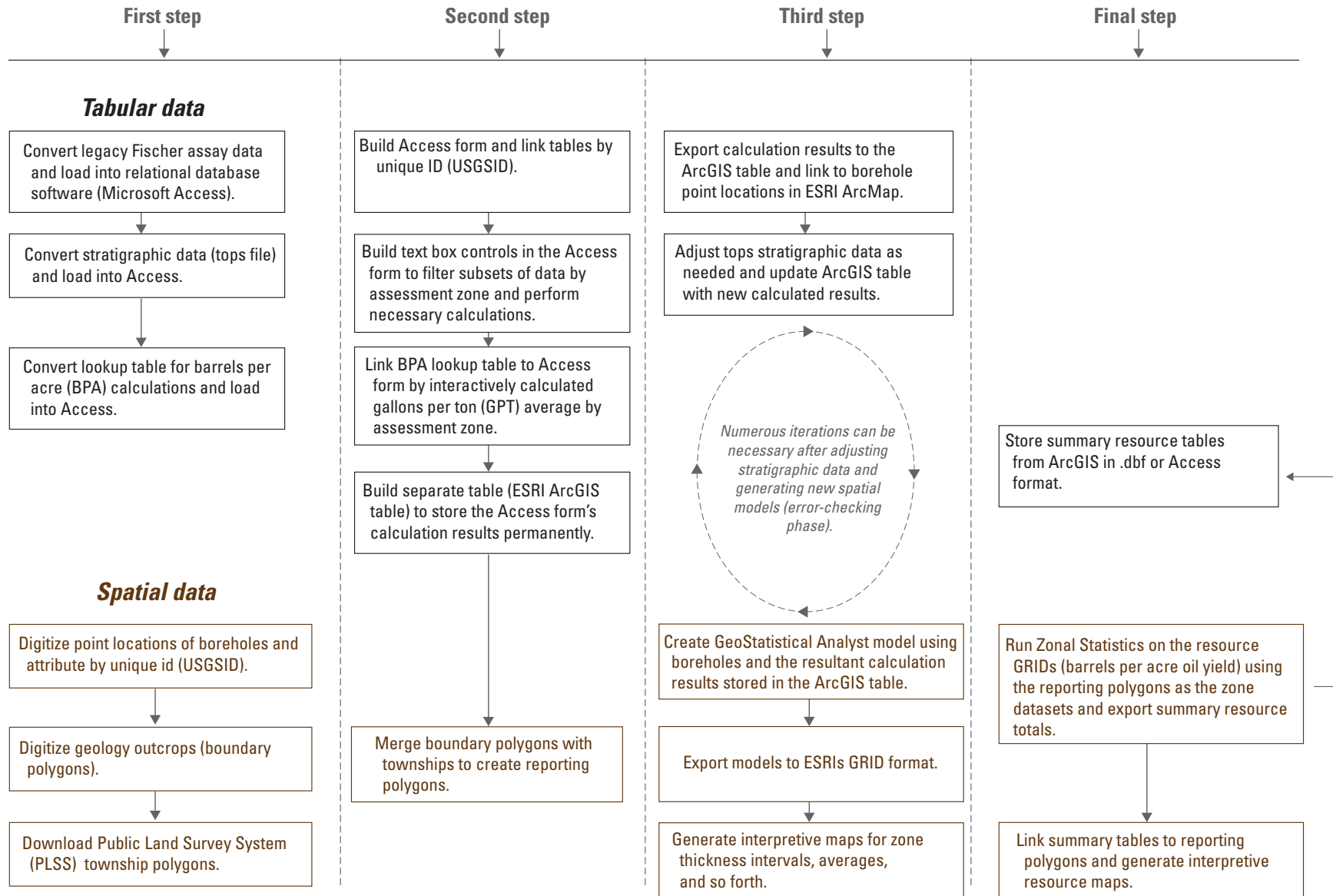


Figure 5. Overview chart showing the four steps and processes carried out on the spatial and tabular data for the Green River and Washakie Basins oil shale assessment.

polygon of each resource-reporting file (the outcrop-polygon file intersected with the township file). Various summary calculations and tables were then generated using the resource estimates for total barrels of oil yield per township. A more detailed and technical description of the zonal statistics function is presented in a case study following this report.

In-Place Resource Calculations

Gallons Per Ton

For each borehole, resource calculations were performed for each of the oil shale zones listed in a Microsoft Access form (fig. 6). An Access form “is a database object that you can use to enter, edit, or display data from a table or a query” (Microsoft Corporation, 2006); it also allows the viewing of many records from several linked tables in an easier and less cluttered manner. Additionally, by creating a custom form with Visual Basic, SQL, and several macros, we were able to apply filters and perform calculations on many subsets of the master Fischer assays table. Although results are calculated within the form interactively, the results are stored permanently in a separate database table that is directly linked to GIS software. By using this method, we could continually revise the database (fig. 7) and concurrently generate numerous iterations of spatial models on corrected values using ArcGIS’s GeoStatistical Analyst (ESRI, 2006) extension. A diagram describing the table relationships in the database is in the accompanying Appendix.

To calculate average oil yield per zone (in GPT) for each borehole, missing records were first removed from each zone so they would not affect the weighted-average calculation. This was accomplished by writing queries that filtered out those records where the INTXOIL (thickness of interval times oil yield in GPT) field had a value of 0. As stated previously, missing records were identified and removed from the computation if either the OILGPT or INTXOIL fields contained 0 values. It should be noted that the weighted-average calculation used only valid values for GPT for a particular zone (no zero values), but used the total thickness of all the sampled intervals within that zone in the formula. The formula used to calculate the weighted average of GPT for each zone was:

$$\frac{\text{Sum of (thickness of interval in feet} \times \text{gallons per ton)}}{\text{thickness of interval in feet.}}$$

Barrels Per Acre

The determination of oil-in-place resource values in BPA was generated from the derived GPT weighted-averages calculated in the database form (fig. 6). Stanfield and others (1954) reported data on volume-weight oil-yield relationships from nearly 20,500 U.S. Bureau of Mines oil-yield analyses (table 2). Smith (1956) reported that oil-yield values were

related to the specific gravity of the oil shale. Table 2 contains original values for oil yield in GPT and associated specific-gravity values and were reported to the nearest 1 GPT. Values for weight of oil shale, volume of oil shale, and oil yield per unit volume were updated using currently accepted conversion factors (table 3). A third-order trendline with a R^2 value (the measure of the reliability of the linear relationship) of 0.9998 was generated to compare oil yield with specific gravity (fig. 8). As the original table contained only integer values for GPT, new records were inserted to fill in values to one decimal place (for example, 0.1 GPT). A linear-trend series-fill function was then used to calculate specific gravity values for each 0.1 GPT value. A third-order trendline was regenerated comparing the new oil yield versus specific-gravity data yielding a R^2 value of 0.9997. Values for weight of oil shale, volume of oil shale, and oil yield per unit volume were recalculated using the new values for oil yield and specific gravity. The updated lookup table was created containing records for oil yield (GPT), specific gravity, and oil yield per unit volume from 1.0 to 80.0 GPT, at 0.1 GPT intervals that were then related to the database form by using the values for oil yield in GPT.

To calculate BPA for each borehole location, the previously calculated weighted-average value for GPT was related to the lookup table (table 3) to retrieve the associated value for oil yield per unit volume (gallons per cubic foot, gal/ft³); this value was needed to perform the BPA calculation:

$$\frac{\text{Interval thickness in feet (without halite or trona beds)} \times 43,560 \text{ (ft}^2\text{/acre)} \times \text{oil yield per unit volume (gal/ft}^3\text{)}}{42 \text{ (gals/barrel of oil)}}.$$

In short, the calculated value for GPT was used as another unique identifier to link to the lookup table (table 3) in order to use the associated value for oil yield per unit volume in that record as input into the BPA formula. For example, if the Microsoft Access form (as in fig. 6) listed GPT to be 10.0 for a specific borehole and zone, this would correspond to a value of 0.790 gal/ft³ in table 3, which would then be the input into the BPA formula as the oil yield per unit volume multiplier. The interval thickness value in the formula was calculated by summing all of the intervals within a zone and subtracting any beds denoted as halite or trona in the ROCK-TYPE column – “NH.”

Missing Intervals

In addition to resource calculations, statistics describing missing core intervals in percent, maximum thickness of missing intervals, and the number of missing intervals for each borehole and zone were generated (fig. 9). In general, the larger the proportion of a given core that constitutes a missing interval, the greater the imprecision of the resource calculation. Therefore, an accurate accounting of the number and thickness of missing intervals is especially important, because a few thick, missing intervals could potentially have a greater impact on the precision of a resource calculation than a large

USGSID

W0006

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W0006

Operator

U.S. Bureau of Mines

Name

Wyoming 01

Township

23 N

Range

107 w

Section

30

1/4 - 1/4

SW NW

Elevation

6466

Tops

Laney

CW1

Lean LaCled

Rich LaCled

422.8

Buffmark

Base Buffmark

Lw Rich LaCled

478.2

Lw Lean LaCled

Godiva Rm

Wilkins Peak

500.2

Cathedral Bluff

Lw Wilkins Peak

Rife

773.3

Farson

813

Scheggs

1157.4

Main Tw

1183.8

Niland

Tp Wilkins Model

500.2

Bs Wilkins Model

773.3

Tp Rife Model

773.3

Bs Rife Model

813

Tp LaCled Model

422.8

Bs LaCled Model

500.2

Tp Scheggs Model

1157.4

Bs Scheggs Model

1183.8

Intervals

LaCled

77.4

Wilkins Peak

273.1

Rife

39.7

Scheggs

26.4

Tipton

410.5

Wilkins Peak Res. Iso.

273.1

Farson Iso.

344.4

Fischer Assays

Choose Zone:

LaCled

Wilkins Peak

Rife

Scheggs

Buff

Tipton

TOPF	BOTFT	OILGPT	USGS	INTVL	INTXOIL	ROCK
422.8	423.5	1.2	W0006	0.7	0.84	
423.5	424.8	2.1	W0006	1.3	2.73	
424.8	425.9	2.6	W0006	1.1	2.86	
425.9	427.2	1.5	W0006	1.3	1.95	
427.2	428.2	0.6	W0006	1	0.6	
428.2	429.2	0.2	W0006	1	0.2	
429.2	430.4	0.00001	W0006	1.2	0.000012	
430.4	431.6	0.2	W0006	1.2	0.24	
431.6	433	0.00001	W0006	1.4	0.000014	
433	434	0.2	W0006	1	0.2	
434	435	0.2	W0006	1	0.2	
435	436.2	0.3	W0006	1.2	0.36	
436.2	437.2	0.00001	W0006	1	0.00001	
437.2	439	0.7	W0006	1.8	1.26	
439	440.3	10.6	W0006	1.3	13.78	
440.3	441.4	15.3	W0006	1.1	16.83	
441.4	444.5	0.4	W0006	3.1	1.24	

Record: 1 of 71

Active Zone: LaCled Bed

Calculations

% Missing

1.6%

Gallons per Ton

9.1

Barrels per Acre

57819

Max Missing

1.0

Count Missing

2.0

ArcGIS Table

USGSID

W0006

AVMSIN

1.6

AVGPT

9.1

BPA

57819

MXMISS

1

CNTMISS

2

Record: 1 of 1

Figure 6. Image clip of Microsoft Access 2007 form used to carry out oil shale resource calculations containing: (1) tops table under the headings Cores, Tops, and Intervals; (2) Fischer Assays table; (3) Calculations section containing controls that performed assessment calculations; and (4) ArcGIS Table used to store calculation values permanently.

Oil Shale Assessment 9

10 Methodology for Calculating Oil Shale Resources for the Green River and Washakie Basins, Southwestern Wyoming

USGSID

W0006

USGSID

W0006

Operator

U.S. Bureau of Mines

Name

Wyoming 01

Township

23 N

Range

107 w

Section

30

1/4 - 1/4

SW NW

Elevation

6466

Tops

Laney

CW1

Lean LaCiede

Rich LaCiede

422.8

Buffmark

Base Buffmark

478.2

Lw Rich LaCiede

Lw Lean LaCiede

Godiva Rm

Wilkins Peak

500.2

Cathedral Bluff

Lw Wilkins Peak

Rife

773.3

Farson

813

Scheggs

1157.4

Main Tw

1183.8

Niland

Tp Wilkins Model

500.2

Bs Wilkins Model

773.3

Tp Rife Model

773.3

Bs Rife Model

813

Tp LaCiede Model

422.8

Bs LaCiede Model

500.2

Tp Scheggs Model

1157.4

Bs Scheggs Model

1183.8

Intervals

LaCiede

77.4

Wilkins Peak

273.1

Rife

39.7

Scheggs

26.4

Tipton

410.5

Wilkins Peak Res. Iso.

273.1

Farson Iso.

344.4

Fischer Assays

Choose Zone:

LaCiede

Wilkins Peak

Rife

Scheggs

Buff

Tipton

TOPF	BOTFT	OILGPT	USGS	INTVL	INTXOIL	ROCK
422.8	423.5	1.2	W0006	0.7	0.84	
423.5	424.8	2.1	W0006	1.3	2.73	
424.8	425.9	2.6	W0006	1.1	2.86	
425.9	427.2	1.5	W0006	1.3	1.95	
427.2	428.2	0.6	W0006	1	0.6	
428.2	429.2	0.2	W0006	1	0.2	
429.2	430.4	0.00001	W0006	1.2	0.000012	
430.4	431.6	0.2	W0006	1.2	0.24	
431.6	433	0.00001	W0006	1.4	0.000014	
433	434	0.2	W0006	1	0.2	
434	435	0.2	W0006	1	0.2	
435	436.2	0.3	W0006	1.2	0.36	
436.2	437.2	0.00001	W0006	1	0.00001	
437.2	439	0.7	W0006	1.8	1.26	
439	440.3	10.6	W0006	1.3	13.78	
440.3	441.4	15.3	W0006	1.1	16.83	
441.4	444.5	0.4	W0006	3.1	1.24	

Record: 1 of 71

Active Zone: LaCiede Bed

Calculations

% Missing

1.6%

Gallons per Ton

9.1

Barrels per Acre

57819

Max Missing

1.0

Count Missing

2.0

ArcGIS Table

USGSID W0006

AVMSIN 1.6

AVGPT 9.1

BPA 57819

MXMISS 1

CNTMISS 2

Record: 1 of 1

USGSID

W0006

USGSID

W0006

Operator

U.S. Bureau of Mines

Name

Wyoming 01

Township

23 N

Range

107 w

Section

30

1/4 - 1/4

SW NW

Elevation

6466

Tops

Laney

CW1

Lean LaCiede

Rich LaCiede

422.8

Buffmark

Base Buffmark

478.2

Lw Rich LaCiede

Lw Lean LaCiede

Godiva Rm

Wilkins Peak

500.2

Cathedral Bluff

Lw Wilkins Peak

Rife

773.3

Farson

813

Scheggs

1157.4

Main Tw

1183.8

Niland

Tp Wilkins Model

500.2

Bs Wilkins Model

773.3

Tp Rife Model

773.3

Bs Rife Model

813

Tp LaCiede Model

427.2

Bs LaCiede Model

500.2

Tp Scheggs Model

1157.4

Bs Scheggs Model

1183.8

Intervals

LaCiede

77.4

Wilkins Peak

273.1

Rife

39.7

Scheggs

26.4

Tipton

410.5

Wilkins Peak Res. Iso.

273.1

Farson Iso.

344.4

Fischer Assays

Choose Zone:

LaCiede

Wilkins Peak

Rife

Scheggs

Buff

Tipton

TOPF	BOTFT	OILGPT	USGS	INTVL	INTXOIL	ROCK
427.2	428.2	0.6	W0006	1	0.6	
428.2	429.2	0.2	W0006	1	0.2	
429.2	430.4	0.00001	W0006	1.2	0.000012	
430.4	431.6	0.2	W0006	1.2	0.24	
431.6	433	0.00001	W0006	1.4	0.000014	
433	434	0.2	W0006	1	0.2	
434	435	0.2	W0006	1	0.2	
435	436.2	0.3	W0006	1.2	0.36	
436.2	437.2	0.00001	W0006	1	0.00001	
437.2	439	0.7	W0006	1.8	1.26	
439	440.3	10.6	W0006	1.3	13.78	
440.3	441.4	15.3	W0006	1.1	16.83	
441.4	444.5	0.4	W0006	3.1	1.24	
444.5	444.9	8.2	W0006	0.4	3.28	
444.9	445.2	2.2	W0006	0.3	0.66	
445.2	446.2	6.4	W0006	1	6.4	
446.2	447.2	5.5	W0006	1	5.5	

Record: 1 of 67

Active Zone: LaCiede Bed

Calculations

% Missing

1.7%

Gallons per Ton

9.5

Barrels per Acre

56774

Max Missing

1.0

Count Missing

2.0

ArcGIS Table

USGSID W0006

AVMSIN 1.6

AVGPT 9.1

BPA 57819

MXMISS 1

CNTMISS 2

Record: 1 of 1

Figure 7. Image clip showing how changing an interpretation of a tops pick in the tops table and re-filtering the Fischer assays table immediately affects the Microsoft Access 2007 form's resource calculations, but not the ArcGIS Table's records. Example shown is for the LaCiede Bed of the Laney Member of the Green River Formation oil shale zone in borehole W0006 (see fig. 14 for location data).

Table 2. Original volume-weight oil-yield relations based upon Green River Formation oil shale from U.S. Bureau of Mines oil-shale mine, Rifle, Colo. From Stanfield and others (1954).[GPT, gallons per ton; lbs/ft³, pounds per cubic foot; ft³/ton, cubic feet per ton; gal/ft³, gallons per cubic foot]

Oil yield by assay (GPT)	Specific gravity of oil shale	Weight of oil shale (lbs/ft ³)	Volume of oil shale (ft ³ /ton)	Oil yield, per unit volume (gal/ft ³)
1	2.740	170.98	11.70	0.085
2	2.715	169.42	11.80	0.169
3	2.690	167.86	11.91	0.252
4	2.655	166.30	12.03	0.333
5	2.640	164.74	12.14	0.412
6	2.618	163.36	12.24	0.490
7	2.596	161.98	12.35	0.567
8	2.574	160.61	12.45	0.642
9	2.552	159.24	12.56	0.716
10	2.530	157.87	12.67	0.789
11	2.508	156.49	12.78	0.860
12	2.486	155.12	12.89	0.930
13	2.464	153.75	13.01	0.999
14	2.442	152.38	13.13	1.067
15	2.420	151.01	13.24	1.133
16	2.400	149.76	13.35	1.198
17	2.380	148.51	13.47	1.262
18	2.360	147.26	13.58	1.325
19	2.340	146.02	13.70	1.387
20	2.320	144.77	13.80	1.448
21	2.302	143.64	13.92	1.508
22	2.284	142.52	14.03	1.567
23	2.266	141.40	14.14	1.625
24	2.248	140.78	14.26	1.683
25	2.230	139.15	14.37	1.740
26	2.216	138.28	14.46	1.797
27	2.202	137.40	14.56	1.854
28	2.188	136.53	14.65	1.910
29	2.174	135.66	14.74	1.966
30	2.160	134.78	14.83	2.022
31	2.147	133.97	14.92	2.077
32	2.134	133.16	15.02	2.131
33	2.121	132.35	15.11	2.184
34	2.108	131.54	15.20	2.236
35	2.093	130.73	15.30	2.288
36	2.082	129.92	15.44	2.339
37	2.069	129.11	15.49	2.389
38	2.056	128.29	15.59	2.438
39	2.043	127.48	15.69	2.486
40	2.030	126.67	15.79	2.534
41	2.018	125.92	15.88	2.581
42	2.006	125.17	15.98	2.628

Table 2. Original volume-weight oil-yield relations based upon Green River Formation oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colo. From Stanfield and others (1954).—Continued[GPT, gallons per ton; lbs/ft³, pounds per cubic foot; ft³/ton, cubic feet per ton; gal/ft³, gallons per cubic foot]

Oil yield by assay (GPT)	Specific gravity of oil shale	Weight of oil shale (lbs/ft³)	Volume of oil shale (ft³/ton)	Oil yield, per unit volume (gal/ft³)
43	1.994	124.43	16.07	2.674
44	1.982	123.68	16.17	2.720
45	1.970	122.93	16.27	2.766
46	1.959	122.24	16.36	2.811
47	1.948	121.56	16.45	2.856
48	1.937	120.87	16.55	2.901
49	1.926	120.18	16.64	2.945
50	1.915	119.50	16.74	2.938
51	1.904	118.81	16.83	3.030
52	1.893	118.12	16.93	3.071
53	1.882	117.44	17.03	3.112
54	1.871	116.79	17.12	3.152
55	1.860	116.06	17.23	3.192
56	1.849	115.38	17.33	3.231
57	1.838	114.69	17.44	3.269
58	1.827	114.00	17.54	3.306
59	1.816	113.32	17.65	3.343
60	1.805	112.63	17.76	3.379
61	1.794	111.95	17.87	3.414
62	1.783	111.26	17.98	3.449
63	1.772	110.57	18.09	3.483
64	1.761	109.89	18.20	3.516
65	1.750	109.20	18.32	3.549
66	1.740	108.58	18.42	3.582
67	1.730	107.95	18.53	3.615
68	1.720	107.33	18.63	3.648
69	1.710	106.70	18.74	3.681
70	1.700	106.08	18.85	3.713
71	1.690	105.46	18.96	3.744
72	1.680	104.83	19.08	3.774
73	1.670	104.21	19.19	3.804
74	1.660	103.58	19.31	3.833
75	1.650	102.96	19.43	3.861
76	1.640	102.34	19.54	3.889
77	1.630	101.71	19.66	3.916
78	1.620	101.09	19.78	3.943
79	1.610	100.46	19.91	3.969
80	1.600	99.84	20.03	3.994
90	1.500	93.75	21.33	4.219

Table 3. Recalculated volume-weight oil-yield relationships based upon Green River Formation oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colo. From Stanfield and others (1954).[GPT, gallons per ton; lbs/ft³, pounds per cubic foot; ft³/ton, cubic feet per ton; gal/ft³, gallons per cubic foot]

Oil yield by assay (GPT)	Specific gravity of oil shale	Weight of oil shale (lbs/ft ³)	Volume of oil shale (ft ³ /ton)	Oil yield, per unit volume (gal/ft ³)
1	2.740	171.06	11.69	0.086
2	2.715	169.50	11.80	0.169
3	2.690	167.94	11.91	0.252
4	2.655	165.75	12.07	0.332
5	2.640	164.82	12.13	0.412
6	2.618	163.44	12.24	0.490
7	2.596	162.07	12.34	0.567
8	2.574	160.69	12.45	0.643
9	2.552	159.32	12.55	0.717
10	2.530	157.95	12.66	0.790
11	2.508	156.57	12.77	0.861
12	2.486	155.20	12.89	0.931
13	2.464	153.83	13.00	1.000
14	2.442	152.45	13.12	1.067
15	2.420	151.08	13.24	1.133
16	2.400	149.83	13.35	1.199
17	2.380	148.58	13.46	1.263
18	2.360	147.33	13.57	1.326
19	2.340	146.09	13.69	1.388
20	2.320	144.84	13.81	1.448
21	2.302	143.71	13.92	1.509
22	2.284	142.59	14.03	1.568
23	2.266	141.47	14.14	1.627
24	2.248	140.34	14.25	1.684
25	2.230	139.22	14.37	1.740
26	2.216	138.34	14.46	1.798
27	2.202	137.47	14.55	1.856
28	2.188	136.60	14.64	1.912
29	2.174	135.72	14.74	1.968
30	2.160	134.85	14.83	2.023
31	2.147	134.04	14.92	2.078
32	2.134	133.23	15.01	2.132
33	2.121	132.41	15.10	2.185
34	2.108	131.60	15.20	2.237
35	2.093	130.67	15.31	2.287
36	2.082	129.98	15.39	2.340
37	2.069	129.17	15.48	2.390
38	2.056	128.36	15.58	2.439
39	2.043	127.54	15.68	2.487
40	2.030	126.73	15.78	2.535
41	2.018	125.98	15.88	2.583
42	2.006	125.23	15.97	2.630

Table 3. Recalculated volume-weight-oil yielded relationships based upon Green River Formation oil shale from U.S. Bureau of Mines oil-shale mine, Rifle, Colo. From Stanfield and others (1954).—Continued[GPT, gallons per ton; lbs/ft³, pounds per cubic foot; ft³/ton, cubic feet per ton; gal/ft³, gallons per cubic foot]

Oil yield by assay, (GPT)	Specific gravity of oil shale	Weight of oil shale (lbs/ft³)	Volume of oil shale (ft³/ton)	Oil yield, per unit volume (gal/ft³)
43	1.994	124.49	16.07	2.676
44	1.982	123.74	16.16	2.722
45	1.970	122.99	16.26	2.767
46	1.959	122.30	16.35	2.813
47	1.948	121.61	16.45	2.858
48	1.937	120.93	16.54	2.902
49	1.926	120.24	16.63	2.946
50	1.915	119.55	16.73	2.989
51	1.904	118.87	16.83	3.031
52	1.893	118.18	16.92	3.073
53	1.882	117.49	17.02	3.114
54	1.871	116.81	17.12	3.154
55	1.860	116.12	17.22	3.193
56	1.849	115.43	17.33	3.232
57	1.838	114.75	17.43	3.270
58	1.827	114.06	17.53	3.308
59	1.816	113.37	17.64	3.344
60	1.805	112.69	17.75	3.381
61	1.794	112.00	17.86	3.416
62	1.783	111.31	17.97	3.451
63	1.772	110.63	18.08	3.485
64	1.761	109.94	18.19	3.518
65	1.750	109.25	18.31	3.551
66	1.740	108.63	18.41	3.585
67	1.730	108.00	18.52	3.618
68	1.720	107.38	18.63	3.651
69	1.710	106.76	18.73	3.683
70	1.700	106.13	18.84	3.715
71	1.690	105.51	18.96	3.745
72	1.680	104.88	19.07	3.776
73	1.670	104.26	19.18	3.805
74	1.660	103.63	19.30	3.834
75	1.650	103.01	19.42	3.863
76	1.640	102.39	19.53	3.891
77	1.630	101.76	19.65	3.918
78	1.620	101.14	19.78	3.944
79	1.610	100.51	19.90	3.970
80	1.600	99.89	20.02	3.996
90	1.500	93.65	21.36	4.214

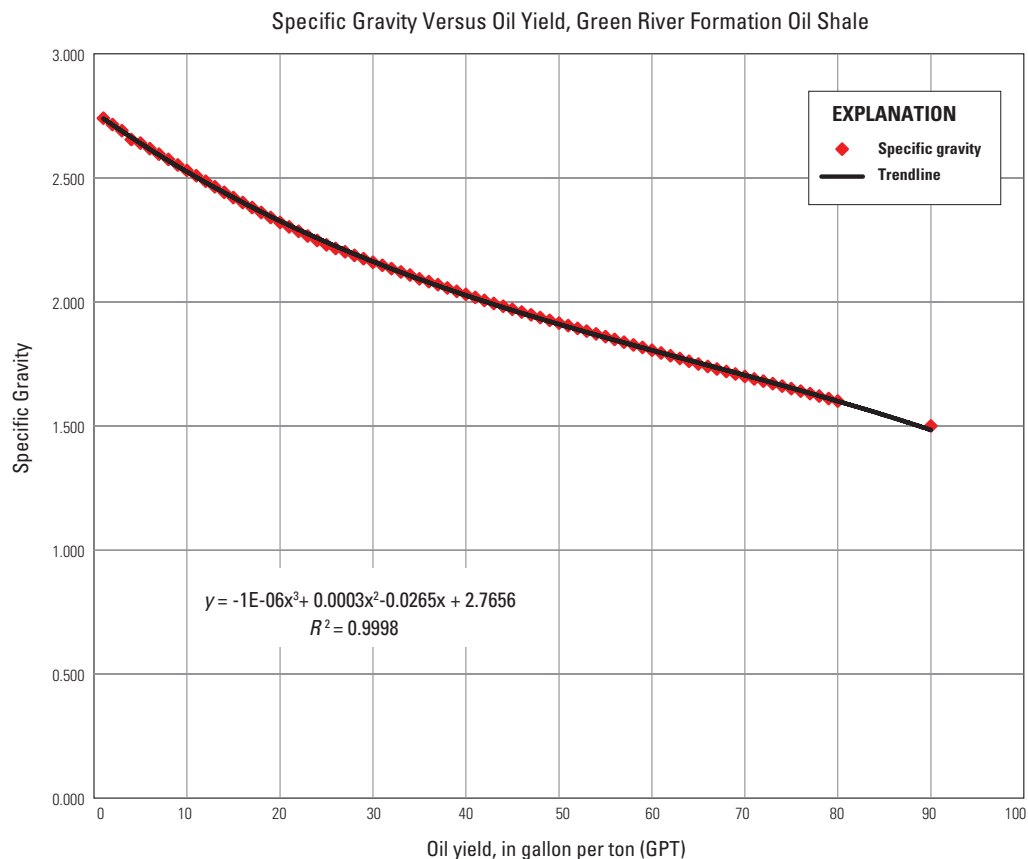


Figure 8. Graph of a third-order trendline showing relationship between oil yield for Green River Formation oil shales and specific gravity.

Fischer Assays

Choose Zone:

TOPF	BOTFT	OILGPT	USGS	INTVL	INTXOIL	ROCK
483.5	484.5	19.3	W0006	1	19.3	
484.5	485.5	22.6	W0006	1	22.6	
485.5	486	19.3	W0006	0.5	9.65	
486	487	24.1	W0006	1	24.1	
487	487.6	16.1	W0006	0.6	9.660001	
487.6	488.3	7.7	W0006	0.7	5.39	
488.3	488.8	29.1	W0006	0.5	14.55	
488.8	490.5	22.2	W0006	1.7	37.74	
490.5	491.5	0	W0006	1	0	
491.5	493	19.3	W0006	1.5	28.95	
493	494	24.2	W0006	1	24.2	
494	495.1	28.4	W0006	1.1	31.24	
495.1	496.2	26.1	W0006	1.1	28.71	
496.2	496.8	14.7	W0006	0.6	8.820001	
496.8	497.4	14.5	W0006	0.6	8.700001	
497.4	498.7	12	W0006	1.3	15.6	
498.7	499.8	33.2	W0006	1.1	36.52	

Record: 1 of 71

Active Zone: LaCiede Bed

Figure 9. Image clip on map of Microsoft Access 2007 form showing how missing intervals are reported for each core sample. Example shown is for the LaCiede Bed of the Laney Member of the Green River Formation oil shale zone in borehole W0006 (see fig. 14 for location data).

Calculations

% Missing	1.6%
Gallons per Ton	9.1
Barrels per Acre	57819
Max Missing	1.0
Count Missing	2.0

Set GPT

Set BPA

ArcGIS Table

USGSID	W0006	MXMISS	1
AVMSIN	1.6	CNTMISS	2
AVGPT	9.1		
BPA	57819		

Record: 1 of 1

number of thin intervals. Once a specific borehole was filtered by zone in the database form, custom-scripting functions counted and performed calculations on the missing records in the Fischer assays table. These values were then permanently stored in the table used for GIS functions and a series of derivative maps were produced by linking the missing-interval statistics to the borehole locations in the GIS. The missing-intervals derivative maps were a valuable aid in assessing the uncertainty of the resource estimates.

Geospatial Modeling, Analysis, and Presentation

Oil Shale Zone Thickness Isopachs

Oil shale zone-thickness values were calculated, based on the zonal contacts as identified in boreholes and listed in a spreadsheet, by subtracting a pick of the top for any given zone from that of the immediately underlying zone. Formulas were created to automate this function, but actual values were used in converting the spreadsheet to a database table. When the pick of a zone top was revised in the database form, the thickness of the zone interval was recalculated. Using this method, values for all resource calculations were continuously and immediately updated, as the new tops and interval values affected all formulas contained in the form and were recalculated interactively (fig. 7).

Once a set of tops for a given zone was finalized, the thickness values for each zone were used to generate spatial-data models using a RBF-Multiquadric modeling method (ESRI, 2006). By generating and analyzing a spatial model for each zone, errors were located in the tops table and changes were made to the correlations as needed. Upon completion of the database, a final model for each oil shale zone was converted to a fixed raster dataset and a series of oil shale-zone-thickness isopach maps were generated.

Generating Oil-Yield Models

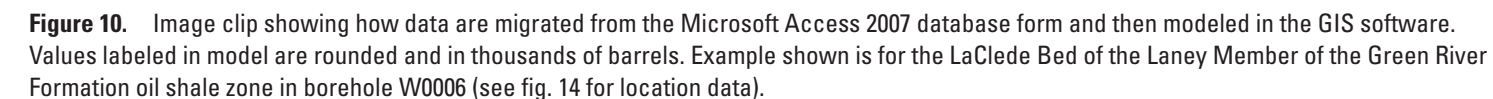
In a previous oil shale assessment, Pitman and others (1989) used geostatistical interpolation by kriging to generate resource maps and numbers. They reported that kriging gave good results in areas with large numbers of control points, but that resource numbers with large error limits were obtained in areas with few control points; consequently, they resorted to hand-contouring and hand-calculating resources in these areas. In the present assessment, three modeling methods were evaluated for spatial interpolation and extrapolation purposes: (1) the RBF method, (2) the Inverse Distance Weighted (IDW) method in ArcGIS (ESRI, 2006), and (3) the minimum-tension gridding technique in EarthVision (Dynamic Graphics, Inc., 2004). The three methods gave remarkably similar results, and RBF was ultimately chosen. One of the determining factors was that the RBF method did not limit the analysis to

a coarse-cell spacing, so we were able to model and report resources using a one-acre cell size. Although not as robust as kriging or other geostatistical spatial modeling methods, it has been demonstrated that the RBF method can give comparable results (Rusu and Rusu, 2006). RBF is an exact interpolator; it honors all data points and does not introduce any error at those locations (ESRI, 2006). Although it is important for the modeling method to honor the measured values, RBF can also extrapolate values above or below the actual values outside the data-point locations. Extrapolation of values beyond the dataset boundaries was appropriate in this geology-based assessment, as each zone's oil yield varies in a predictable manner throughout the basin areas.

After the database revisions were completed, the resultant calculated values for GPT and BPA were written to a separate database table and related to the borehole-locations file. RBF models were then generated using the resultant borehole data containing oil-yield values (fig. 10). The values for GPT and BPA were modeled using the RBF-Multiquadric method. The final resource models were created using a sampling method containing eight moving window sectors with eight neighbors in each sector; after numerous tests, these parameters yielded the most geologically reasonable oil shale resource models that can be constructed from the number of boreholes and the extent of the dataset that are available. After all models were finalized, they were exported to a fixed raster format with a one-acre cell size (63.615 m (208.7 ft) per side) along with a mean error, root mean-squared error (RMS), and cross-validation table for each BPA model. A more detailed description of the error tables is presented in the case study at the end of this report. A series of derivative maps were then created using ArcGIS (ESRI, 2006).

Summarizing Resource Models

A zonal-statistics function was used on the finalized BPA models to calculate resources per township, this step being critical inasmuch as the software was able to count each cell's BPA value within a specified zone (fig. 11). In this case, the surface zones required as input for the software to summarize the raster cells (not to be confused with the subsurface oil shale zones) included townships or portions thereof that were cropped by the outcrop lines. As the analysis cell size of one acre and the BPA were modeled, a straightforward summary of total barrels of oil yield per township was performed, with the software simply counting all of the BPA values for each cell (acre) contained within each resource township. The summary statistics were then linked to each township and another series of derivative maps detailing the total barrels of oil yield per township was generated. Although a polygon file delineating township boundaries within the resource zones was used, in the future a user could easily run statistics using a different zone boundary, such as for a 640-acre (1 mi²) section to obtain a summary of barrels of oil yield per section.



ESRI ArcGIS Spatial Analyst's Zonal Statistics Function

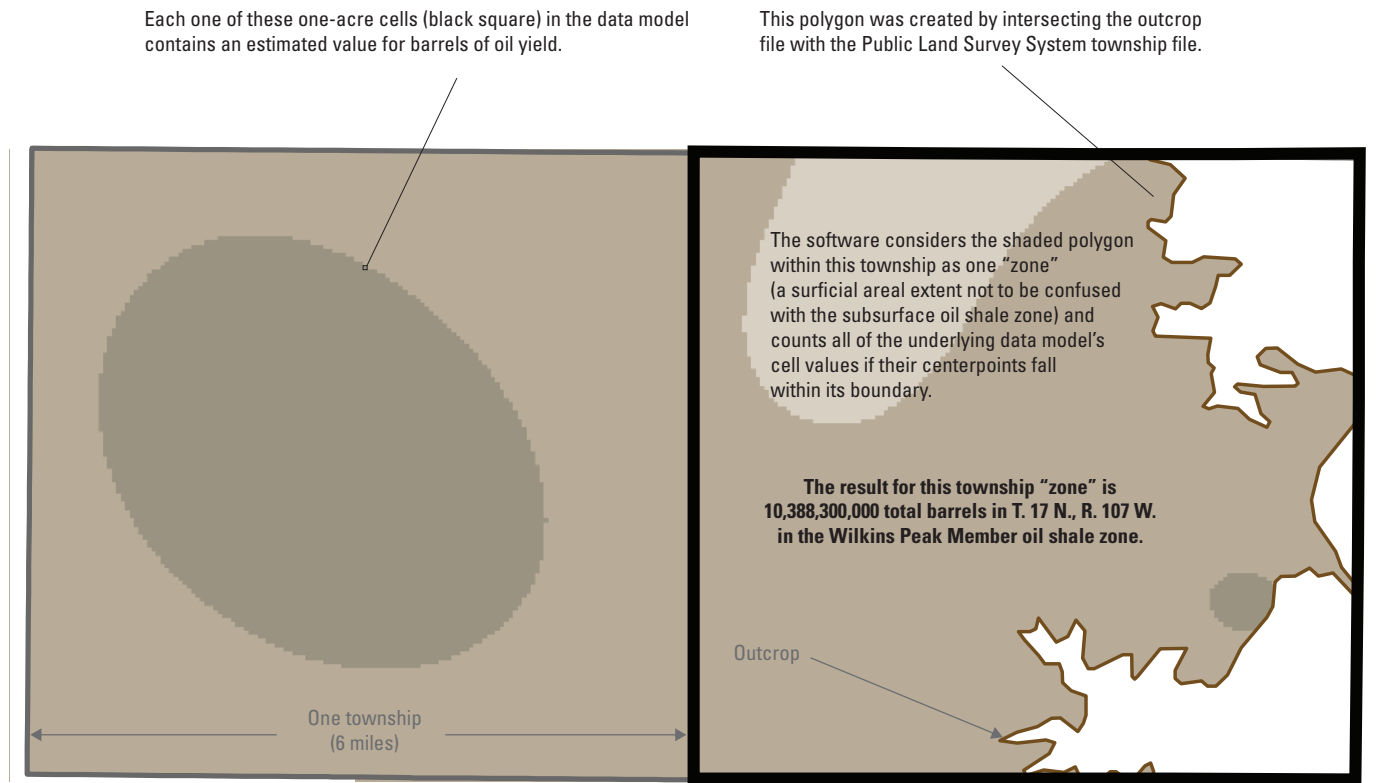


Figure 11. Map of the eastern part of the Green River Basin, southwestern Wyoming, showing how the GIS software summarizes total barrels of oil yield by township.

Interpretive Maps

Once the spatial analysis and quantification of resources were completed, a series of interpretive maps were generated for each of the three oil shale zones, including thickness isopachs of individual oil shale zones, average oil yield in GPT, oil yield in BPA, oil yield in barrels per township, and the percentage of missing intervals in each core sample (figs. 12, 13).

Conclusions

For the three oil shale zones in the Green River and Washakie Basins, an updated and reproducible method was created to calculate in-place oil resources using current relational database management (fig. 14) and GIS software. The process involved the conversion of legacy data and the generation of new data. The results are presented in digital formats that can be used by other investigators to develop their own interpretations and generate their own data models using other spatial-modeling techniques.

Acknowledgments

The authors thank William R. Keefer and Susan M. Hall of the U.S. Geological Survey for helpful comments and suggestions during their technical reviews of this report.

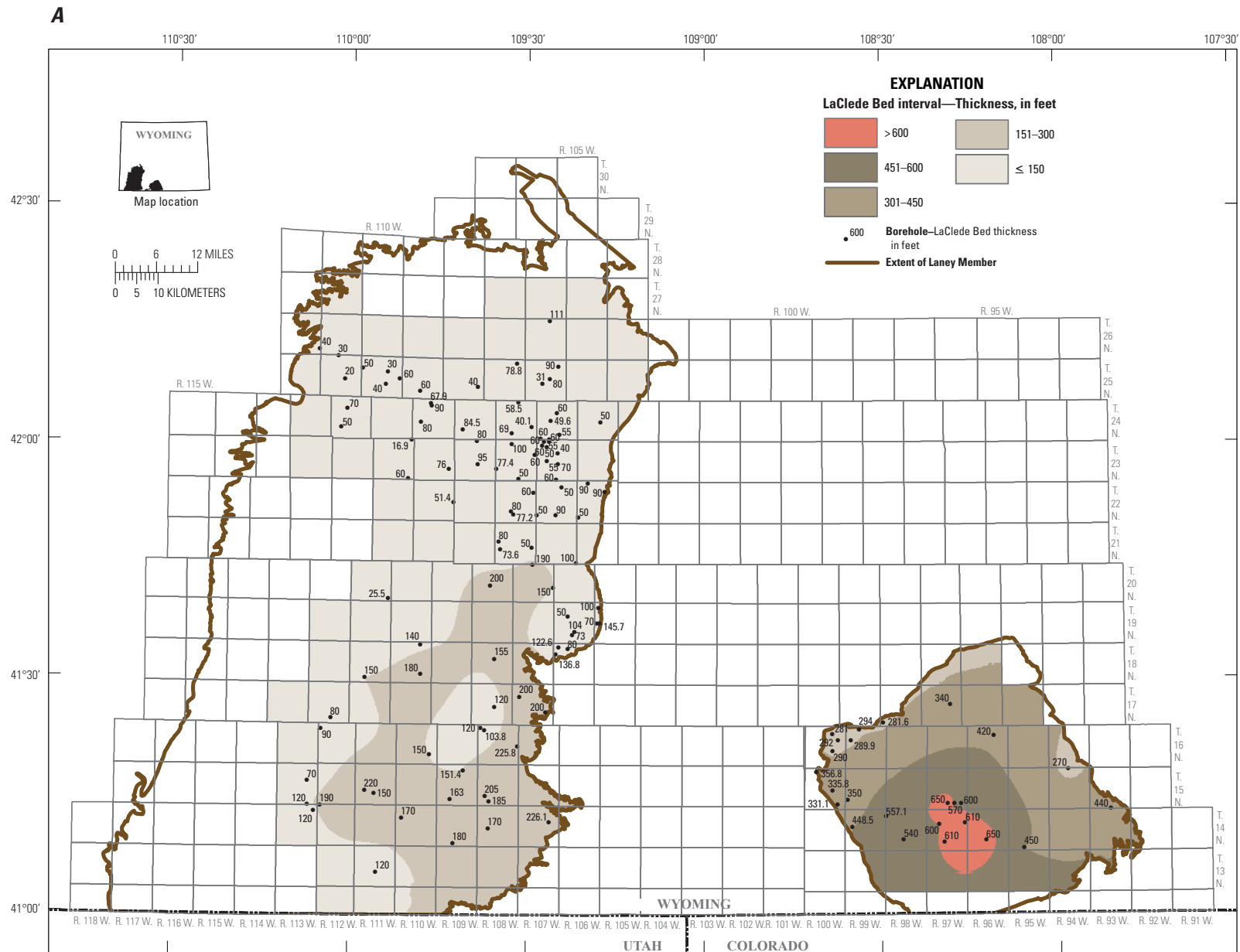


Figure 12. Examples of interpretive maps generated from resource models: *A*, oil shale zone isopachs; *B*, average oil yield in gallons per ton; *C*, oil yield in barrels per acre. See Johnson and others, chap. 1, this report, for original figures.

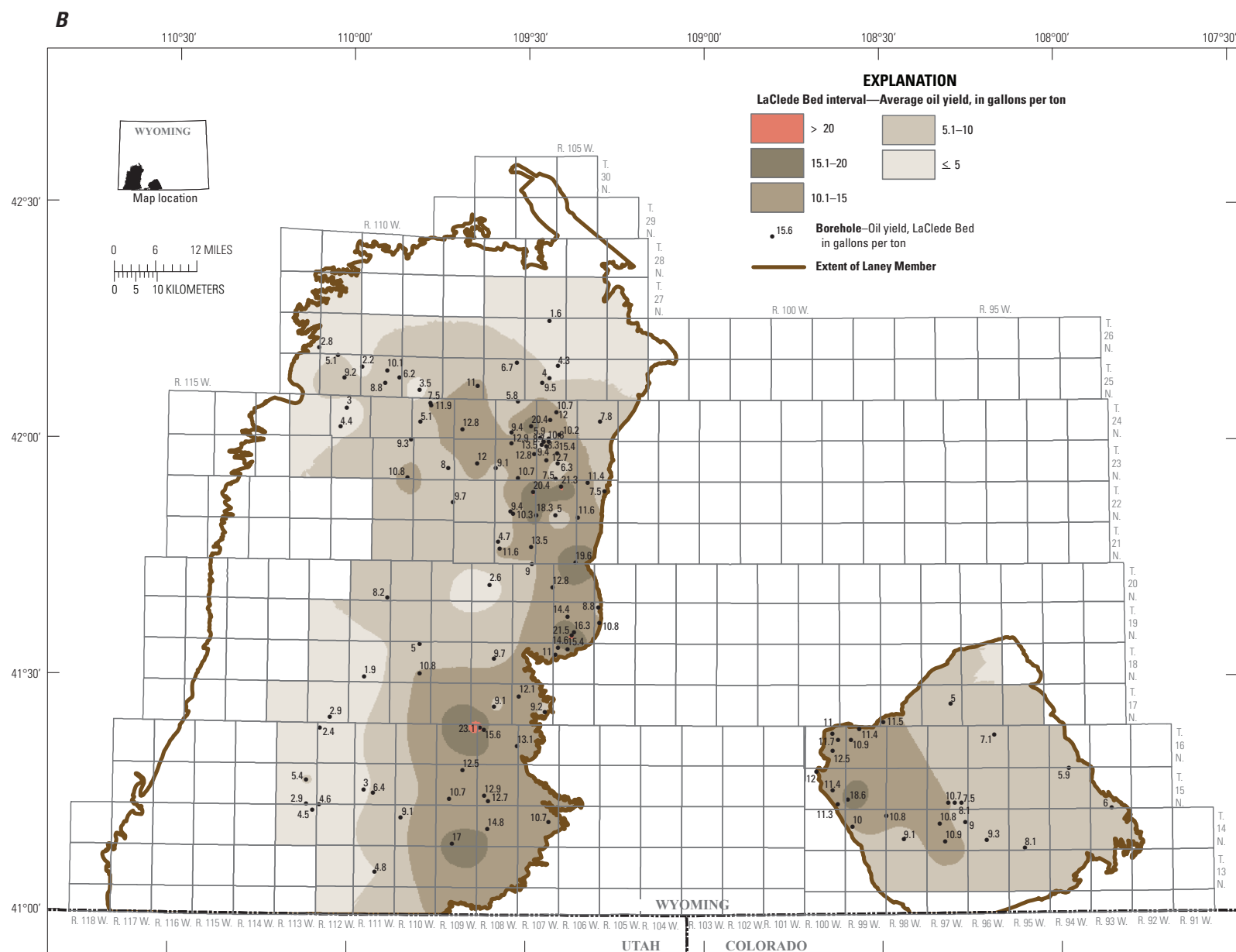


Figure 12. Examples of interpretive maps generated from resource models: *A*, oil shale zone isopachs; *B*, average oil yield in gallons per ton; *C*, oil yield in barrels per acre. See Johnson and others, chap. 1, this report, for original figures.—Continued

C

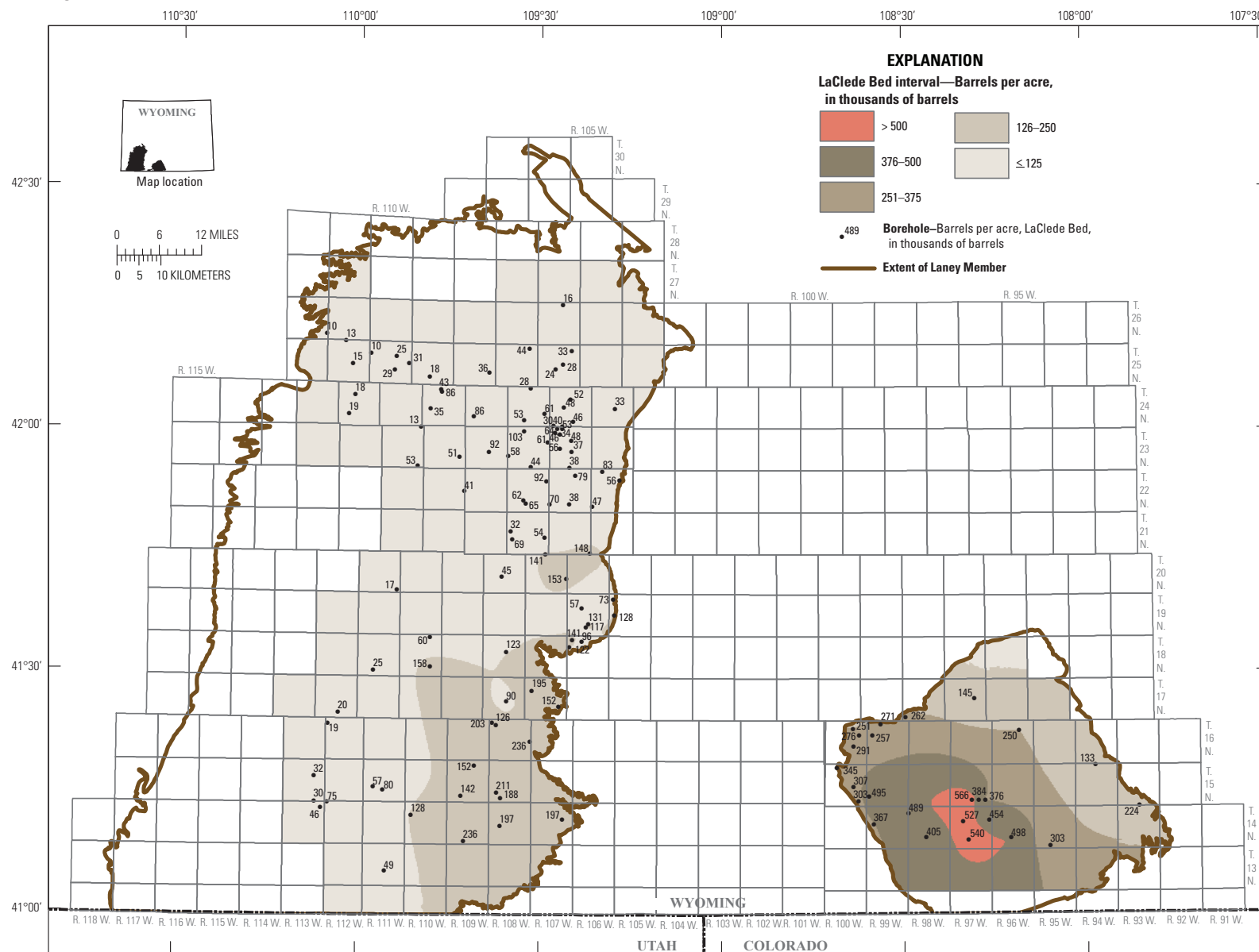


Figure 12. Examples of interpretive maps generated from resource models: *A*, oil shale zone isopachs; *B*, average oil yield in gallons per ton; *C*, oil yield in barrels per acre. See Johnson and others, chap. 1, this report, for original figures.—Continued

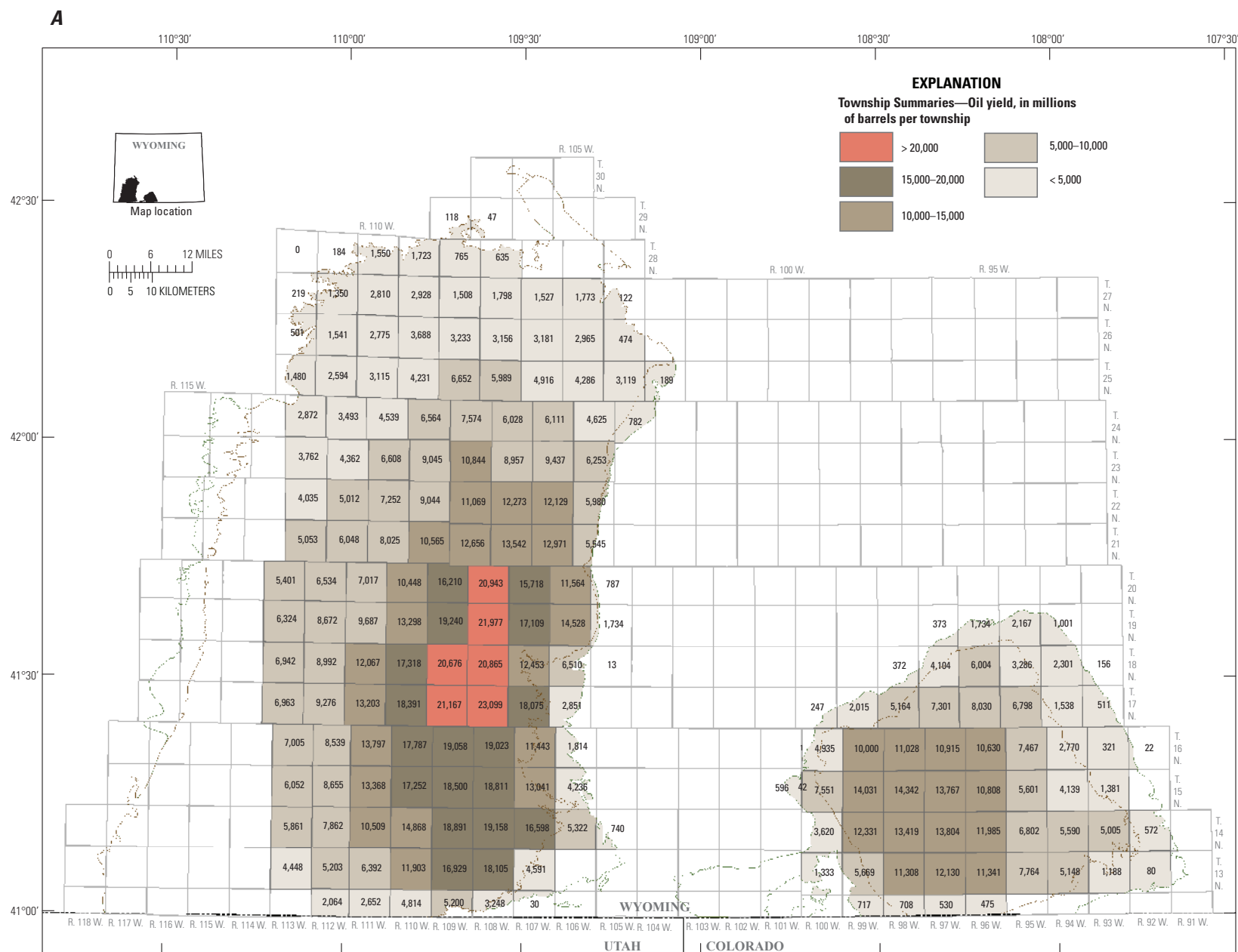


Figure 13. Examples of interpretive maps generated from resource models: *A*, oil yield in millions of barrels per township; *B*, percentage of missing intervals from each core sample. See Johnson and others, chap. 1, this report, for original figures.

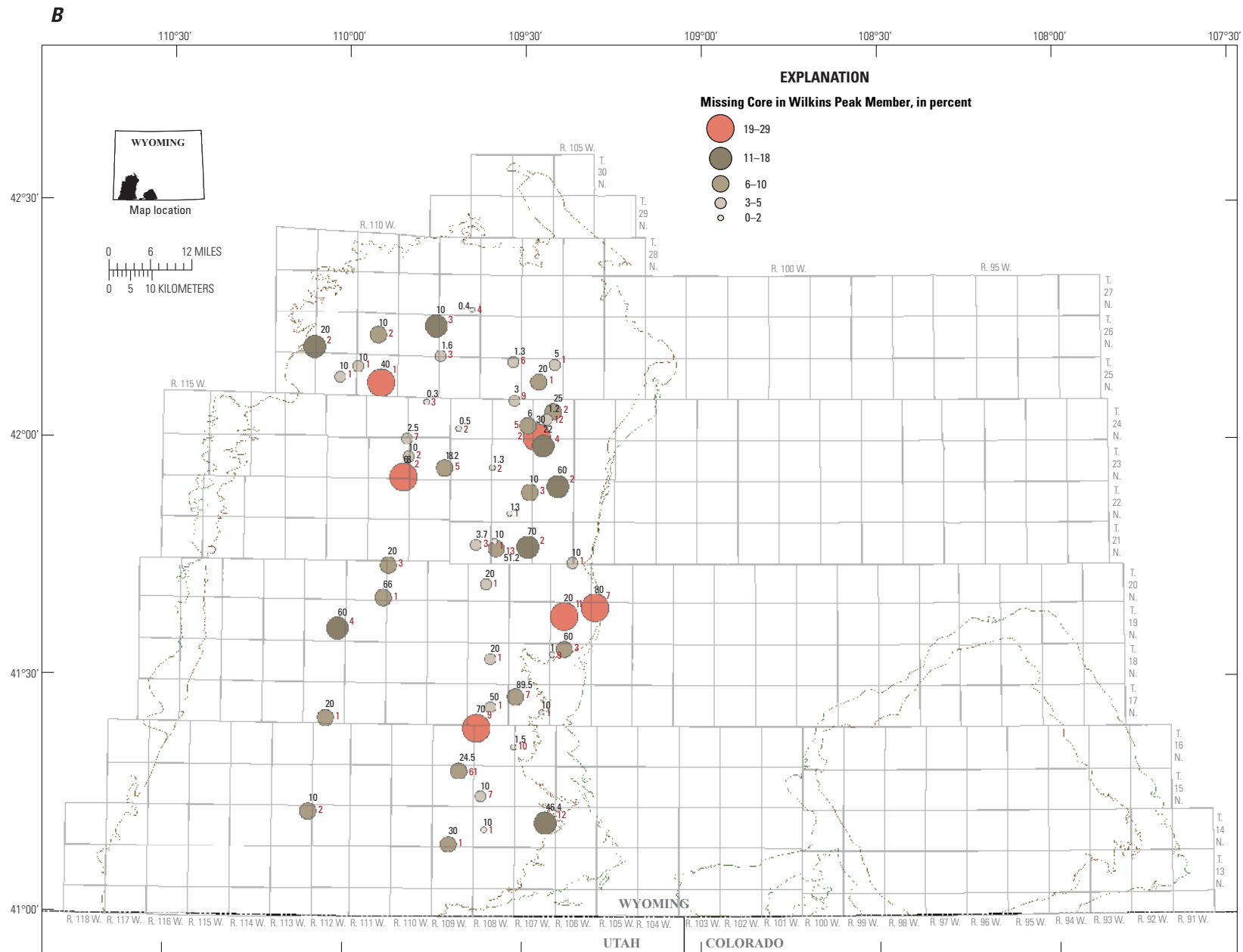


Figure 13. Examples of interpretive maps generated from resource models: *A*, oil yield in millions of barrels per township; *B*, percentage of missing intervals from each core sample. See Johnson and others, chap. 1, this report, for original figures.—Continued

All of these data are stored in the "tops" table (WY_TOPS_090318)

These buttons filter the assays table by the desired oil shale zone

All of this data is stored in the assays table (WY_Assays_INTV)

Cores

USGSID W0006

USGSID W0006

Operator U.S. Bureau of Mines

Name Wyoming 01

Township 23 N

Range 107 w

Section 30

1/4 - 1/4 SW NW

Elevation 6466

Tops

Location	Elevation
Laney	
CW1	
Lean LaCiede	
Rich LaCiede	422.8
Buffmark	
Base Buffmark	
Lw Rich LaCiede	478.2
Lw Lean LaCiede	
Godiva Rm	
Wilkins Peak	500.2
Cathedral Bluff	
Lw Wilkins Peak	
Rife	773.3
Farson	813
Scheggs	1157.4
Main Tw	1193.8
Niland	
TP Wilkins Model	500.2
Bo Wilkins Model	773.3
TP Rife Model	773.3
Bo Rife Model	813
TP LaCiede Model	422.8
Bo LaCiede Model	500.2
TP Scheggs Model	1157.4
Bo Scheggs Model	1193.8

Intervals

Location	Elevation
LaCiede	77.4
Wilkins Peak	273.1
Rife	39.7
Scheggs	26.4
Tipton	410.5
Wilkins Peak Res. Iso.	273.1
Farson Iso.	344.4

Fischer Assays

Choose Zone:

LaCiede

Wilkins Peak

Rife

Scheggs

Buff

Tipton

TOPT	BOTFT	OILGPT	USGS	INTVL	INTXOIL	ROCK
422.8	423.5	1.2	W0006	0.7	0.84	
423.5	424.8	2.1	W0006	1.3	2.73	
424.8	425.9	2.6	W0006	1.1	2.86	
425.9	427.2	1.5	W0006	1.3	1.95	
427.2	428.2	0.6	W0006	1	0.6	
428.2	429.2	0.2	W0006	1	0.2	
429.2	430.4	0.00001	W0006	1.2	0.000012	
430.4	431.6	0.2	W0006	1.2	0.24	
431.6	433	0.00001	W0006	1.4	0.000014	
433	434	0.2	W0006	1	0.2	
434	435	0.2	W0006	1	0.2	
435	436.2	0.3	W0006	1.2	0.36	
436.2	437.2	0.00001	W0006	1	0.00001	
437.2	439	0.7	W0006	1.8	1.26	
439	440.3	10.6	W0006	1.3	13.78	
440.3	441.4	15.3	W0006	1.1	16.83	
441.4	444.5	0.4	W0006	3.1	1.24	

Record: 1 of 71

Active Zone: LaCiede Bed

Calculations

% Missing 1.6%

Gallons per Ton 9.1

Barrels per Acre 57819

Max Missing 1.0

Count Missing 2.0

ArcGIS Table

USGSID W0006

AVMSIN 1.6

AVGPT 9.1

BPA 57819

MXMISS 1

CNTMISS 2

Record: 1 of 1

Calculation results are stored in this table to link with ArcGIS

Calculations done interactively as the user scrolls through borehole records

These buttons use Visual Basic scripting to populate the fields in the ArcGIS table

Figure 14. Image clip of Microsoft Access 2007 form detailing how the user interacts with the form's buttons and controls. Red text and linework details the visual representation of the database's tables within the form, as well as buttons and controls added to utilize Visual Basic scripting and macros.

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Case Study—Oil Shale Assessment

Converting and Loading Legacy Fischer Assay Data

Legacy Fischer assay data files (Dyni, 1998) were loaded into a Microsoft Access database table (fig. 15) using Import Wizard ver. 9 (Beside Software, 2006). It was necessary, initially, to create an Import Wizard model file (A_FISCHER_DEPTHS.iwm; fig. 16) that defined the column names according to the delimiters in the original ASCII text files (Dyni, 1998). After the model was created, more than 400 Fischer assay files were imported into one Access table. We then defined the fields according to the character spacing in the original ASCII files. Once the table was created and populated using Access, columns were added for (1) the thickness of each sampled interval (INTVL), (2) the thickness of the interval times the oil yield in gallons per ton (INTXOIL), and (3) a field to denote halite, trona, or records added by staff geologists (ROCKTYPE). We populated the INTVL and INTXOIL fields by using update queries in Access.

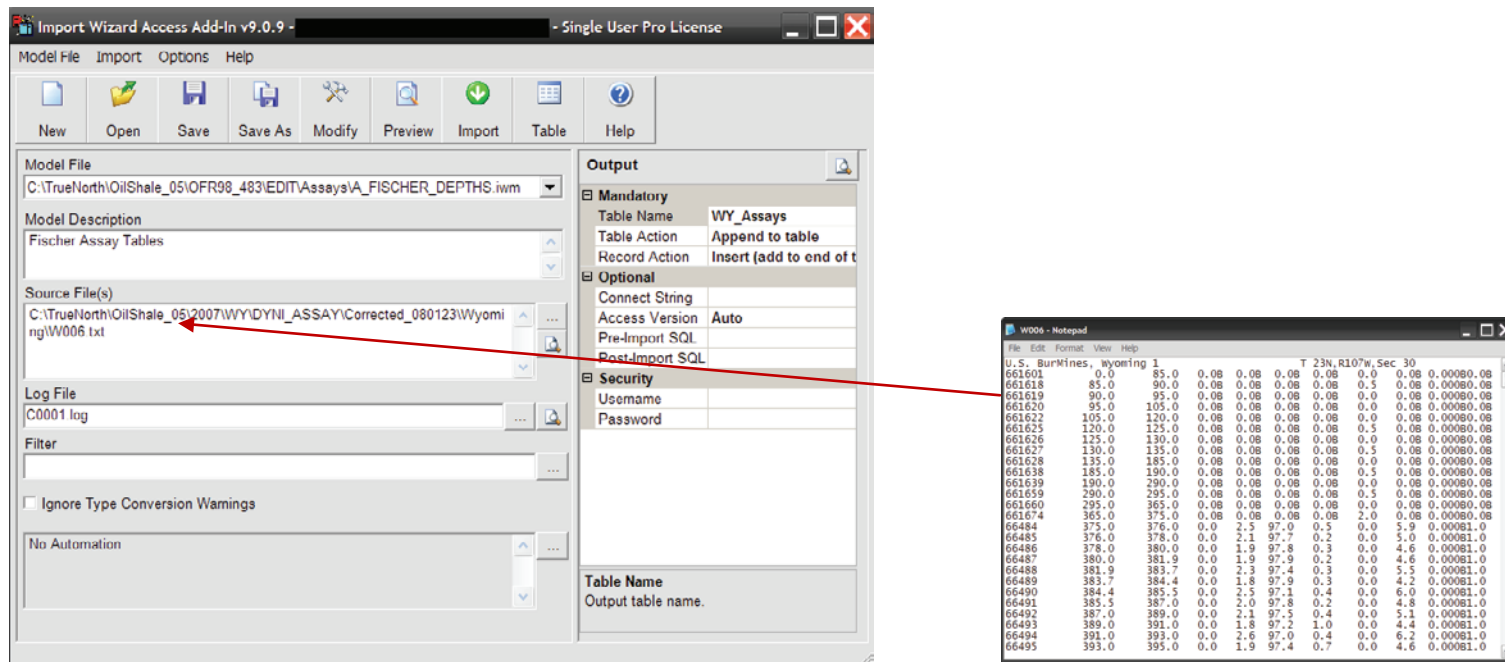


Figure 15. Image clip of Beside Software Import Wizard dialog window used to import legacy Fischer assay data (Dyni, 1998). A portion of the original Fischer assay data for the U.S. Bureau of Mines Wyoming 1 borehole is shown to the right (see fig. 4, table 1).

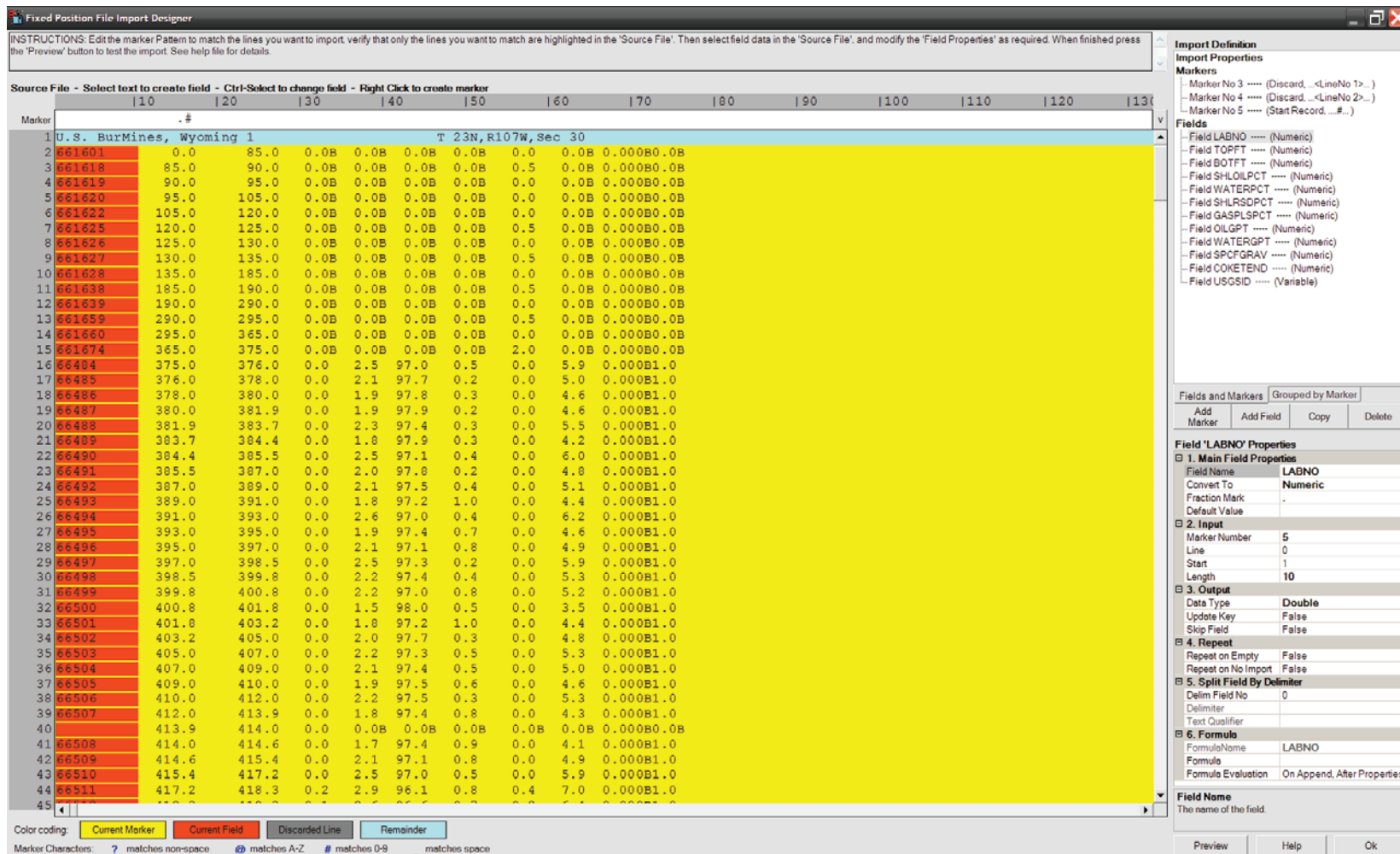


Figure 16. Image clip of Import Wizard model file (A_FISCHER_DEPTH5.iwm) setup dialog window. The different colors denote: (1) blue, header information that was ignored during the import process, (2) red, selected field (LABNO, laboratory number) and width of column, and (3) yellow, remainder of the fields to be imported.

Converting and Loading Stratigraphic “Tops” Data

The stratigraphic “tops” table (fig. 17) contains depths (in ft) from the surface to each oil shale zone, from which the thickness of each oil shale zone was then determined. Formulas were created in Microsoft Excel to calculate the interval thicknesses, and the results were converted to cell values in order to transfer all the necessary data to Access. The Excel spreadsheet was then imported to an Access table (WY_TOPS_090318).

USGSID	WKBTMODL	WKTPMODL	RFTPMODL	RFBTMODL	LCTPMODL	LCBTMODL	SCTPMODL	SCBTMODL
W0001	0	0	0	0	0	0	0	0
W0002	1951.7	770	1951.7	2028.7	585	770	2033	0
W0003	0	0	64.5	130	0	0	136.3	192.8
W0004	0	0	360	422.2	0	0	432.5	493
W0005	1255	821.3	0	0	0	0	0	0
W0006	773.3	500.2	773.3	813	422.8	500.2	1157.4	1183.8
W0007	0	0	1586.4	1642.7	0	0	1698.4	1748
W0008	1786.7	790	1786.7	1848.5	590	790	1857	1913.5
W0009	0	0	0	0	0	0	0	0
W0010	0	0	0	0	276.4	399	0	0
W0011	1861.9	805	1861.9	1928	0	0	1934	2009
W0012	0	0	2110	2174	0	0	2185.7	0
W0013	0	0	0	0	0	0	0	0
W0014	0	0	1889.7	1946	0	0	2069	2110
W0015R	1925	750	1925	2015	545	750	2025	2125
W0016R	0	0	710	795	0	0	820	890
W0017	0	0	0	0	139.5	243.3	0	0
W0018	0	0	0	0	0	0	0	0

Figure 17. Structure of the stratigraphic tops table (WY_TOPS_090318) as viewed in Microsoft Access 2007, showing the depth, in ft, to top of the LaClède Bed of the Laney Member of the Green River Formation through the Scheggs Bed of the Tipton Shale Member of the Green River Formation for boreholes W0001 through W0018. Tops and bases of oil shale zones in Green River Formation are listed: WKBTMODL, Wilkins Peak Member base; WKTPMODL, Wilkins Peak Member top; RFTPMODL, Rife Bed of Tipton Shale Member top; RFBTMODL, Rife Bed base; LCTPMODL, LaClède Bed top; LCBTMODL, LaClède Bed base; SCTPMODL, Scheggs Bed top; SCBTMODL, Scheggs Bed base.

Converting and Loading the Barrels Per Acre (BPA) Lookup Table

The Lookup Table containing the updated values for gallons per cubic foot necessary for the barrels per acre (BPA) calculations was converted from a Microsoft Excel 2007 spreadsheet to an Access table (BPA Lookup Table). After the gallons per ton (GPT) weighted average was calculated for a particular zone interactively in the Access form, the “GALFT3NEW” value associated with that GPT average was required as a multiplier in the formula. For example, if a zone’s weighted average for gallons per ton oil yield is 1.4, the multiplier is 0.119 for the calculation. We used a linear trend based on Excel 2007s fill series function to fill in values for every 0.1 gallon per ton in Excel before importing the spreadsheet to Access (fig. 18).

ID	GALPERTON	GALFT3NEW
793	0.0	0.000
794	0.1	0.009
795	0.2	0.017
796	0.3	0.026
797	0.4	0.034
798	0.5	0.043
799	0.6	0.052
800	0.7	0.060
801	0.8	0.069
802	0.9	0.077
93	1.0	0.086
94	1.1	0.094
95	1.2	0.102
96	1.3	0.111
97	1.4	0.119
98	1.5	0.128
99	1.6	0.136
100	1.7	0.144
101	1.8	0.153
102	1.9	0.161
103	2.0	0.169

Figure 18. Structure of the barrels per acre lookup table (BPA Lookup Table) used for the form calculations as viewed in Microsoft Access 2007, showing how values for gallons per cubic foot (GALFT3NEW) oil yield were filled in for every 0.1 gallon using a linear trend fill series function. GALPERTON, gallons per ton.

Building the Microsoft Access 2007 Form

A custom Access Form (WY Form) (fig. 20) was built that allowed the linking of tables by a unique identifier, or primary key (USGSID), that was used in all tables except for the BPA Lookup Table. The form is based on the stratigraphic tops table (WY_TOPS_090318), and the linked tables are displayed in Access subforms.

The screenshot displays the main Microsoft Access 2007 form for the Wyoming Oil Shale Assessment. The form is organized into several sections:

- Cores:** Contains a subform for USGSID W0006, with fields for USGSID, Operator (U.S. Bureau of Mines), Name (Wyoming 01), Township (23 N), Range (107 W), Section (30), 1/4 - 1/4 (SW NW), and Elevation (6466).
- Tops:** A list of stratigraphic tops with columns for Name and Elevation. The list includes:

Name	Elevation
Laney	
CW1	
Lean LaCade	
Rich LaCade	422.8
Buffmark	
Base Buffmark	
Lw Rich LaCade	470.2
Lw Lean LaCade	
Godiva Km	
Wilkins Peak	500.2
Cathedral Bluff	
Lw Wilkins Peak	
Rife	773.3
Farson	813
Scheggs	1157.4
Main Tw	1183.8
Niland	
Top Limen	
Base Limen	
Ip Wilkins Model	500.2
Bs Wilkins Model	773.3
Tp Rife Model	773.3
Bs Rife Model	813
Tp LaCade Model	422.8
Bs LaCade Model	500.2
Tp Scheggs Model	1157.4
Bs Scheggs Model	1183.8
- Intervals:** A list of intervals with columns for Name and Elevation. The list includes:

Name	Elevation
LaCade	77.4
Wilkins Peak	273.1
Rife	39.7
Scheggs	26.4
Tipton	410.5
Wilkins Peak Res. Iso.	273.1
Farson Iso.	344.4
- Fischer Assays:** A table showing assay data for various zones. The table has columns: TOP, DOT, OILGPT, USGS, INTVL, INTXOIL, and ROCK. The data is filtered for the 'LaCade' zone.

TOP	DOT	OILGPT	USGS	INTVL	INTXOIL	ROCK
422.8	423.5	1.2	W0006	0.7	0.84	
423.5	424.0	2.1	W0006	1.3	2.73	
424.8	425.9	2.6	W0006	1.1	2.86	
425.9	427.2	1.5	W0006	1.3	1.95	
427.2	428.2	0.6	W0006	1	0.6	
428.2	429.2	0.2	W0006	1	0.2	
429.2	430.4	0.00001	W0006	1.2	0.000012	
430.4	431.6	0.2	W0006	1.2	0.24	
431.6	433	0.00001	W0006	1.4	0.000014	
433	434	0.2	W0006	1	0.2	
434	435	0.2	W0006	1	0.2	
435	436.2	0.3	W0006	1.2	0.36	
436.2	437.2	0.00001	W0006	1	0.00001	
437.2	439	0.7	W0006	1.8	1.26	
439	440.3	10.6	W0006	1.3	13.78	
440.3	441.4	15.3	W0006	1.1	16.83	
441.4	444.5	0.4	W0006	3.1	1.24	
- Calculations:** A section for resource calculations.

Field	Value
% Missing	1.6%
Gallons per Ton	9.1
Barrels per Acre	57819
Max Missing	1.0
Count Missing	20
- ArcGIS Table:** A table showing data for the ArcGIS application.

Field	Value
USGSID	W0006
AVMSIN	1.6
AVGPT	9.1
BPA	57819
MXMISS	1
CNTMISS	2

Figure 20. Image clip of the main Access form showing how subforms were linked by the unique identifier, USGSID, and how all resource calculations were carried out.

Intersecting Polygon Files to Create Reporting Polygons

Initially, outcrop lines were loaded in ArcMap for the top of the Laney and Tipton Shale Members of the Eocene Green River Formation, based on a 1:500,000-scale published geologic map (Green and Drouillard, 1994). These polygons served as bounding resource polygons for resource assessments by oil shale zone. Township lines in ESRI shapefile format were downloaded from the Bureau of Land Management (BLM, 2002), and the township polygons were intersected with the outcrop boundary resource polygons in ArcGIS's ArcToolbox to create "reporting" polygons (fig. 21). The reporting polygons provided the areal extents used to quantify barrels per acre oil yield for only that part of each township underlain by a particular oil shale zone.

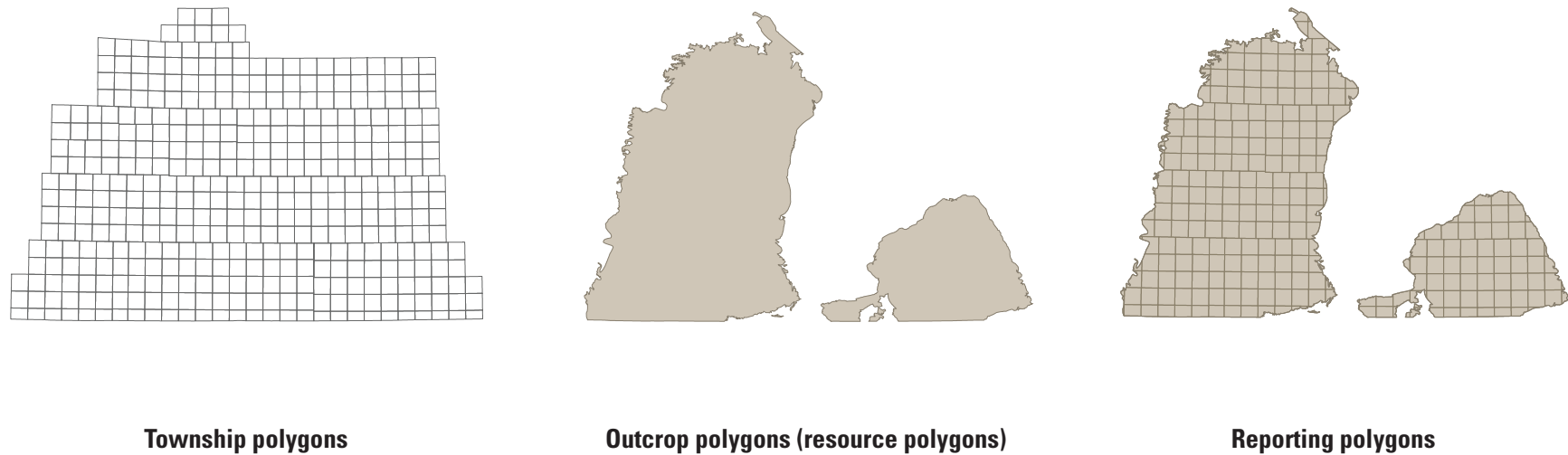


Figure 21. Diagram showing how ESRI ArcToolbox's Intersect command was used to create the assessment's reporting polygons for the Green River and Washakie Basins in southwestern Wyoming.

SQL Query to Filter Assays By Zone

Following linkage of the Fischer assays table (WY_Assays_INTV) with the tops table (WY_TOPS_090318) by USGSID in the Access form, Structured Query Language (SQL) queries were written to filter out subsets of assay records for each oil shale zone. For example, the query (QuerWYLCLD) to select only those assay records that were between the top and base of the LaCledde Bed of the Laney Member of the Green River Formation in the tops table, and to display those records in the assays subform, utilized a BETWEEN statement:

```
SELECT WY_Assays_INTV.TOPFT, WY_Assays_INTV.BOTFT, WY_Assays_INTV.OILGPT, WY_Assays_INTV.USGSID, WY_Assays_INTV.INTVL,  
WY_Assays_INTV.INTXOIL, WY_Assays_INTV.ROCKTYPE  
  
FROM WY_Assays_INTV  
  
WHERE (((WY_Assays_INTV.TOPFT) Between Forms![WY form]!LCTPMODL And Forms![WY form]!LCBTMODL) And ((WY_Assays_INTV.  
BOTFT) Between Forms![WY form]!LCTPMODL And Forms![WY form]!LCBTMODL) And ((Forms![WY form]!LCTPMODL)<=0 And (Forms![WY  
form]!LCTPMODL)>0) And ((Forms![WY form]!LCBTMODL)<=0 And (Forms![WY form]!LCBTMODL)>0))  
  
ORDER BY WY_Assays_INTV.TOPFT;
```

In effect, the LaCledde Bed zone query returned assay records from the top of the LaCledde Bed to the base of the LaCledde Bed, but only if (1) the value for the top of an assay record (TOPFT) was equal to or greater than the LaCledde tops pick (LCTPMODL), (2) the base of an assay record (BOTFT) was equal to or less than the base of the LaCledde Bed pick (LCBTMODL), and (3) all assay records in between as long as those records contained the same USGSID as the currently selected borehole in the Access form.

Calculating Gallons Per Ton Weighted Average

Formula: Sum of (thickness of interval × gallons per ton) / thickness of interval

Within the assessed zones, any OILGPT value equal to 0.0 or any INTXOIL (thickness of interval times OILGPT) value equal to 0.0 was not factored into weighted-average calculations; those records were considered missing or erroneous. In the Fischer Assays subform (fig. 22), we built a text box control to calculate the weighted average for each oil shale zone. We accomplished this by creating a text-box control in the subform's footer and placed the following statement in that control:

=Sum(If([INTXOIL]>0,[INTXOIL],0))/Sum(If([INTXOIL]>0,[INTVL],0))

After filtering the assays subform using the SQL zone query, the Access form (1) sums all of the INTXOIL values and the INTVL values, (2) performs the division on those sums, and (3) returns the result in the box as long as each record met the criteria of INTXOIL being greater than 0 (that is, not missing or erroneous).

Fischer Assays

Choose Zone:

LaCiede

Wilkins Peak

Rife

Scheggs

Buff

Tipton

ALL

Active Zone: Unbound

Form Footer

Avg OilGPT:	=Sum(IIf([INTXOIL]>
SumINTXOIL:	=Sum([INTXOIL])
SumINTVL:	=Sum([INTVL])
PtMissing:	=Sum(IIf([OILGPT]=
Max Missing:	=Max(IIf([OILGPT]=
Count Missing:	=Sum(IIf([OILGPT]=
Avg OilGPT: no H:	=Sum(IIf([INTXOIL]>
Sum INTV: no HAL:	=Sum(IIf([ROCKTYF

Calculations

% Missing	=([CO_Assay
Gallons per Ton	=([CO_Assay
Barrels per Acre	=Round([Tex
Max Missing	=([CO_Assay
Count Missing	=([CO_Assay

Set GPT

Set BPA

Set NTON

ArcGIS Table

Form Header

Detail

USGSID	USGSID	MXMISS	TIPTM
AVMSIN	TIPTAVMSIN	CNTMISS	TIPTCI
AVGPT	TIPTAVGPT		
BPA	TIPTBPA		

Figure 22. The oil shale assessment's Microsoft Access 2007 form as viewed in Design mode. Some text box control calculations are "hidden" in the Fischer assays subform footer.

Calculating Barrels Per Acre Oil Yield

Formula: Interval thickness × 43,560 (ft²/acre) × oil yield per unit volume / 42 (gals/barrel of oil)

Following determination of a weighted-average value for gallons per ton oil yield, it was necessary to calculate the total thickness of the oil shale zone, minus any halite beds or trona, if present. We added text-box controls to the Fischer Assays subform that contained the following statements:

To sum all intervals for the subset of assays:

=Sum([INTVL])

To sum all halite or trona intervals for the subset of assays:

=Sum(If([ROCKTYPE]="NH",[INTVL],0))

To subtract halite or trona intervals from the total and round to one decimal place:

=Round((Text218-[Text333]),1) where Text218 is the sum of all intervals and Text333 is the sum of halite and (or) trona intervals.

Next, we retrieved our multiplier for oil yield per unit volume from the Lookup Table based on the GPT calculation in the Access form, which was accomplished by adding a text box control containing the following statement:

=DLookup("[GALFT3NEW]", "[BPA Lookup Table]", "[GALPERTON]=" & Forms![CO Form]!Text151) where Text151 is the text-box control that calculated the weighted-average value for gallons per ton oil yield. In effect, this statement “looks up” the GALFT3NEW value in the BPA Lookup Table that is associated with the calculated GPT average. For example, for the LaClede Bed in borehole W0006, a GPT average of 9.1 was returned. The associated value in the BPA Lookup table for 9.1 is 0.724. Using the statements above, the Access form also returned a value of 77 for the total thickness of the LaClede Bed. Using the formula to calculate barrels per acre oil yield, the following statement was entered into another text box control in the Access form:

=Round([Text335]*43560*[Text239]/42,0) where Text335 is the sum of all intervals minus halite and (or) trona and Text239 is the value returned from the Lookup Table, with the result rounded to 0 decimal places. In this case, for the LaClede Bed in borehole W0006, the Access form calculated 57,819 barrels per acre oil yield (77 * 43,560 * 0.724 / 42).

Calculating the Percentage of Missing Intervals From Each Core Sample

Text-box controls were added to the footer of the Fischer Assays subform to report the percentage of missing intervals from each core sample, the maximum thickness of missing intervals, and the number of intervals missing from each core sample. The following statements were added to three separate controls.

To calculate the percentage missing:

=Sum(If([INTXOIL]=0,[INTVL],0))/Sum([INTVL])

To calculate the maximum thickness of missing intervals:

=Max(If([INTXOIL]=0,[INTVL],0))

To count the number of records missing:

=Sum(If([OILGPT]=0,1,0))

Storing Calculated Values in a Separate Table

To expedite attributing in Access and to help avoid data entry errors, buttons and macros (fig. 23) were added to the main Access form to transfer temporary, calculated values from the text-box controls to a separate table that could then be linked to in ArcGIS. We stored the results permanently in another table in the database (OilShale_Holes_pts).

Four buttons were created to transfer values for gallons per ton, barrels per acre, maximum interval missing, and the number of records missing. The buttons in the main Access form triggered a macro to run using a SetValue action. The SetValue action would populate the appropriate field in the ArcGIS table with the value that was calculated interactively in the form.

For example, the macro to store the value for the maximum interval missing from a core sample for a particular zone in the permanent table required two statements:

Item: [Forms]![WY form]![OilShale_Holes_pts subform].[Form]![Text21]

Expression: [Forms]![WY form]![Text341]

The Item statement contains the field we wanted to set. Text21 refers to the fieldname for MXMISS in the ArcGIS Table subform. The Expression statement simply refers to the value calculated in the main Access form—in this case, the Text341 text-box control that contained the statement to calculate the maximum thickness of missing intervals.

The screenshot displays a Microsoft Access 2007 form with two main sections: 'Calculations' and 'ArcGIS Table'.

Calculations Section:

% Missing	1.6%
Gallons per Ton	9.1
Barrels per Acre	57819
Max Missing	1.0
Count Missing	2.0

Below the calculations are two buttons: 'Set GPT' and 'Set BPA'.

ArcGIS Table Section:

USGSID	W0006	MXMISS	1
AVMSIN	1.6	CNTMISS	2
AVGPT	9.1		
BPA	57819		

At the bottom of the ArcGIS Table section, it shows 'Record: 1 of 1' and 'No Filter'.

Figure 23. Image clip of a portion of the Microsoft Access 2007 form showing how calculation results performed interactively in the form were stored in a table permanently using buttons and macros. Example shown is for the LaCleda Bed of the Laney Member of the Green River Formation oil shale zone in borehole W0006.

Filtering Subforms From the Main Form

A method to filter the assay records by a particular oil shale zone was established by using SQL BETWEEN statements. Three buttons were added to the main Access form to filter assays by each assessed oil shale zone and an “All” button was added to display all assay records for a particular borehole (that is, unfiltered). However, a method was also needed to restrict the display of fields in the ArcGIS Table subform by the zone being filtered. Each of the three oil shale zones contained a separate field for gallons per ton (AVGPT), barrels per acre (BPA), percentage of missing intervals (AVMSIN), maximum interval missing (MXMISS), and the number of records missing (CNTMISS). For example, the LaCledé Bed contained the fields LCLDAVGPT, LCLDBPA, LCLDAVMSIN, LCLDMXMISS, and LCLDCNTMISS. We were able to change the fields being displayed in the ArcGIS Table subform by applying ControlSource statements to each zone button in addition to the SQL BETWEEN query. Not only would the button filter the assay records by a particular zone, it would also change the fields to be attributed in the OilShale_Holes_pts subform. This was accomplished by using the following code:

Private Sub Command260_Click()

Me.CO_Assays_subform.Form.RecordSource = “QuerWYLCLD”

OilShale_Holes_pts_subform.Form.[MXMISS].ControlSource = “LCLDMXMISS”

End Sub

Linking Spatial and Tabular Data

Upon completing the calculations in Access and populating all of the fields in the ArcGIS table for each oil shale zone, the data were linked to borehole locations in ArcGIS. Although several different interpretive maps could thereby be generated, this case study focuses on the barrels per acre oil-yield mapping and resource-summary task.

Our borehole locations file was stored in a point feature class (OilShale_Holes_pts) contained in an ESRI ArcGIS personal geodatabase (COPLATOS.mdb). The calculation values were stored in a table (OilShale_Holes_pts) in a separate Access database (WYOS.mdb). In ArcMap ver.9.2, the attribute table was joined to the point feature class and, through several definition queries, three separate point layers were created corresponding to each oil shale zone. It is important to note that boreholes having only rotary cuttings that were analyzed were included in the assessments—that is, those boreholes containing an “R” in their USGSID identifier.

Creating GeoStatistical Analyst Models and GRIDs

Once layers were defined for each oil shale zone in ArcMap, we generated models using ESRI ArcGIS's GeoStatistical Analyst (GA) extension (fig. 24). The Radial Basis Function(RBF)-Multiquadric method was used to model BPA values. The searching neighborhood parameters used were the standard eight sectors containing eight neighbors in each sector. Although not as robust as kriging or other geostatistical methods in assessing error, the RBF-Multiquadric method does return a mean and Root Mean Squared (RMS) error for each model generated. We assessed these errors and judged them to be acceptable using the chosen parameters. We also exported the cross validation tables containing predictions and errors at each data point for each BPA model. To obtain the difference between the predicted value and the measured value, the RBF method predicts a value at a given control point from the nearest control points without knowing the actual value measured at that control point. That predicted value is then compared with the measured value, and the difference between the two is calculated.

A GA model will only interpolate and extrapolate values within the rectangular extent of the input point layer. We extrapolated values to outcrop lines by changing the extent of the model to the rectangular extent of a separate polygon file. For example, for the LaCledé Bed BPA model we changed the extent of the GA model to the rectangular extent of a Green River and Washakie Basins township file that contained the LaCledé resource area within its boundaries. We used the extent of this file for all models to ensure adequate coverage for extrapolation purposes.

After all revisions were made, in some cases after there were numerous iterations between the Access form and GeoStatistical Analyst, the final GA model was exported to an ESRI GRID format at a one-acre cell size (63.615 m (208.7 ft) per side) using one point for each block (acre) interpolation. One drawback to extrapolating beyond our dataset boundary was that a model may have contained negative values. To sum all of the values in one-acre cells, all negative values were removed from the GRIDs by using a CON statement. In ESRI ArcGIS's Spatial Analyst extension the Raster Calculator was used to remove the negative values with this statement:

CON(([GRIDNAME] < 0), 0, [GRIDNAME]) where GRIDNAME is the name of the GRID, such as laclede_b

For all cells in the final BPA GRID, the CON statement set the negative values to 0. If the values were greater than or equal to 0, the values remained unchanged.

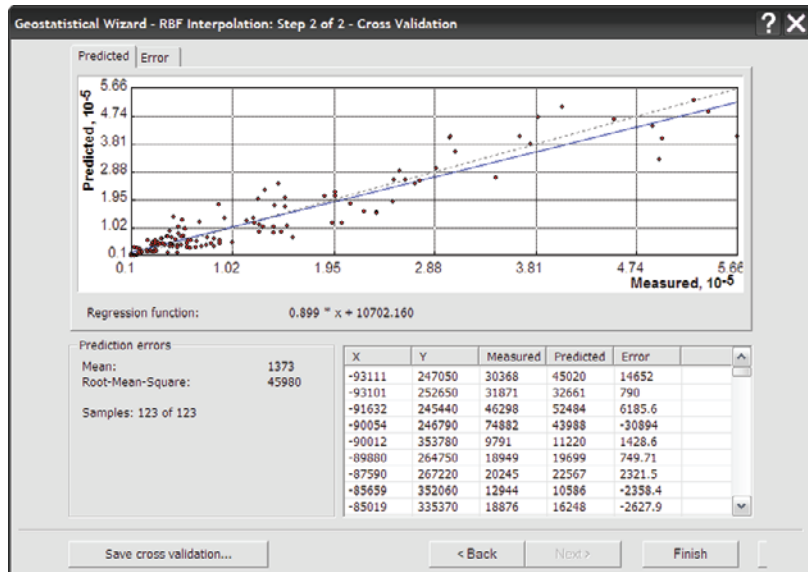
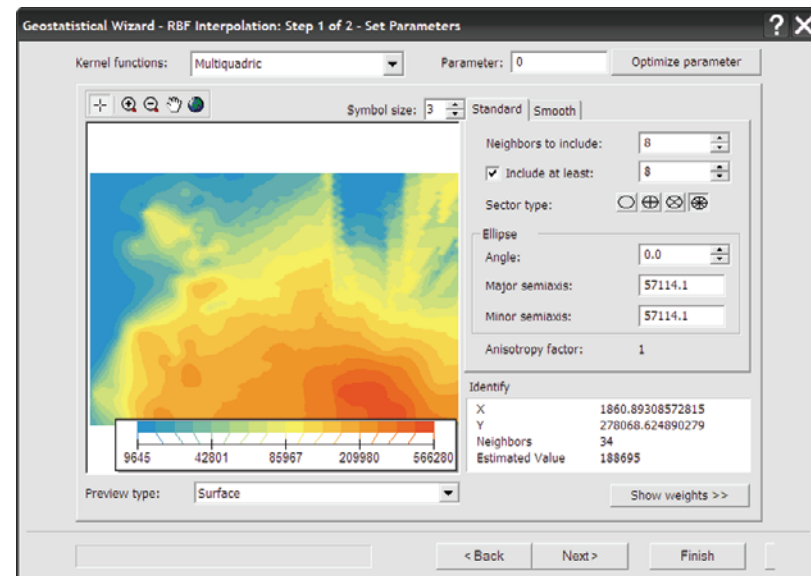
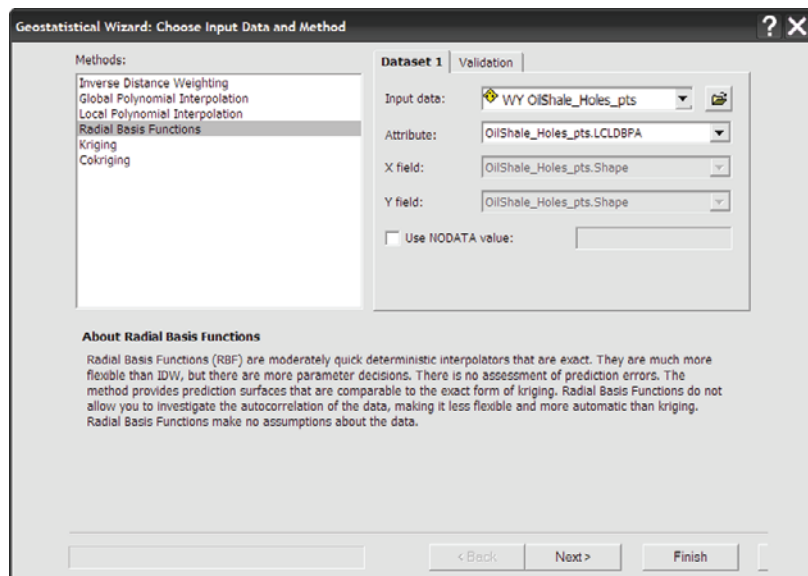


Figure 24. Image clips of the dialog windows used for creating the barrels per acre (BPA) GeoStatistical Analyst model in ArcGIS.

Running Barrels Per Acre Zonal Statistics to Calculate Total Barrels of Oil Yield Per Township

The final BPA GRID model was used as the value raster for counting cell values using ESRI's Spatial Analyst extension. The Zonal Statistics function (fig. 25) was used to count all of the estimated values contained within each one-acre cell of our model, as long as their centerpoints fell within a specified zone dataset. In the case for the LaClède Bed, the zone dataset (WY_LaClède_Resource_Limit) was a polygon feature class stored in a geodatabase created by intersecting the resource polygon for the LaClède Bed with the township polygons. The Zonal Statistics function used the "DXF_TEXT" attribute as the zone field from the polygon feature class to count the GRID's BPA values (figs. 11, 25). That is, for all polygons in the zone dataset file with the same value in the "DXF_TEXT" field, the Zonal Statistics function counted all of the underlying cells in the BPA GRID and provided the sum total for each "DXF_TEXT," or township. It is important to note that our Spatial Analyst analysis-cell size was the same as our BPA GRID cell size: 63.615 m (208.7 ft) per side.

The resultant statistics were then exported to a .dbf table named by zone, such as lacledesummary.dbf for the LaClède Bed. We linked this table to the reporting polygons feature class by the "DXF_TEXT" field, thus we were able to provide an interpretive map that quantified the total barrels of oil yield from oil shale in each oil shale zone for each township in the Green River and Washakie Basins.

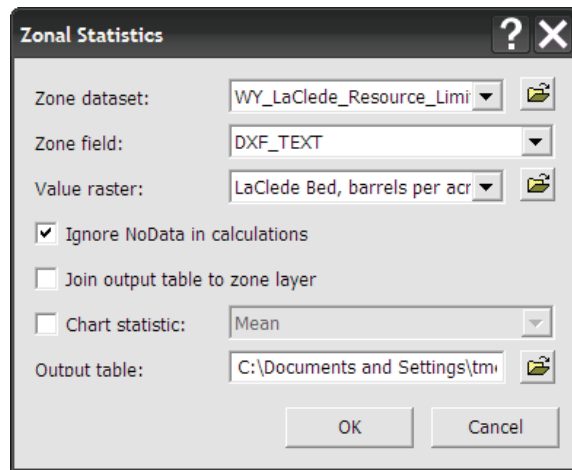


Figure 25. Image clip of the dialog window used to generate zonal statistics using ESRI's Spatial Analyst.

Appendix

Digital Files, Entity Relationship Diagram, and Data Dictionaries

Digital file—WYOS.mdb (Microsoft Access database)
Entity relationship diagram (fig. A1)
Data dictionaries (tables A1–A4)

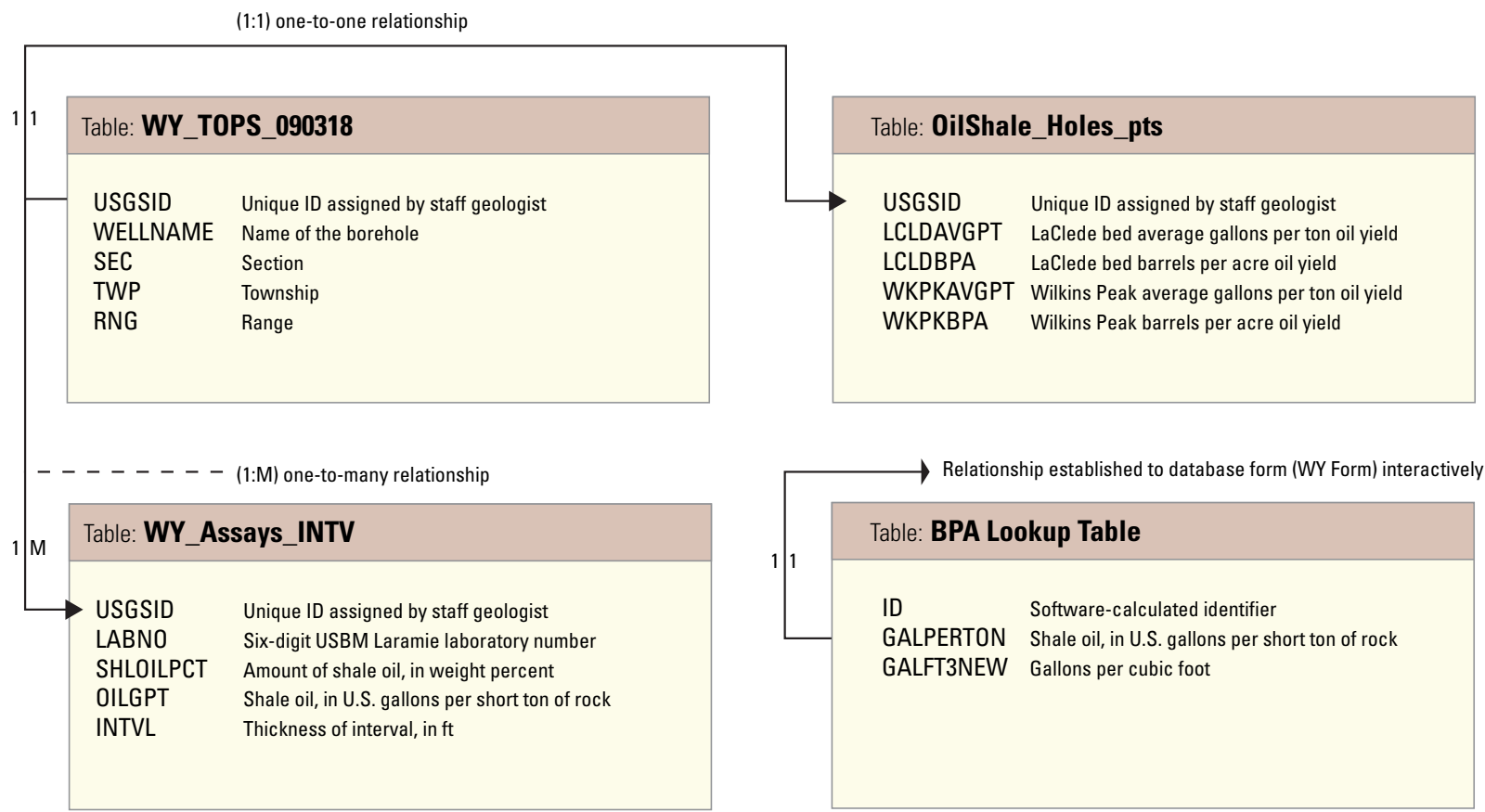


Figure A1. Entity Relationship Diagram (ERD) showing how the tables are linked in the calculations form (WY Form).

Table A1. The column names and definitions of the Microsoft Access table WY_TOPS_090318.

Column name	Column definition
ID	Software-calculated identifier
USGSID	Unique ID assigned by staff geologist
USGSIDJ	Unique ID assigned by staff geologist
1/41/4	Quarter-quarter section
EW	Distance, in ft, measured east or west from section line
NS	Distance, in ft, measured north or south from section line
RNG	Range
SEC	Section
TWP	Township
Latitude	Latitude, in decimal degrees, North American Datum 1927
Longitude	Longitude, in decimal degrees, North American Datum 1927
County	Name of county in Wyoming
Operator	Name of the company or agency that drilled the borehole
WELLNAME	Name of the borehole assigned by the company or agency that drilled it
ELEVSRC	Source of elevation, usually from the Fischer assay file, geophysical log, lithologic log, topo or survey
LOCSOURCE	Source of the borehole location, usually from the Fischer assay file, geophysical log, lithologic log, or survey
REFELEVFT	A borehole reference elevation, such as ground surface, rotary bushing, or rotary table, from which downhole depths were measured
TDFT	Total depth of the borehole, in ft
COREDEP_FT	Depths, in ft, of the sequence that was cored in the borehole
REFDATUM	Elevation, in ft, for various reference surfaces including Kelly bushing, ground level, topographic map, and rotary table
KB	Drilling rig Kelly bushing elevation, in ft
EST_TOPO	Estimated ground elevation, in ft, of borehole plotted on topographic map
GL	Ground level elevation, in ft
Topo	Surveyed ground elevation, in ft, shown on topographic map adjacent to borehole
RT	Elevation, in ft, of the drilling rig rotary table
7_5_QUAD	Name of the 7.5-minute USGS topographic map, borehole may or may not be shown on map
CORE2	Physical location of the core from corehole, for example, USGS Core Research Center
SHOWN_MAP	Indicates whether the actual borehole location is shown on the topographic map
YEARDRILL	Year that the borehole was drilled
LITHLOG_FT	Top and bottom borehole depths, in ft, of sequence of core or rotary cuttings for which a lithologic log was prepared
PHOTOLOG_FT	Top and bottom borehole depths, in ft, of photographic record of drill core
ELECLOG_FT	Top and bottom depths, in ft, of electric log of borehole
RQD	Top and bottom depths, in ft, of rock quality data log
SONICLOG_FT	Top and bottom depths, in ft, of sonic log of borehole
TEMPLOG_FT	Top and bottom depths, in ft, of temperature log of borehole
GAMMALOG_FT	Top and bottom depths, in ft, of gamma ray log of borehole
CALIPLOG_FT	Top and bottom borehole depths, in ft, of caliper log of borehole
DENSLOG_FT	Top and bottom depths, in ft, of density log of borehole
NEUTLOG_FT	Top and bottom depths, in ft, of neutron log of borehole
FISCHASSAY_FT	Top and bottom depths, in ft, of sequence analyzed by Fischer assays
ASSAYLAB	Name of laboratory where Fischer assays were performed
NUMB_ASSAYS	Number of Fischer assays that were made

Table A1. The column names and definitions of the Microsoft Access table WY_TOPS_090318. —Continued

Column name	Column definition
LOCATNOTE	Additional information, commonly used where there is a problem with the location
USBMNO	Number assigned to the report of Fischer assays made by the former U.S. Bureau of Mines
XRD	Top and bottom depths, in ft, of X-ray diffraction analyses made on samples from the borehole
ELEVNOTE	Additional information, commonly used where there is a problem with the elevation
MISCNOTE	Miscellaneous information, such as publications related to the borehole, and other data
TP_LANEY	Depth to top of Laney, in feet
TP_CW1	Depth to top of clastic wedge 1, in ft
TP_BUFFMARK	Depth to top of Buff marker, in ft
TP_L_LACLEDE	Depth to top of lean LaClede, in ft
TP_R_LACLEDE	Depth to top of rich LaClede, in ft
BS_BUFFMARK	Depth to base of Buff marker, in ft
TP_LW_R_LACLEDE	Depth to top of lower rich LaClede in ft
TP_LW_L_LACLEDE	Depth to top of lower lean LaClede, in ft
TP_CATHBUFF	Depth to top of Cathedral Bluffs, in ft
TP_GODIVA_RM	Depth to top of Godiva Rim, in ft
TP_WILKPK	Depth to top of Wilkins Peak, in ft
TP_FARSON	Depth to top of Farson, in ft
TP_LW_WILKPK	Depth to top of lower Wilkins Peak, in ft
TP_RIFEBD	Depth to top of Rife, in ft
TP_SCHEGGS	Depth to top of Scheggs, in ft
TP_MAINTW	Depth to top of main Wasatch, in ft
TP_NILAND	Depth to top of Niland, in ft
TP_LUMAN	Depth to top of Luman, in ft
BS_LUMAN	Depth to base of Luman, in ft
FARS2SCHEGG	Thickness of interval from Farson to Scheggs, in ft
LACLEDE_STRUC	Elevation above sea level on top of the LaClede, in ft
RIFE_STRUC	Elevation above sea level on top of the Rife, in ft
MAINWAST_ST	Elevation above sea level on top of the main Wasatch, in ft
SCHEGGS_ST	Elevation above sea level on top of the Scheggs, in ft
TIPMODL_ST	Elevation above sea level on top of the Tipton oil shale assessment zone, in ft,
RLC2MNTW	Thickness of interval from rich LaClede to main Wasatch, in ft
SCH2MNTW	Thickness of interval from Scheggs to main Wasatch, in ft
RIF2FAR	Thickness of interval from Rife to Farson, in ft
LWK2RIF	Thickness of interval from lower Wilkins Peak to Rife, in ft
CATH2LWK	Thickness of interval from Cathedral Bluffs to lower Wilkins Peak, in ft
WIK2RIF	Thickness of interval from Wilkins Peak to Rife, in ft
RLC2WK	Thickness of interval from rich LaClede to Wilkins Peak, in ft
LC2WK	Thickness of interval from LaClede to Wilkins Peak, in ft

Table A1. The column names and definitions of the Microsoft Access table WY_TOPS_090318. —Continued

Column name	Column definition
FAR2SCHG	Thickness of interval from Farson to Scheggs, in ft
WKPKISOP	Thickness of Wilkins Peak oil shale assessment zone, in ft
WKPK2RIF	Thickness of interval from Wilkins Peak to Rife, in ft
WKBTMODL	Depth to base of Wilkins Peak oil shale assessment zone, in ft
WKTPMODL	Depth to top of Wilkins Peak oil shale assessment zone, in ft
RFTPMODL	Depth to top of Rife bed (Tipton oil shale assessment zone), in ft
RFBTMODL	Depth to base of Rife (Tipton oil shale assessment zone), in ft
LCTPMODL	Depth to top of LaClede oil shale assessment zone, in ft
LCBTMODL	Depth to base of LaClede oil shale assessment zone, in ft
SCTPMODL	Depth to top of Scheggs (Tipton oil shale assessment zone), in ft
SCBTMODL	Depth to base of Scheggs (Tipton oil shale assessment zone), in ft
TIPTISOP	Thickness of Tipton oil shale assessment zone, in ft
LCWPTISOP	Thickness of LaClede, Wilkins Peak, and Tipton oil shale assessment zones, in ft

Table A2. The column names and definitions of the Microsoft Access table WY_Assays_INTV.

Column name	Column definition
OBJECTID	Software-calculated identifier
LABNO	Six-digit U.S. Bureau of Mines (USBM) Laramie laboratory number
TOPFT	Depth, in ft, measured from the surface datum to the top of the sampled interval
BOTFT	Depth, in ft, measured from the surface datum to the base of the sampled interval
SHLOILPCT	Amount of shale oil, in weight percent
WATERPCT	Amount of water, in weight percent
SHLRSDPCT	Amount of shale residue, in weight percent
GASPLSPCT	Amount of "gas plus loss," in weight percent
OILGPT	Shale oil, in U.S. gallons per short ton of rock
WATERGPT	Water, in U.S. gallons per short ton of rock
SPCFGRAV	Specific gravity of the shale oil
COKETEND	Tendency for spent shale to coke
USGSID	Unique ID assigned by staff geologist
INTVL	Thickness of interval, in ft (BOTFT-TOPFT)
INTXOIL	Column used for weighted-average gallons per ton calculation (INTVL * OILGPT)
ROCKTYPE	Column added to denote intervals that were edited to distinguish between missing records and records found in core descriptions to be halite and (or) trona ("NH"), or sandstone ("NO").

Table A3. The column names and definitions of the Microsoft Access table BPA Lookup Table.

Column name	Column definition
ID	Software-calculated identifier
GALPERTON	Shale oil, in U.S. gallons per short ton of rock
GALFT3NEW	Oil yield, per unit volume, gallons per cubic foot

Table A4. The column names and definitions of the Microsoft Access table OilShale_Holes_pts.

Column name	Column definition
OBJECTID	Software-calculated identifier
USGSID	Unique ID assigned by staff geologist
LATDD	Latitude, in decimal degrees, North American Datum 1927, software-calculated, this report
LONGDD	Longitude, in decimal degrees, North American Datum 1927, software-calculated, this report
LCLDAVGPT	LaClede average gallons per ton oil yield
LCLDAVMSIN	LaClede percent missing intervals from core, represented as a floating point value
LCLDBPA	LaClede barrels per acre oil yield
LCLDMXMISS	LaClede maximum thickness of records missing from core
LCLDCNTMISS	LaClede number of records missing from core
WKPKAVGPT	Wilkins Peak average gallons per ton oil yield
WKPKAVMSIN	Wilkins Peak percent missing intervals from core, represented as a floating point value
WKPKBPA	Wilkins Peak barrels per acre oil yield
WKPKMXMISS	Wilkins Peak maximum thickness of records missing from core
WKPKCNTMISS	Wilkins Peak number of records missing from core
TIPTAVGPT	Tipton average gallons per ton oil yield
TIPTAVMSIN	Tipton percent missing intervals from core, represented as a floating point value
TIPTBPA	Tipton barrels per acre oil yield
TIPTMXMISS	Tipton maximum thickness of records missing from core
TIPTCNTMISS	Tipton number of records missing from core



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