Chapter 3

Methodology for Calculating Oil Shale Resources for the Uinta Basin, Utah and Colorado

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Volume Title Page

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

Chapter 3 of 7

Oil Shale Resources of the Uinta Basin, Utah and Colorado

By U.S. Geological Survey Oil Shale Assessment Team

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Methodology for Calculating Oil Shale Resources for the Uinta Basin, Utah and Colorado

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Abstract

Advancements in computer and database technology since an assessment of the in-place oil shale resources for the Piceance Basin, Colorado was made in 1989, have provided the U.S. Geological Survey (USGS) 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 seamlessly to streamline the storage and manipulation of data. A deterministic spatial interpolation method, the Radial Basis Function (RBF), 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 in-place oil shale resources.

Introduction

This report presents the methodology used in the geology-based assessment of the in-place oil resources in 18 oil shale zones of the Eocene Green River Formation in the Uinta Basin of northeastern Utah (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.

After converting, combining, and loading individual legacy Fischer assay (American Society for Testing and Materials, 1980) data files into a relational database (Dyni, 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 18 oil shale zones within the Green River Formation in the Uinta Basin.

Spatial Data

The legacy Fischer assay data files contained header information detailing the locations of boreholes, but not all of the files contained latitude and longitude coordinates. To maintain consistency, the majority of 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 contained in a separate database (Vanden Berg and others, 2006), 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, 18 oil shale zones (Donnell and Blair, 1970; Cashion and Donnell, 1972; Donnell, 2008) were defined and correlated between holes in the subsurface using oil-yield histograms generated from the Fischer assay data files (fig. 2). Previous USGS assessments of the Piceance Basin (Pitman and Johnson, 1978; Pitman, 1979; Pitman and others, 1989) subdivided the oil shale interval into a series of oil-rich and oil-lean zones that were traced across most of the basin (Cashion and Donnell, 1972), and each zone was assessed separately. For this study, the same set of rich and lean zones were used as much as possible in order to compare the results of the previous and present assessments.

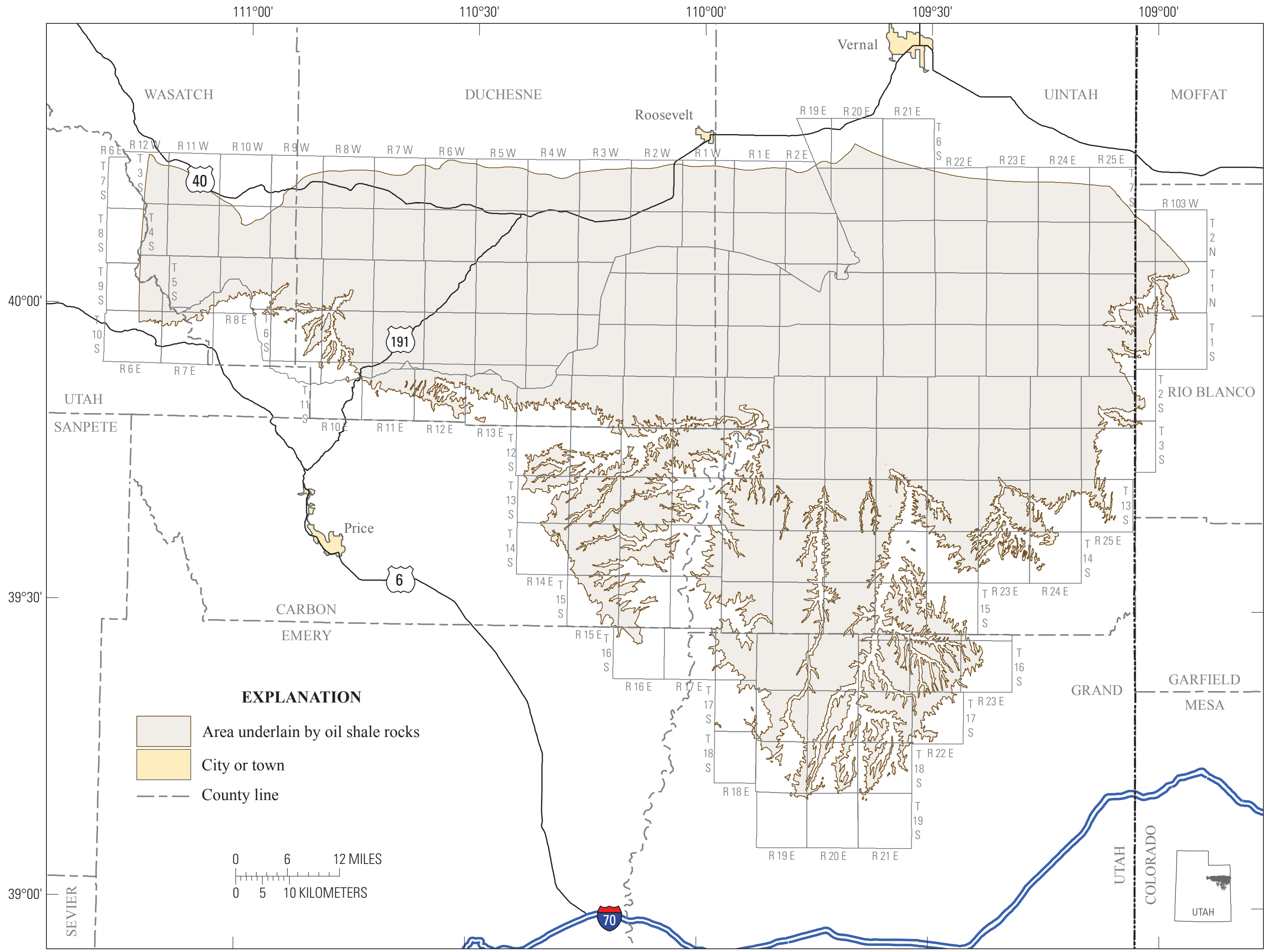


Figure 1. Uinta Basin, northeastern Utah, showing area underlain by oil shale-bearing rocks; cut-off to north is at the 6,000-ft depth contour to the Mahogany bed of the Parachute Creek Member of the Green River Formation. Outcrops of the Mahogany bed and the Parachute Creek Member of the Green River Formation shown in brown.

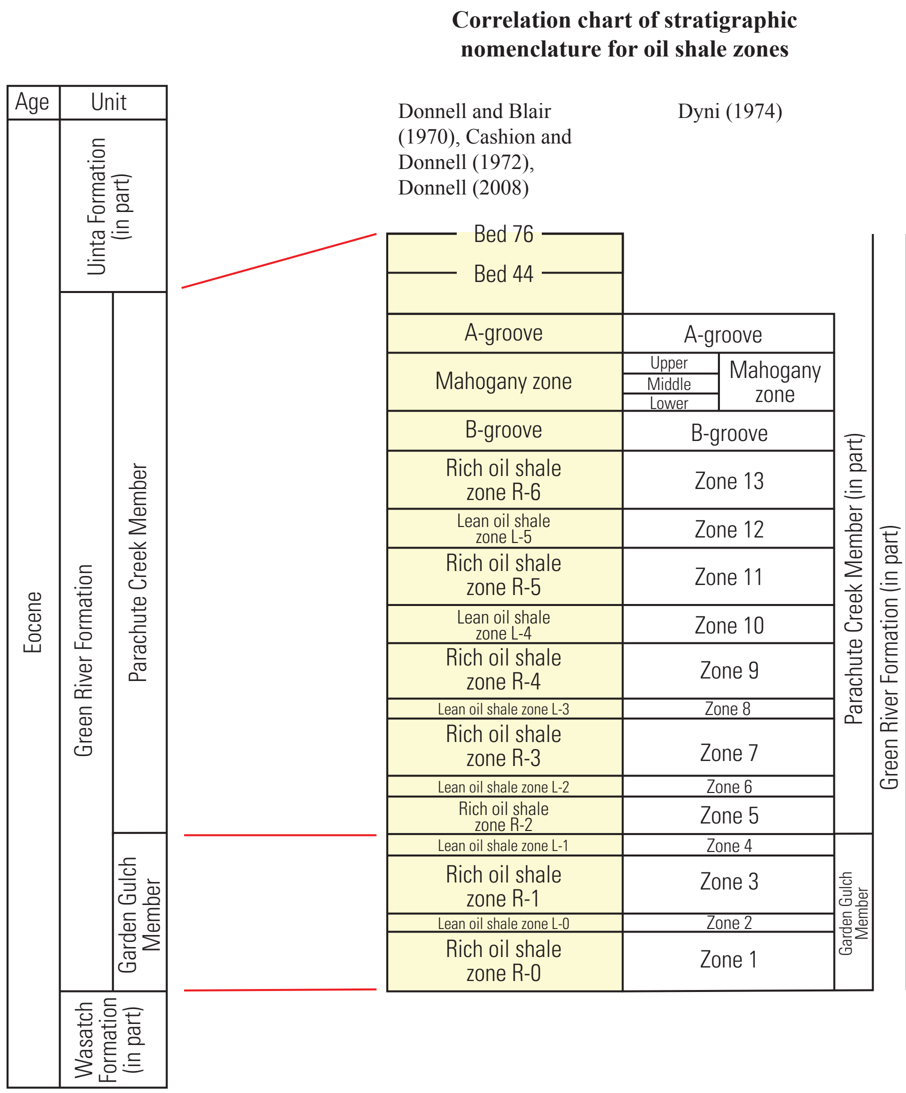


Figure 2. Stratigraphic columns and nomenclature for oil shale zones in the Eocene Green River Formation, Uinta Basin, Utah. The assessments of in-place oil resources use the nomenclature (shown in yellow) of Donnell and Blair (1970), Cashion and Donnell (1972), and Donnell (2008).

Vanden Berg and others (2006) published a file listing tops for oil shale zones in boreholes in the Uinta Basin. Tops were not picked for all of the boreholes used in this assessment and many of the boreholes did not have tops listed for all of the oil shale zones assessed. The tops file of Vanden Berg and others (2006) formed the basis of this assessment with new boreholes and additional tops added. In some isolated cases, it was necessary to correct minor errors in the tops file published by Vanden Berg and others (2006). The tops and bases of the 18 identified zones were entered in a spreadsheet and imported into the database where the tops and bases were linked with their associated Fischer assay records to create subsets of data on which calculations were performed.

Two updated boundary files (fig. 3) were created for the oil shale deposits of the Uinta Basin by digitizing mapped outlines of the top of the Mahogany bed and the base of the Parachute Creek Member of the Green River Formation from four published 1:250,000-scale geologic maps—Bryant (1992), Cashion (1973), Rowley and others (1985), and Witkind (1995). These mapped horizons served as bounding polygons for in-place resource calculations. Due to the steepness of the vertical cliffs formed by these strata throughout the Uinta Basin, only two resource-bounding polygons were needed for the 18 zones. The top of the Mahogany bed outcrop was used to delineate a resource-polygon file for the five uppermost zones—B-groove, Mahogany zone, A-groove, Bed 44, and

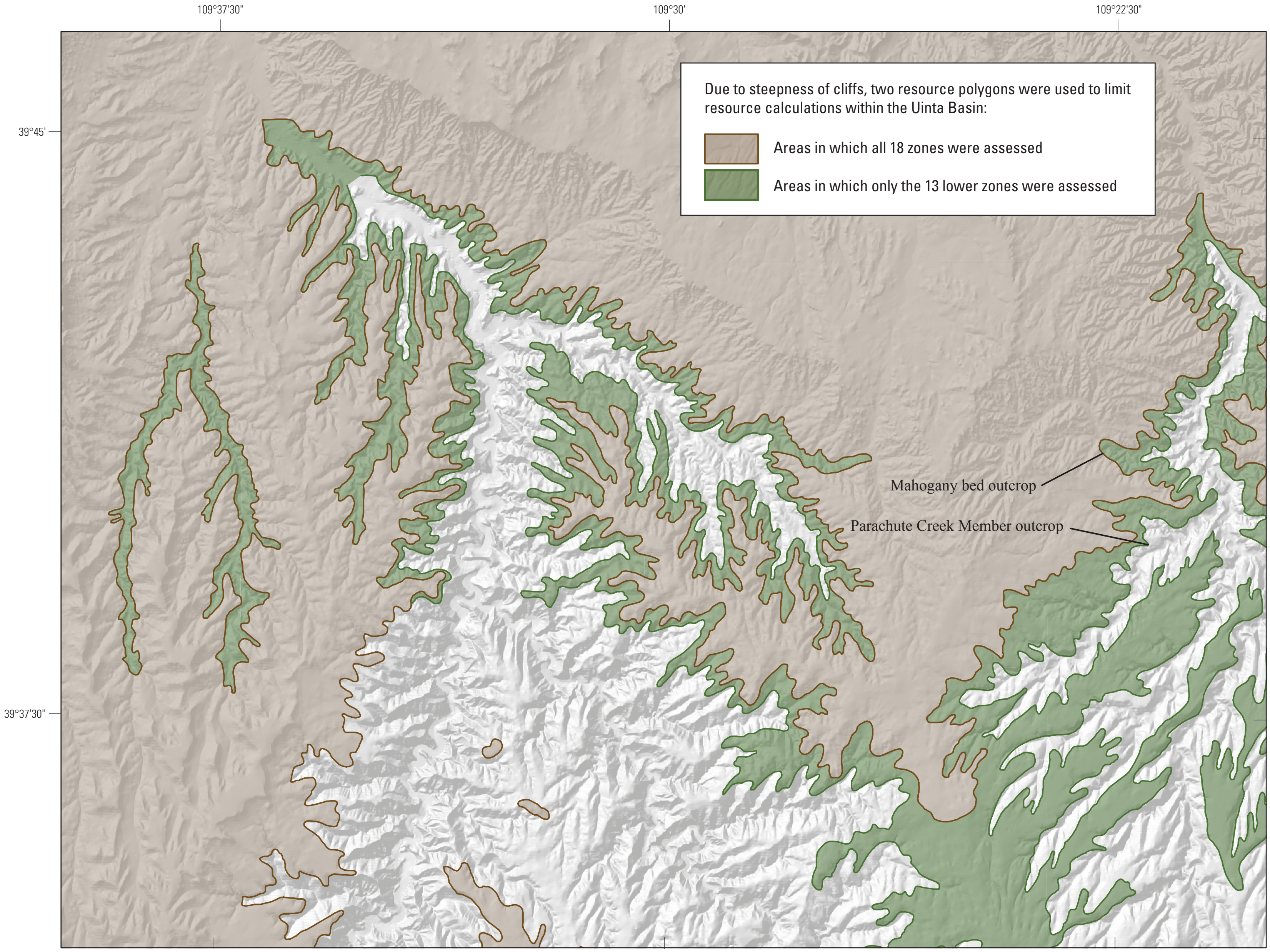


Figure 3. Central part of the Uinta Basin, Utah, showing the two resource polygons used to limit in-place oil shale resource calculations; base of the Parachute Creek Member of the Green River Formation and top of the Mahogany bed. Small outcrop areas excluded from resource calculations due to erosion.

Bed 76 (figs. 2, 3). This polygon file excluded areas within the basin where the upper five zones were eroded. The second resource-polygon file was created for all oil shale zones below the B-groove (fig. 3) by expanding the Mahogany bed polygon to include the areal extent of the Parachute Creek Member in the eastern half of the basin.

The two resource-polygon files were intersected spatially with a Public Land Survey System (PLSS) land grid for the Uinta Basin 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, and only township polygons were used to define a resource area for the L-2 zone. Ten different resource polygon files were needed to perform resource calculations for the 18 oil shale zones.

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 "U" for Utah. 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 100,000 records) instead of hundreds of different files.

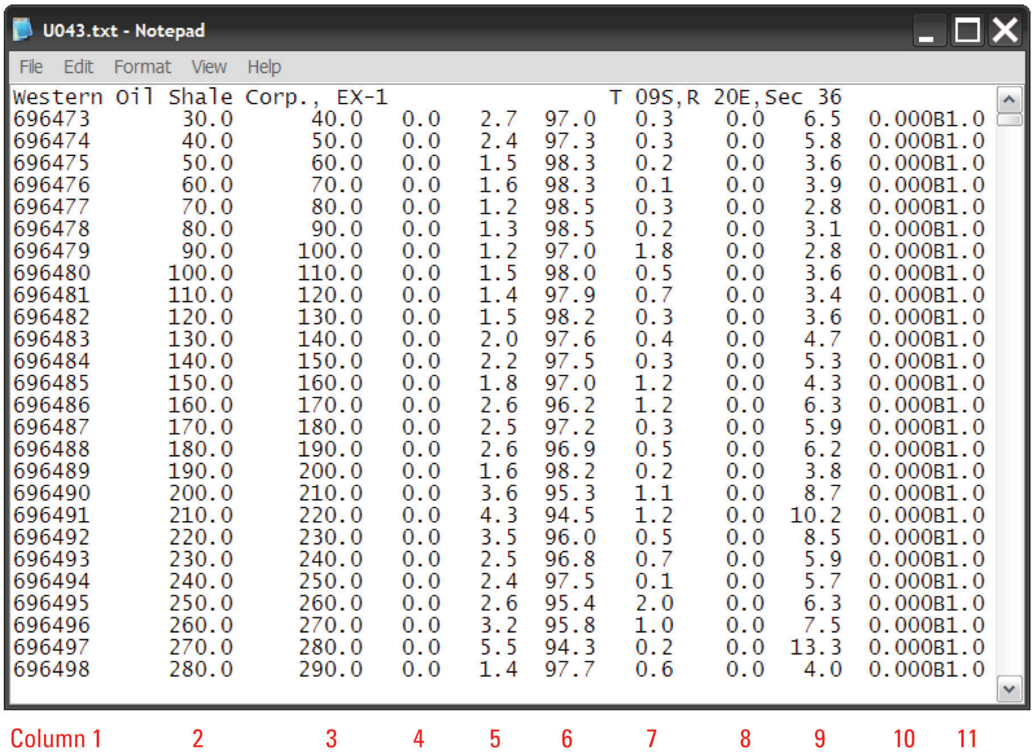
Some legacy Fischer assay records were incomplete, especially those associated with rotary drill cuttings instead of core—those boreholes have the character "R" in their USGS identifier (USGSID). Almost all boreholes contain missing intervals that represent samples that were not recovered during the 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 conversion process by using the original text filename; (2) the "INTVL" field, an abbreviation for thickness of the sampled interval, was calculated in Access 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 ("NH") and (or) nahcolite, and 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 0.5 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 (CO_Tops_080115.xlsx) with correlation data for Colorado and Utah was converted from a Microsoft Excel 2007 spreadsheet and also stored in the Access database (CO_Tops_080115). A one-to-many relation was established between formation tops and the Fischer assay data (CO_Assays_INTV), providing access to many assay records for each borehole. (Note: The Utah data were combined with the Colorado data because of similar stratigraphy, and also to create a plateau-wide database, thus the "CO" filenames.) 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 thicknesses, (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.

Footages measured from north, south, east, and west of PLSS section corners were used to digitize the spatial location for each borehole using GIS software (Vanden Berg and others, 2006). 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 the RBF-Multiquadric function 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 used to quantify resources using the defined resource polygons intersected with townships as 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 polygon of each resource-reporting file (the outcrop-polygon file



```
U043.txt - Notepad
File  Edit  Format  View  Help
Western Oil Shale Corp., EX-1                    T 09S,R 20E,Sec 36
696473       30.0       40.0   0.0   2.7  97.0   0.3    0.0   6.5   0.000B1.0
696474       40.0       50.0   0.0   2.4  97.3   0.3    0.0   5.8   0.000B1.0
696475       50.0       60.0   0.0   1.5  98.3   0.2    0.0   3.6   0.000B1.0
696476       60.0       70.0   0.0   1.6  98.3   0.1    0.0   3.9   0.000B1.0
696477       70.0       80.0   0.0   1.2  98.5   0.3    0.0   2.8   0.000B1.0
696478       80.0       90.0   0.0   1.3  98.5   0.2    0.0   3.1   0.000B1.0
696479       90.0      100.0   0.0   1.2  97.0   1.8    0.0   2.8   0.000B1.0
696480      100.0      110.0   0.0   1.5  98.0   0.5    0.0   3.6   0.000B1.0
696481      110.0      120.0   0.0   1.4  97.9   0.7    0.0   3.4   0.000B1.0
696482      120.0      130.0   0.0   1.5  98.2   0.3    0.0   3.6   0.000B1.0
696483      130.0      140.0   0.0   2.0  97.6   0.4    0.0   4.7   0.000B1.0
696484      140.0      150.0   0.0   2.2  97.5   0.3    0.0   5.3   0.000B1.0
696485      150.0      160.0   0.0   1.8  97.0   1.2    0.0   4.3   0.000B1.0
696486      160.0      170.0   0.0   2.6  96.2   1.2    0.0   6.3   0.000B1.0
696487      170.0      180.0   0.0   2.5  97.2   0.3    0.0   5.9   0.000B1.0
696488      180.0      190.0   0.0   2.6  96.9   0.5    0.0   6.2   0.000B1.0
696489      190.0      200.0   0.0   1.6  98.2   0.2    0.0   3.8   0.000B1.0
696490      200.0      210.0   0.0   3.6  95.3   1.1    0.0   8.7   0.000B1.0
696491      210.0      220.0   0.0   4.3  94.5   1.2    0.0  10.2   0.000B1.0
696492      220.0      230.0   0.0   3.5  96.0   0.5    0.0   8.5   0.000B1.0
696493      230.0      240.0   0.0   2.5  96.8   0.7    0.0   5.9   0.000B1.0
696494      240.0      250.0   0.0   2.4  97.5   0.1    0.0   5.7   0.000B1.0
696495      250.0      260.0   0.0   2.6  95.4   2.0    0.0   6.3   0.000B1.0
696496      260.0      270.0   0.0   3.2  95.8   1.0    0.0   7.5   0.000B1.0
696497      270.0      280.0   0.0   5.5  94.3   0.2    0.0  13.3   0.000B1.0
696498      280.0      290.0   0.0   1.4  97.7   0.6    0.0   4.0   0.000B1.0
```


Figure 4. Image clip of a portion of the original Fischer assay data (Dyni, 1998) for the Western Oil Shale Corp. EX-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.

Table 1. Column names and definitions of 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 sandstone ("NO").

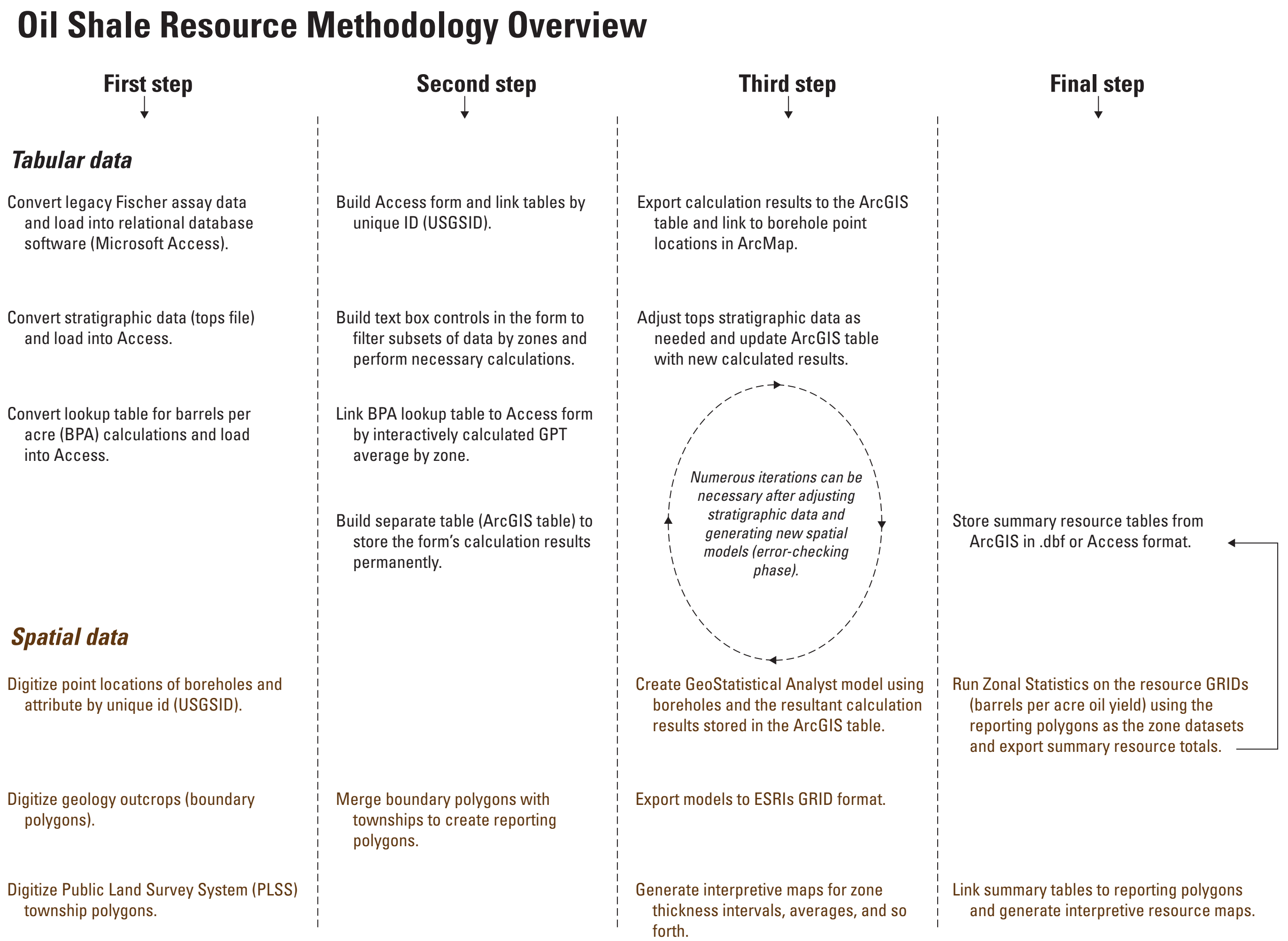


Figure 5. Overview chart showing the four steps and processes performed on the spatial and tabular data for the Uinta Basin oil shale assessment.

intersected with the township file). Various summary calculations and presentation-quality 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), and to view 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 were stored permanently in a separate database table that was 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 figures 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,

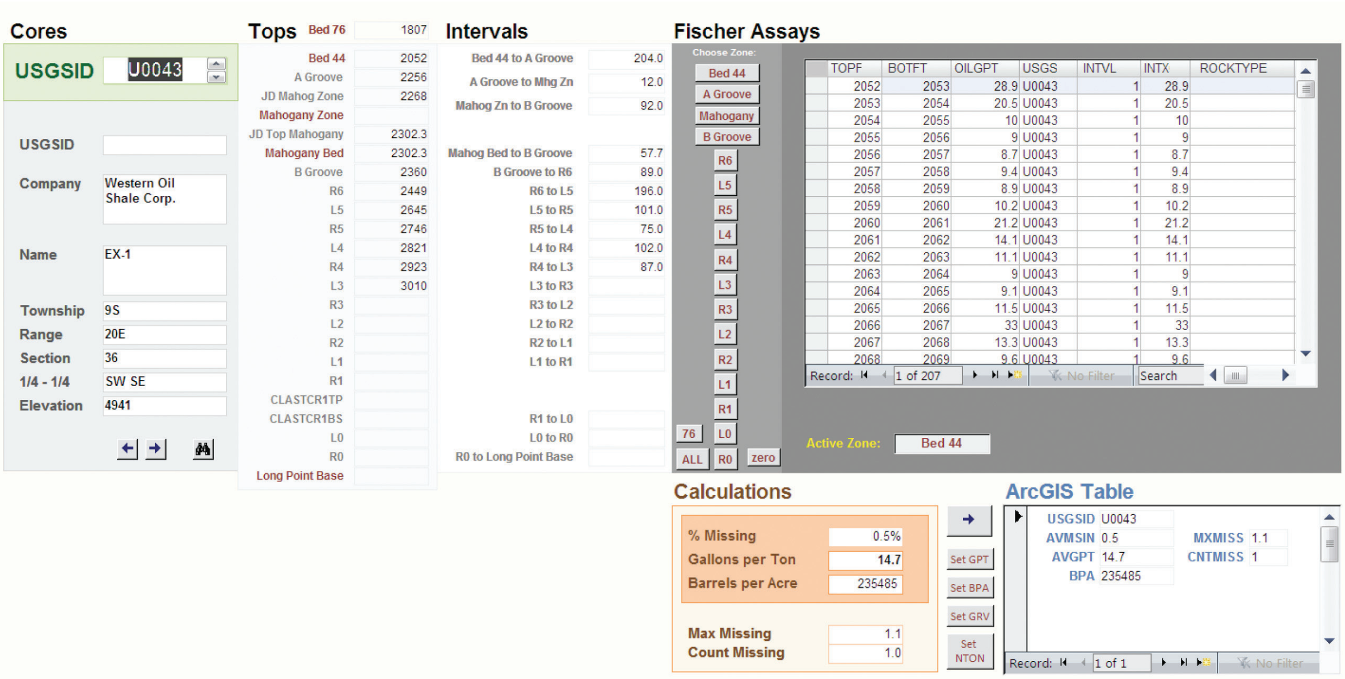


Figure 6. Image clip of Microsoft Access 2007 form used to perform oil shale resource calculations containing (1) tops table under the headings Cores, Tops, and Intervals; (2) Fischer Assays table; (3) Calculations section containing controls that performed assessment calculations; and (4) ArcGIS Table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

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:

Sum of (thickness of interval in feet * gallons per ton) / thickness of interval in feet.

Barrels Per Acre

The determination of oil-in-place resource values in BPA were 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/ft^3); this value was needed to perform the BPA calculation:

Interval thickness in feet (without halite beds) * 43,560 (ft^2/acre) * oil yield per unit volume (gal/ft^3) / 42 (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

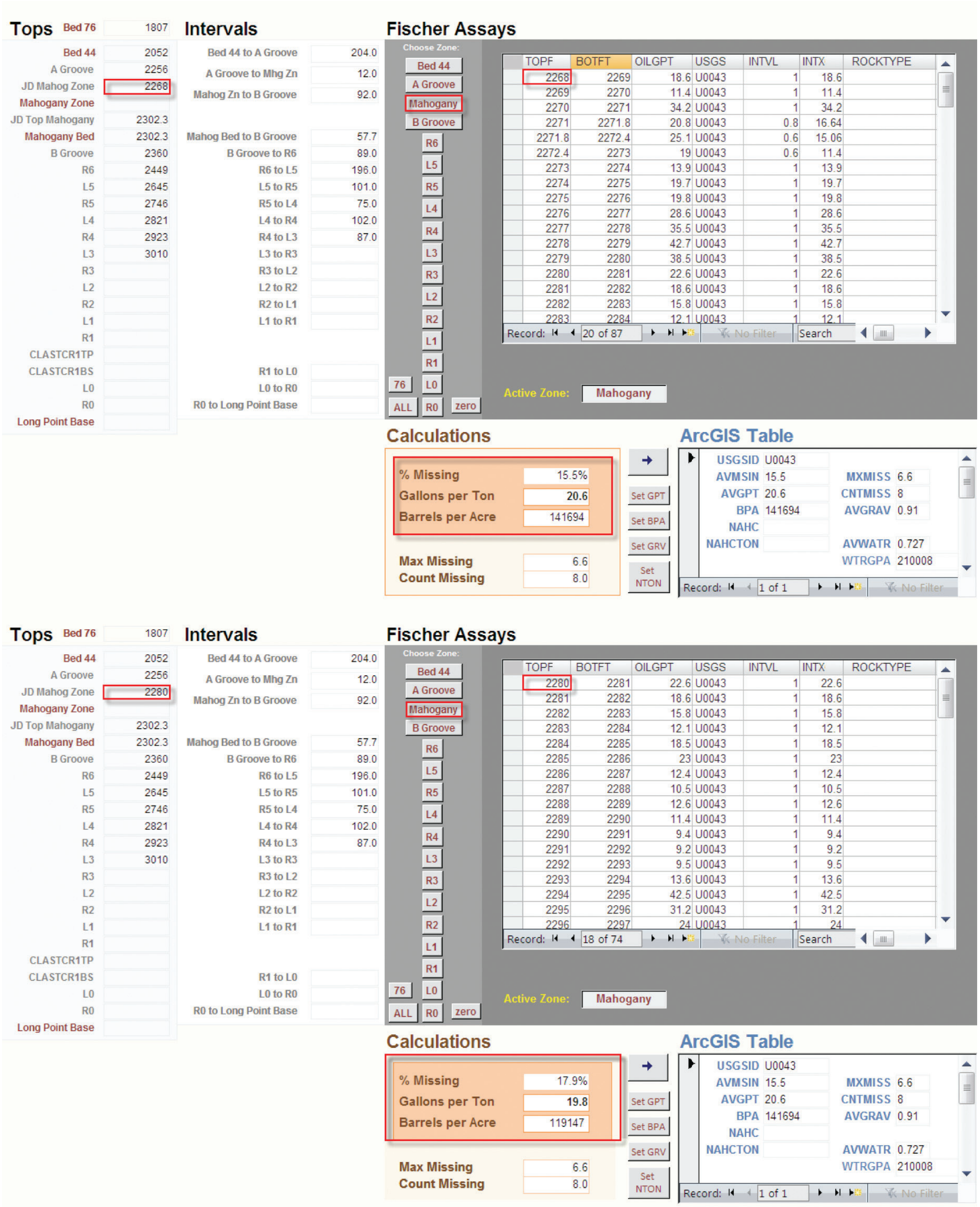


Figure 7. Image clip showing how changing an interpretation of a tops pick in the tops table and re-filtering the Fischer assays table immediately affects the Microsoft Access 2007 form's resource calculations, but not the ArcGIS Table's records. Example shown is for the Mahogany oil shale zone in borehole U0043 (see fig. 14 for location data).

Table 2. Original volume-weight oil-yield relations based upon Green River oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colorado from Stanfield and others (1954).

[GPT, gallons per ton; lbs/ft^3, pounds per cubic foot; ft^3/ton, cubic feet per ton; gal/ft^3, 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 oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colorado 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 oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colorado 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/ft³)	Volume of oil shale (ft³/ton)	Oil yield, per unit volume (gal/ft³)
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 oil shale from U.S. Bureau of Mines oil shale mine, Rifle, Colorado from Stanfield and others (1954).—Continued

[GPT, gallons per ton; lbs/ft^3, pounds per cubic foot; ft^3/ton, cubic feet per ton; gal/ft^3, 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)
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

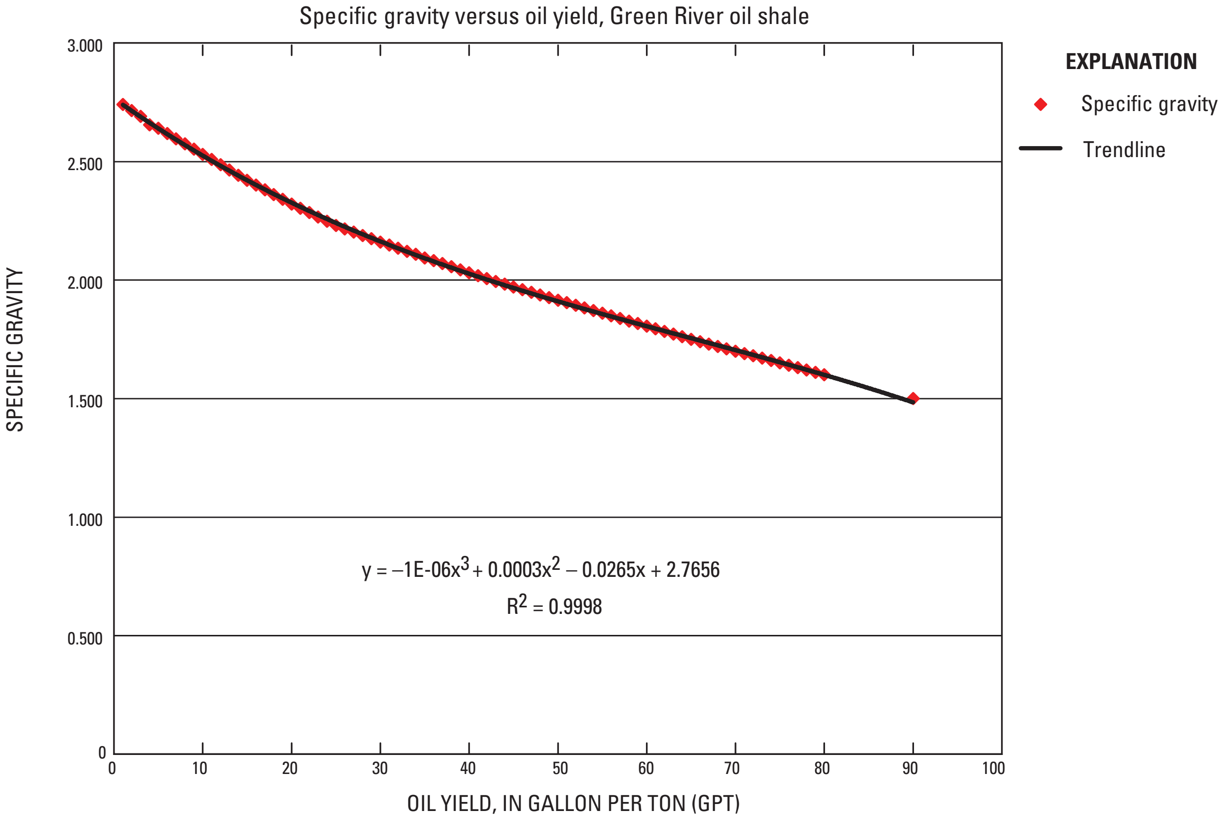


Figure 8. Graph of a third-order trendline showing relation between oil yield for Green River oil shales and specific gravity.

10.0 for a specific borehole and zone, this would correspond to a value of 0.790 gal/ft^3 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 sandstone in the ROCKTYPE column–"NO."

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 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 are 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 using 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

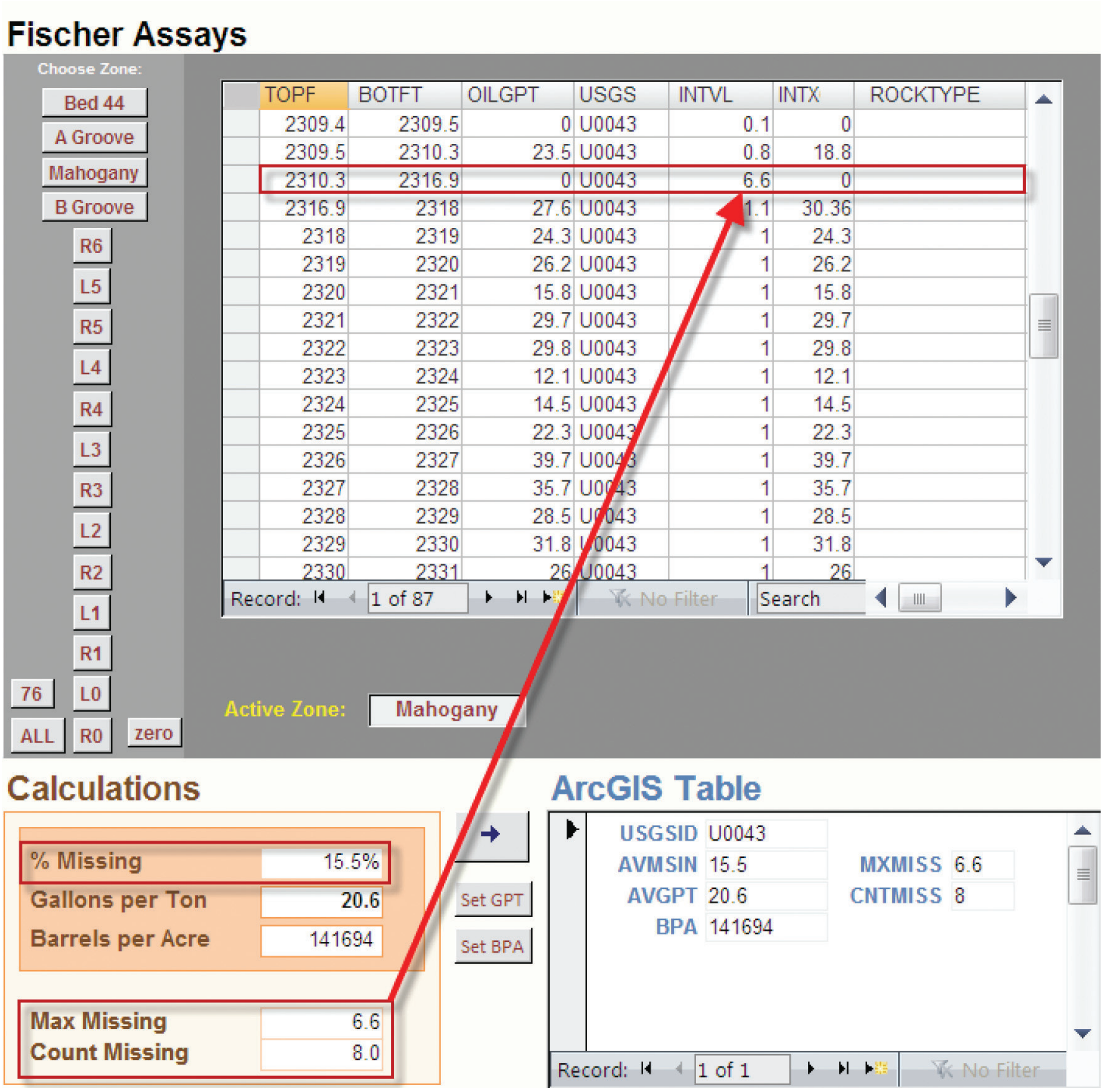


Figure 9. Image clip of Microsoft Access 2007 form showing how missing intervals are reported for each core sample. Example shown is for the Mahogany oil shale zone in borehole U0043 (see fig. 14 for location data).

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 the calculations gave unreliable resource numbers with large error limits 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 us 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 will honor all data points and 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.

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 based on the number of boreholes and the extent of the dataset. After all of the 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 model 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 (those 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 as the software simply counted all of the values for BPA 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 were 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 mi^2) section to obtain a summary of barrels of oil yield per section.

Interpretive Maps

Once the spatial analysis and quantification of resources were completed, a series of interpretive maps were generated for each of the 18 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 18 oil shale zones in the Uinta Basin, 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 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 Keefer and Michael Pantea of the U.S. Geological Survey for performing thorough technical reviews of this report. Their comments and suggestions led to improvements and clarity to many of the discussed topics

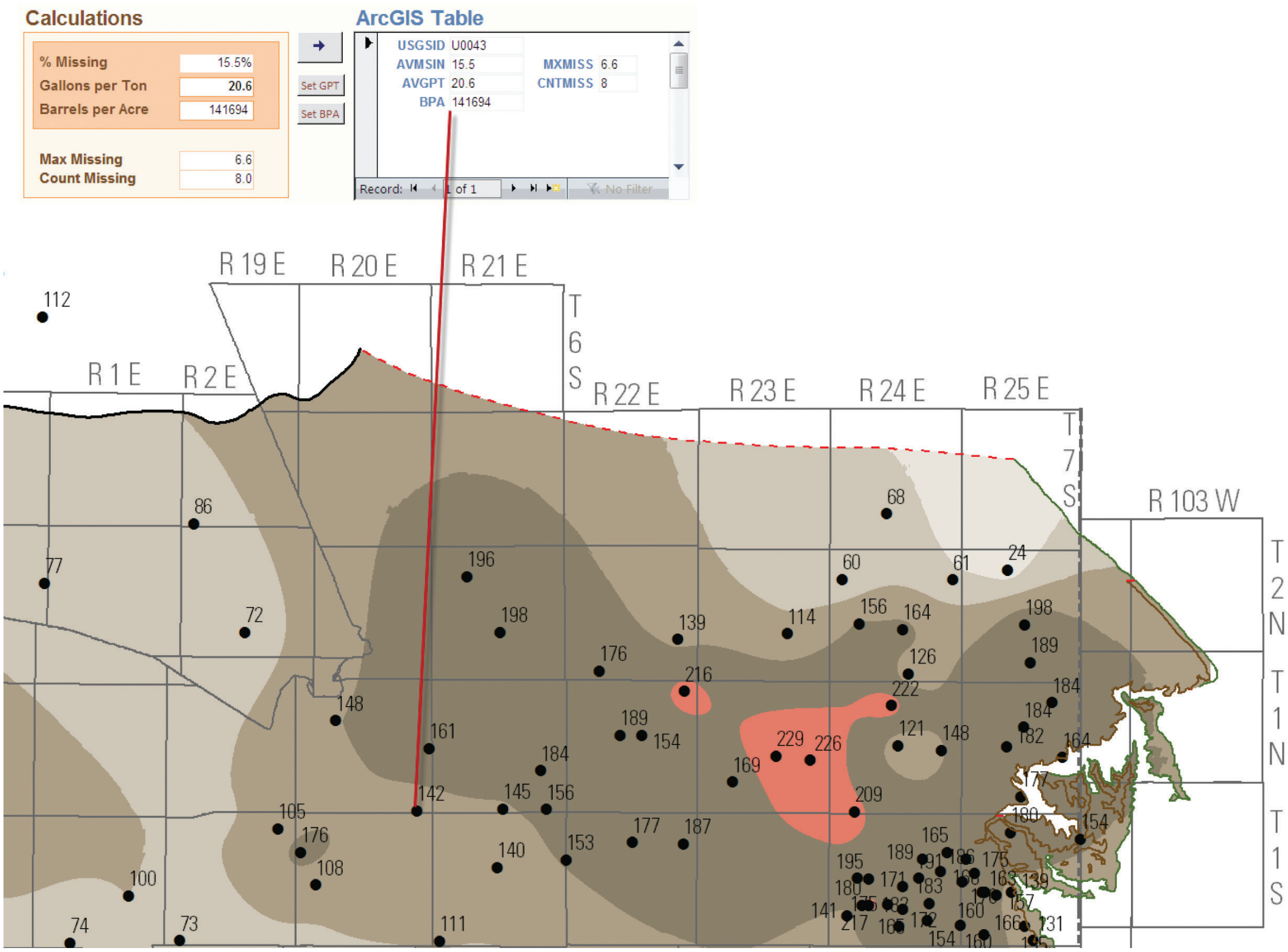


Figure 10. Image clip showing how data are migrated from the Microsoft Access 2007 database form and then modeled in the GIS software. Values labeled in model are in thousands of barrels. Example shown is for the Mahogany oil shale zone in borehole U0043 (see fig. 14 for location data).

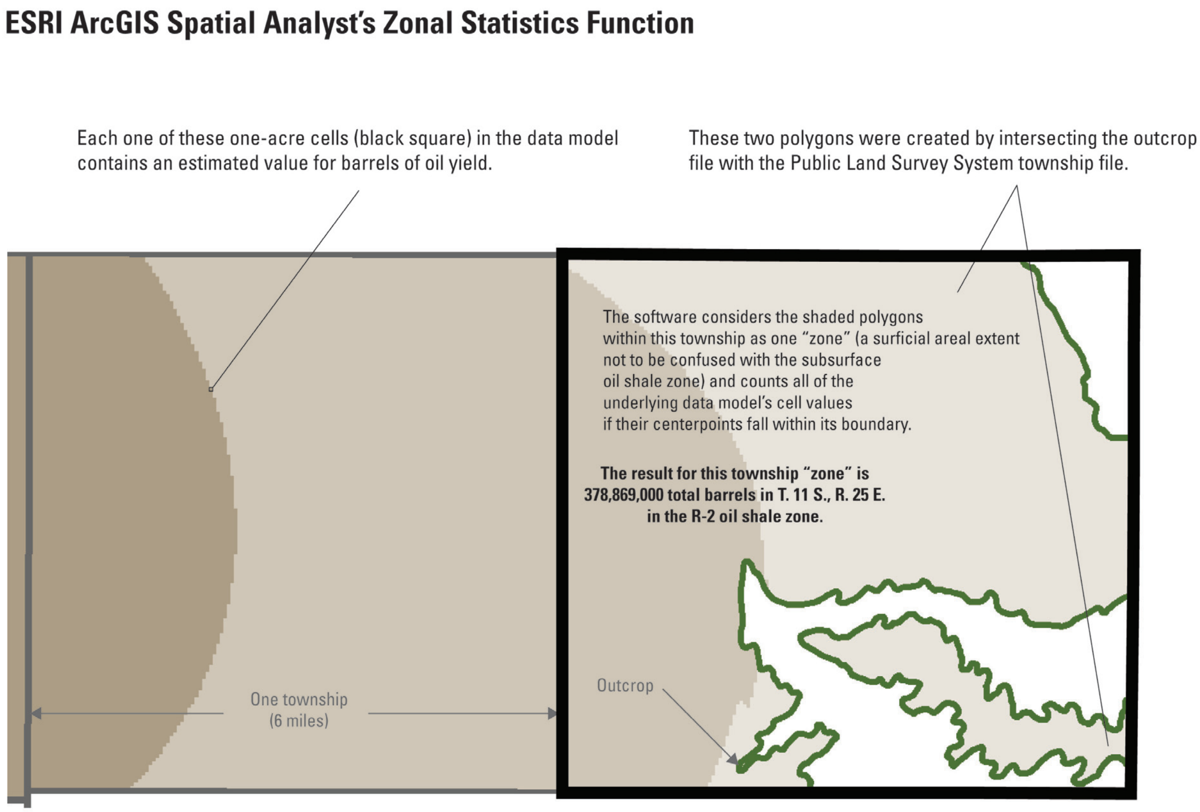


Figure 11. Eastern part of the Uinta Basin, Utah, showing how the GIS software summarizes total barrels of oil yield by township.

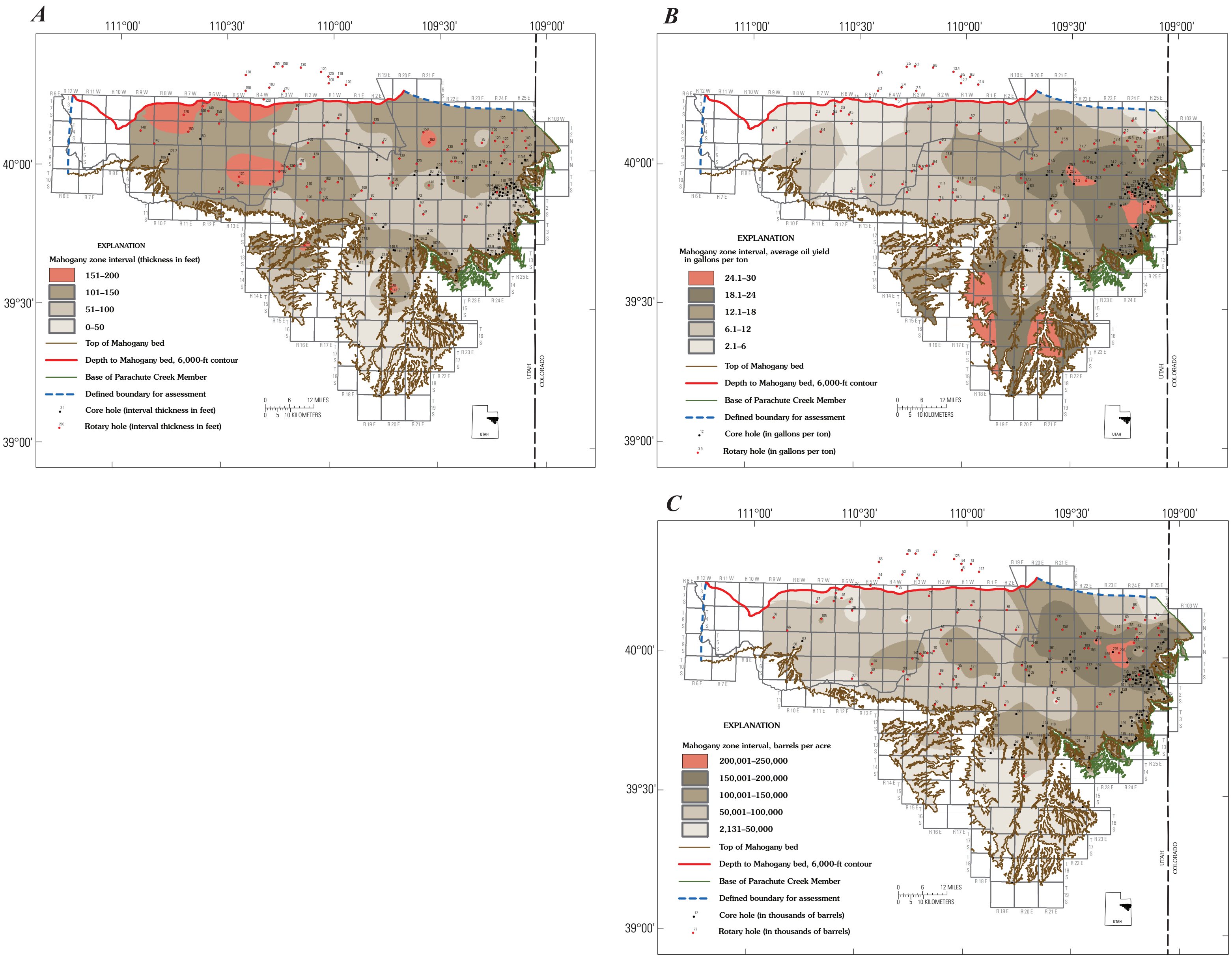


Figure 12. Examples of interpretive maps generated from resource models: *A*, oil shale zone isopachs; *B*, average oil yield in gallons per ton; *C*, oil yield in barrels per acre. See Johnson and others, Chapter 1, this CD–ROM, for original figures.

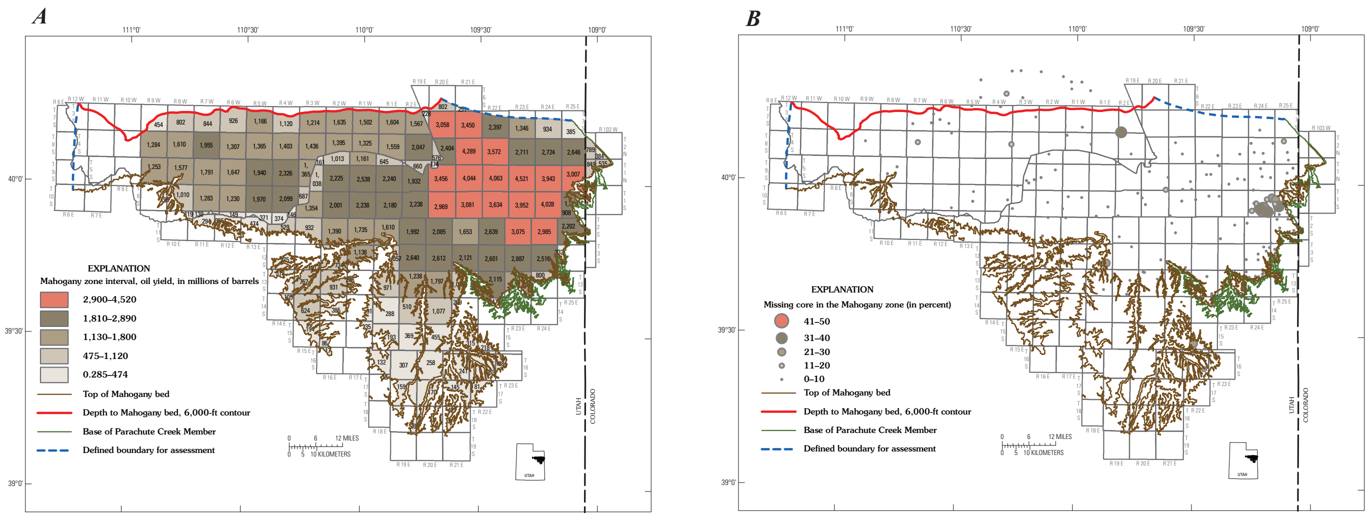


Figure 13. Examples of interpretive maps generated from resource models: *A*, oil yield in barrels per township; *B*, percentage of missing intervals from each core sample. See Johnson and others, Chapter 1, this CD-ROM, for original figures.

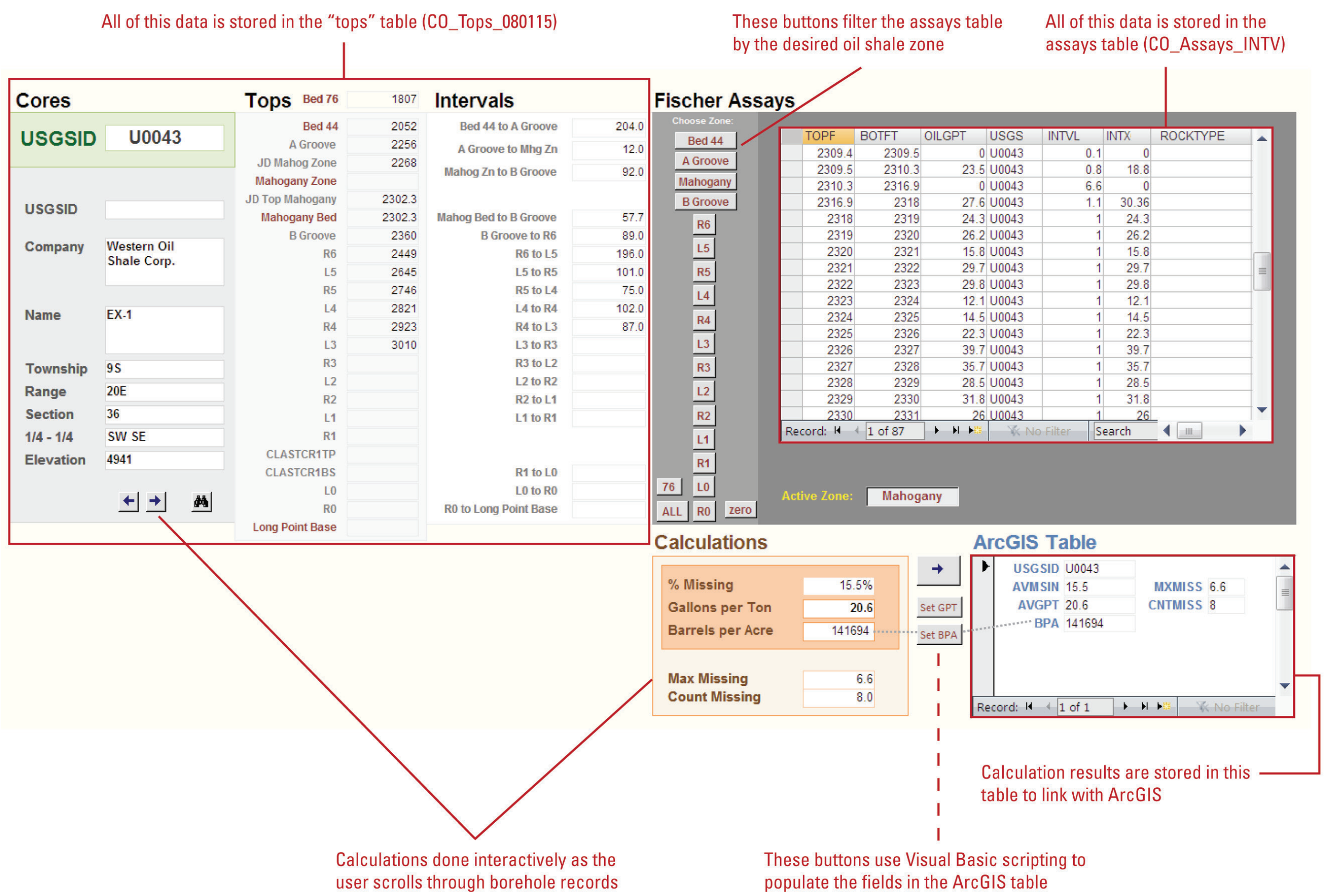


Figure 14. Image clip of Microsoft Access 2007 form detailing how the user interacts with the form's buttons and controls. Red text and linework details the visual representation of the database's tables within the form, as well as buttons and controls added to utilize Visual Basic scripting and macros.

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Case Study—Oil Shale Assessment

Converting and Loading Legacy Fischer Assay Data

We loaded legacy Fischer assay data files (Dyni, 1998) 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 300 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 the thickness of each sampled interval (INTVL), the thickness of the interval times the oil yield in gallons per ton (INTXOIL), and a field to denote halite and records added by staff geologists (ROCKTYPE). We populated the INTVL and INTXOIL fields by using update queries in Access.

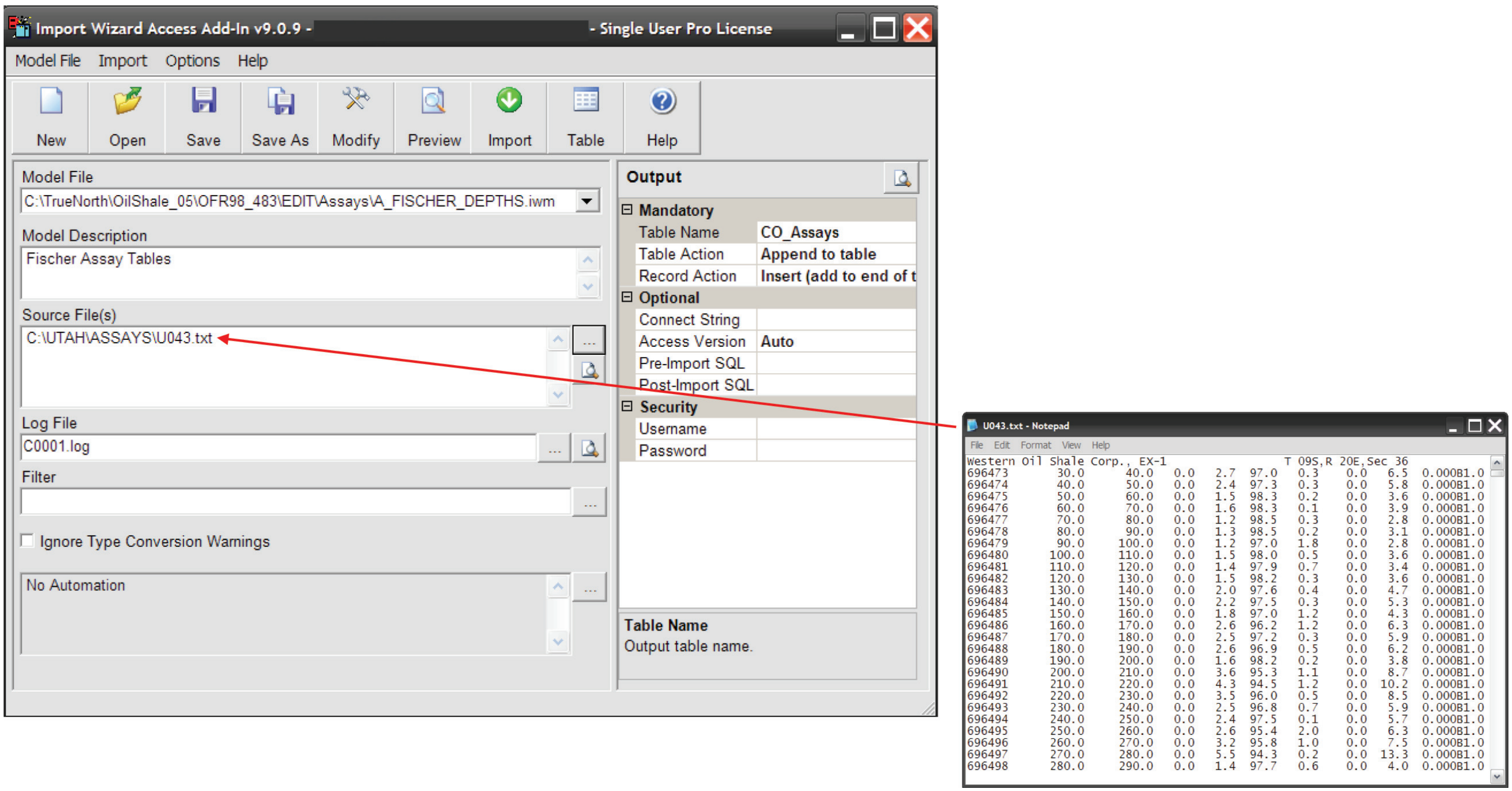

Figure 15. Image clip of Beside Software Import Wizard dialog window used to import legacy Fischer assay data (Dyni, 1998). A portion of the original Fischer assay data for the Western Oil Shale Corp. EX-1 borehole is shown to the right (see fig. 4, table 1).

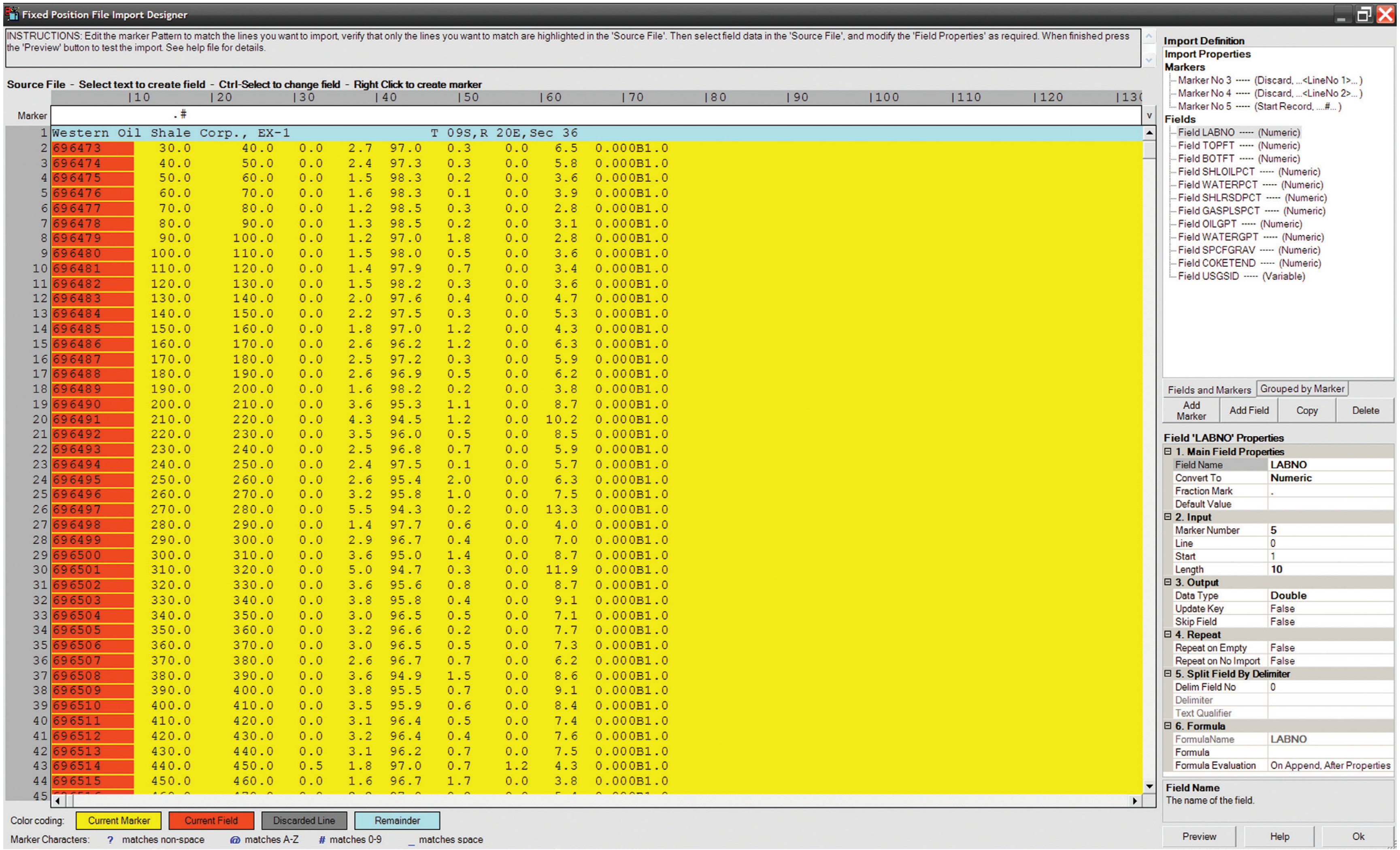

Figure 16. Image clip of Import Wizard model file (A_FISCHER_DEPTHS.iwm) setup dialog window. The different colors denote (1) blue—header information that was ignored during the import process; (2) red—selected field (LABNO, laboratory number) and width of column; and (3) yellow—remainder of the fields 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 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 (CO Tops_080115). (Note: The Utah data were combined with the Colorado data in one database, as the Piceance and Uinta Basins share the same stratigraphy, thus the "CO" filenames.)

USGSID	JDAGROOV	JDMAHOGZN	OMAHOGZN	JDTPMAHOG	OMAHOG	JDBGROOV	JDR6	JDL5
U0020	106.8	137.4		179.2	179.2	247.2		
U0021	75.1	90.6		165.3	165.3	231.4		
U0022	77.2	96.8		157.7	157.7	227.0		
U0023	88.2	112.2		166.0	166.0	233.7	257.0	
U0024	678.0	689.0						
U0025	477.0	488.0		518.0	518.0			
U0026		153.4		181.0	179.5	217.2	233.1	
U0027	81.0	89.9		119.6	119.6	158.8	163.3	
U0028	463.9	475.8		515.0	515.0			
U0029	593.9	603.5		636.6	636.6	700.0	737.2	903.5
U0030	430.9	443.4		480.0	480.0	544.8		
U0031	401.2	411.2		446.5	446.5			
U0032	363.5	374.3		405.4	405.4	460.0		
U0033	348.1	356.0		382.7	382.7	431.9		
U0034	342.0	350.6		380.0	380.0			
U0035	358.0	370.0		405.0	405.0	481.5		
U0036A	118.0	134.5		165.0	165.0	234.5	261.5	
U0037A	56.5	66.5		100.0	100.0			

Figure 17. Structure of the stratigraphic tops table (CO_Tops_080115) as viewed in Microsoft Access 2007, showing the depth, in ft, to top of the A-groove through L-5 oil shale zones for boreholes U0020 through U0037A. Tops of oil shale zones are listed stratigraphically from left to right: AGROOV, A-groove; MAHOGZN, Mahogany Zone; TPMAHOG, Mahogany Bed; MAHOG, Mahogany Bed; BGROOV, B-groove; R6 (rich-zone 6); L5 (lean-zone 5). Tops picked by: JD, John Donnell (USGS); O, authors of this report.

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 is calculated for a particular zone interactively in the Access form, the "GALFT3NEW" value associated with that GPT average is 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 2007's 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.

Digitizing Borehole Locations

Locations of boreholes (fig. 19) were digitized in ESRIs ArcMap based on footage measurements from section corners recorded in a separate database (Vanden Berg and others, 2006). A custom tool was developed that combined the distance and sketch tools in ArcMap to digitize points. Each point was attributed with its unique borehole identifier, USGSID, which allowed the linking of spatial and tabular data.

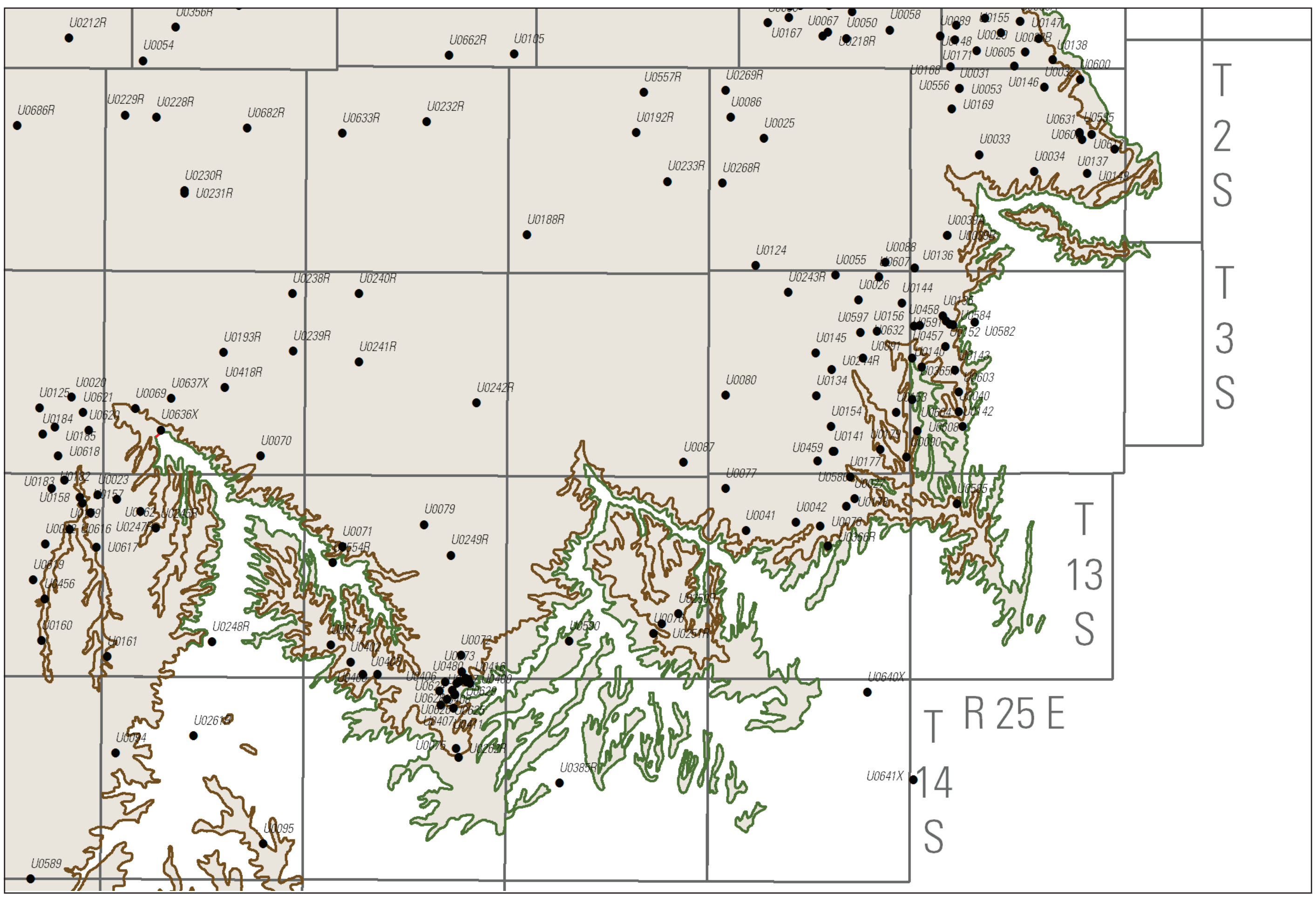

Figure 19. Eastern part of the Uinta Basin, Utah, showing borehole locations after digitizing in ArcMap. Parachute Creek Member outcrop areas shown between green and brown lines. Mahogany bed outcrops shown by brown lines.

Building the Access Form

A custom Access Form (CO 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 was based on the stratigraphic tops table (CO_Tops_080115), and the linked tables are displayed in Access subforms.

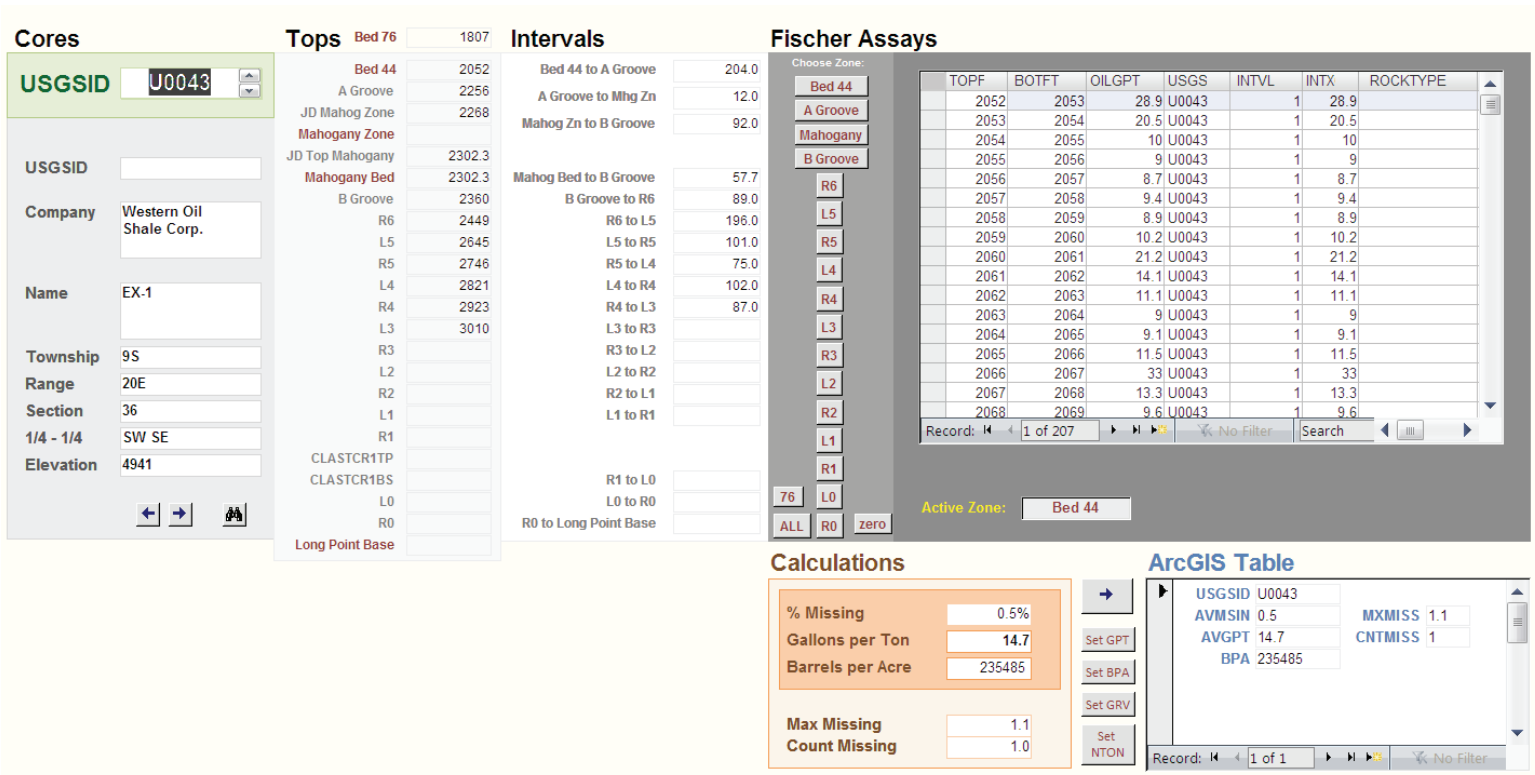

Figure 20. Image clip of the main Access form showing how subforms were linked by the unique identifier, USGSID, and performed all resource calculations.

Intersecting Polygon Files to Create Reporting Polygons

Initially, outcrop lines were digitized in ArcMap for the top of the Mahogany bed and the base of the Parachute Creek Member of the Green River Formation, based on 1:250,000-scale published geologic maps—Bryant (1992), Cashion (1973), Rowley and others (1985), and Witkind (1995). 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's (BLM) GeoCommunicator website (*http://www.geocommunicator.gov*), 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.

Township polygons

Outcrop polygons (resource polygons)

Reporting polygons

Figure 21. Diagram showing how ESRI ArcToolbox's Intersect command was used to create the assessment's reporting polygons for the Uinta Basin in northeastern Utah.

SQL Query to Filter Assays By Zone

Following linkage of the Fischer assays table (CO_Assays_INTV) with the tops table (CO_Tops_080115) by USGSID in the form, Structured Query Language (SQL) queries were written to filter out subsets of assay records for each oil shale zone. For example, the query (QuerR4toL3) to select only those assay records that were between the R-4 zone top and the L-3 zone top picks in the tops table, and to display those records in the assays subform, utilized a BETWEEN statement:

```
SELECT CO_Assays_INTV.TOPFT, CO_Assays_INTV.BOTFT, CO_Assays_INTV.OILGPT, CO_Assays_INTV.USGSID, CO_Assays_INTV.INTVL, CO_Assays_INTV.INTXOIL, CO_Assays_INTV.ROCKTYPE

FROM CO_Assays_INTV

        WHERE (((CO_Assays_INTV.TOPFT) Between [Forms]![CO Form]![JDR4] And [Forms]![CO Form]![JDL3])

        AND ((CO_Assays_INTV.BOTFT) Between [Forms]![CO Form]![JDR4] And [Forms]![CO Form]![JDL3])

        AND (([Forms]![CO Form]![JDR4])>0) AND (([Forms]![CO Form]![JDL3])>0))

ORDER BY CO_Assays_INTV.TOPFT;
```

In effect, the R-4 zone query returned assay records from the top of the R-4 zone to the top of the L-3 zone, but only if (1) the value for the top of an assay record (TOPFT) was equal to or greater than the R-4 tops pick (JDR4), (2) the base of an assay record (BOTFT) was equal to or less than the top of the L-3 zone pick (JDL3), and (3) all assay records in *between* as long as those records contained the same USGSID as the currently selected borehole in the 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 thus, 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(IIf([INTXOIL]>0,[INTXOIL],0))/Sum(IIf([INTXOIL]>0,[INTVL],0))

After filtering the assays subform using the SQL zone query, the Access form would (1) sum all of the INTXOIL values and the INTVL values, (2) perform the division on those sums, and (3) return 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).

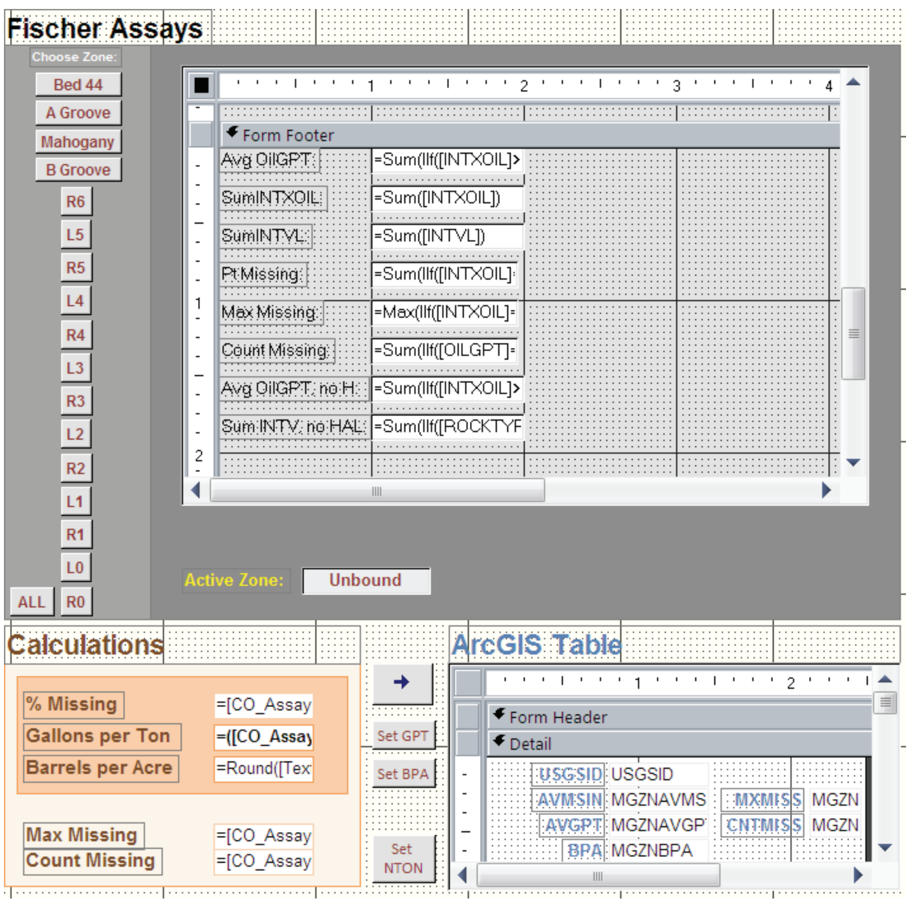

Figure 22. The oil shale assessment's Microsoft Access 2007 form as viewed in Design mode. Some text box control calculations are "hidden" in the Fischer assays subform footer.

Calculating Barrels Per Acre Oil Yield

Formula: Interval thickness * 43,560 (sq. ft/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, if present. (Note: While no halite beds were present in Utah, it was necessary to retain the following statements for the form, based on the Piceance Basin, Colorado Assessment, to function correctly). We added text-box controls to the subform that contained the following statements:

To sum all intervals for the subset of assays:

=Sum([INTVL])

To sum all halite intervals for the subset of assays:

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

To subtract halite 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 intervals.

Next, we retrieved our multiplier for oil yield per unit volume from the Lookup Table based on the GPT calculation in the 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 R-4 zone in borehole U0043, a GPT average of 9.5 was returned. The associated value in the BPA Lookup table for 9.5 is 0.754. Using the statements above, the form also returned a value of 87.0 for the total thickness of the R-4 zone. Using the formula to calculate barrels per acre oil yield, the following statement was entered into another text box control in the form:

=Round([Text335]*43560*[Text239]/42,0) where Text335 is the sum of all intervals minus halite and Text239 is the value returned from the Lookup Table, with the result rounded to 0 decimal places. In this case, for the R-4 zone in borehole U0043, the form calculated 68,034 barrels per acre oil yield (87.0 * 43,560 * 0.754 / 42).

Calculating the Percentage of Missing Intervals From Each Core Sample

Text-box controls were added to the form footer of the 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(IIf([INTXOIL]=0,[INTVL],0))/Sum([INTVL])

To calculate the maximum thickness of missing intervals:

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

To count the number of records missing:

=Sum(IIf([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 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 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 which 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]![CO form]![OilShale_Holes_pts subform].[Form]![Text21]

Expression: [Forms]![CO 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 form—in this case, the Text341 text-box control that contained the statement to calculate the maximum thickness of missing intervals.

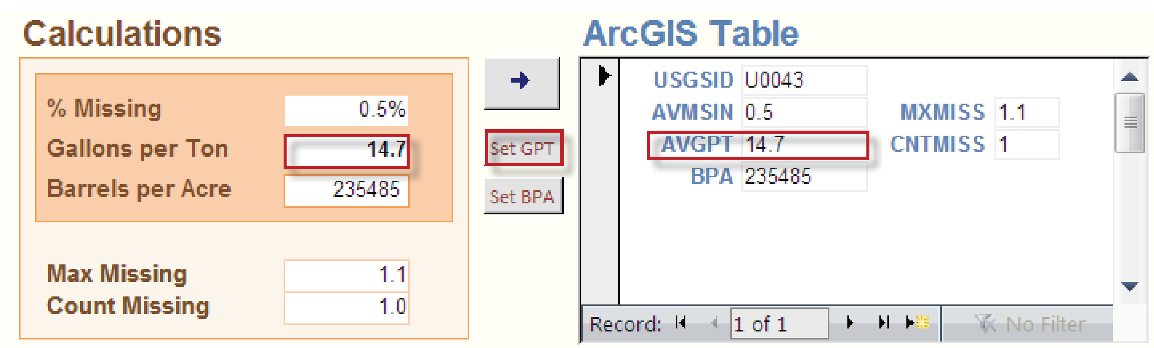

Figure 23. Image clip of a portion of the Microsoft Access 2007 form showing how calculation results performed interactively in the form were stored in a table permanently using buttons and macros. Example shown is for the Bed 44 oil shale zone in borehole U0043.

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. Eighteen buttons were added to the main form to filter assays by each oil shale zone as well as an "All" button that would 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 18 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 R-4 zone contained the fields R4AVGPT, R4BPA, R4AVMSIN, R4MXMISS, and R4CNTMISS. 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 = "QuerR4toL3"
    OilShale_Holes_pts_subform.Form.[MXMISS].ControlSource = "R4MXMISS"

    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 (COPLATOS.mdb). In ArcMap ver.9.2, the attribute table was joined to the point feature class and, through several definition queries, 18 separate point layers were created corresponding to each oil shale zone. It is important to note that boreholes having only rotary cuttings 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 R-4 zone BPA model we changed the extent of the GA model to the rectangular extent of an Uinta Basin township file that contained the R-4 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 r4_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.

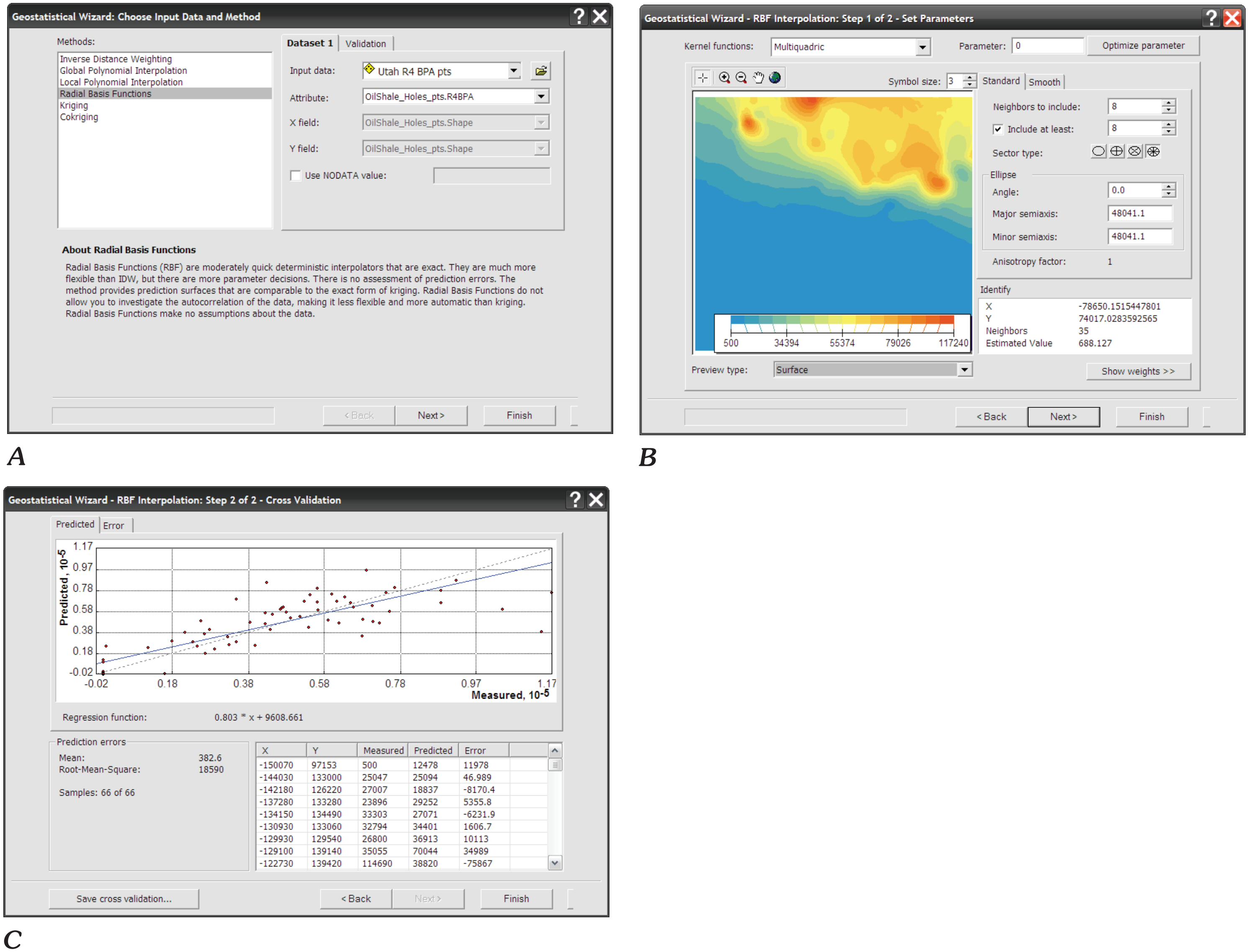

Figure 24. Image clips of the dialog windows used for creating the barrels per acre (BPA) GeoStatistical Analyst model in ArcGIS.

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 ESRIs 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 R-4 zone, the zone dataset (UTr6_to_r4_res) was a polygon feature class stored in a geodatabase created by intersecting the resource polygon for zones R-6 through R-4 with the township polygons. The Zonal Statistics function used the “label” 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 “label” field, the Zonal Statistics function counted all of the underlying cells in the BPA GRID and provided the sum total for each “label,” 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 r4_sum_twsp.dbf for the R-4 zone. We linked this table to the reporting polygons feature class by the “label” 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 Uinta Basin.

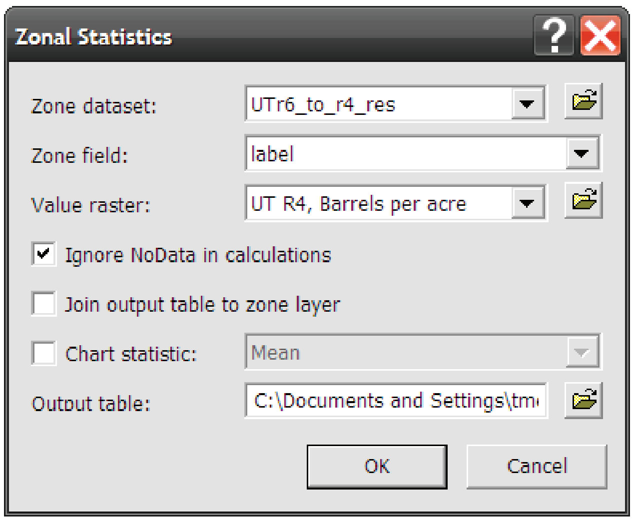

Figure 25. Image clip of the dialog window used to generate zonal statistics using ESRIs Spatial Analyst.

Appendix

Digital Files, Entity Relationship Diagram, and Data Dictionaries

Digital file—COPLATOS.mdb (Microsoft Access database)

Entity relationship diagram (fig. A1)
Data dictionaries (tables A1–A4)

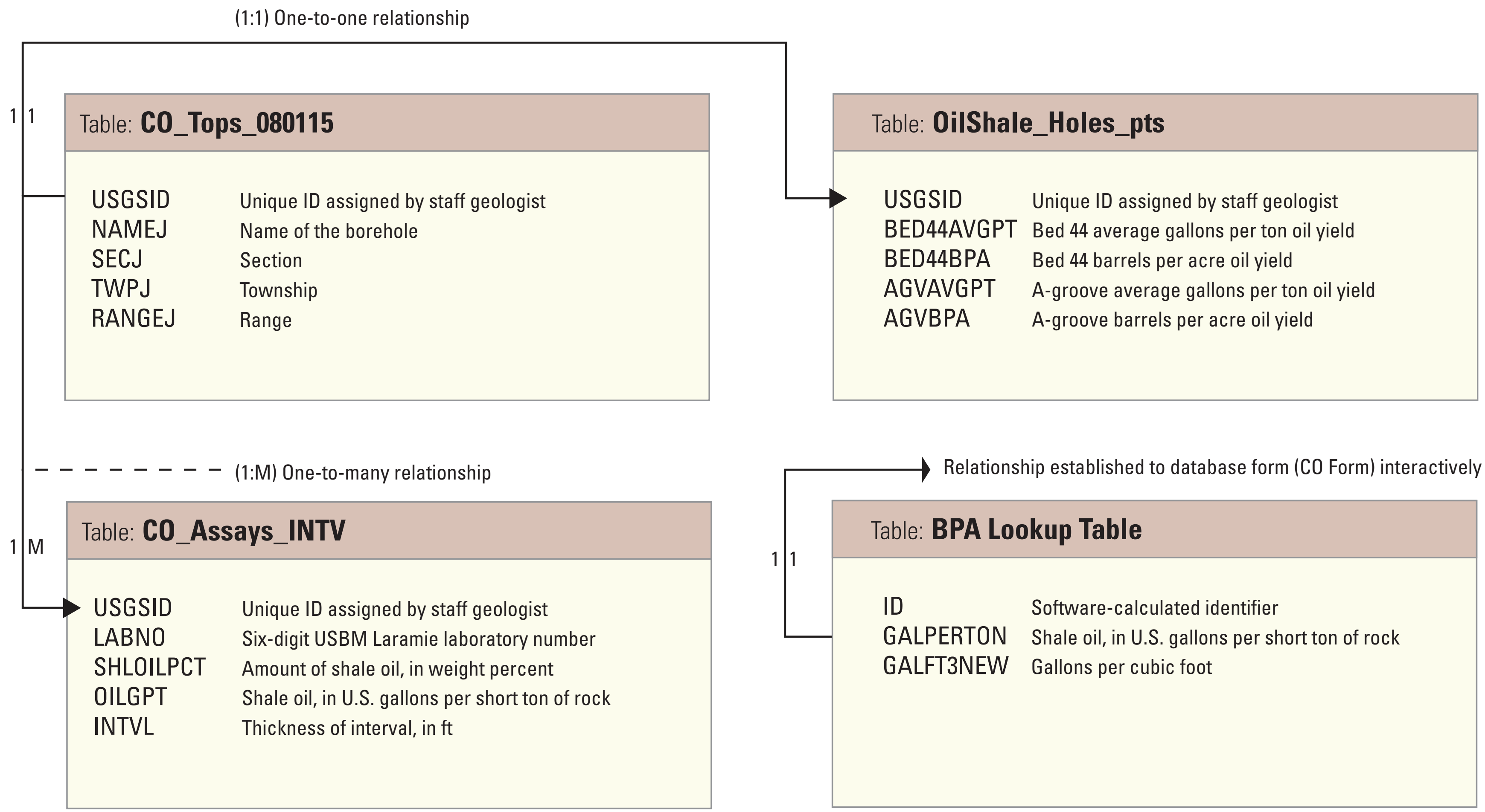

Figure A1. Entity relationship diagram (ERD) of the tables in the Microsoft Access 2007 database (COPLATOS.mdb) showing how the tables are linked in the calculations form (CO Form). The figure contains a partial listing of column names for illustrative purposes only.

Table A1. Column names and definitions of the Microsoft Access table CO_Tops_080115.

Column name	Column definition
(Note: all column names ending in "J" originated from J. Dyni's original tops file)	
ID	Software-calculated identifier
USGSIDJ	Unique ID assigned by staff geologist
CMPNYPROJJ	Name of the company or agency that drilled the borehole
NAMEJ	Name of the borehole assigned by the company or agency that drilled it
EASTWESTJ	Distance, in ft, measured east or west from section line
NORSOUJ	Distance, in ft, measured north or south from section line
QQJ	Quarter-quarter section
RANGEJ	Range
SECJ	Section
TWPJ	Township
LATDDJ	Latitude, in decimal degrees, North American Datum 1927, original record
LONGDDJ	Longitude, in decimal degrees, North American Datum 1927, original record
LOCSRCJ	Source of the borehole location, usually from the Fischer assay file, geophysical log, lithologic log, or survey
COUNTYJ	Name of county in Utah or Colorado
ELEVFTJ	A borehole-reference elevation, such as ground surface, rotary bushing, or rotary table, from which down hole depths were measured
COREDINTVJ	Depths, in ft, of the sequence that was cored in the borehole
ELEVSRCJ	Source of elevation, usually from the Fischer assay file, geophysical log, lithologic log, topo or survey
TOTDEPTFTJ	Total depth of the borehole, in ft
QUADJ	Name of 7.5-minute USGS topographic map, borehole may or may not be shown on map
ARCHIVEDJ	Core archived, yes or no
YRDRILLEDJ	Year that the borehole was drilled
LOCCOREJ	Physical location of the core from core hole, for example, USGS Core Research Center
SHOWNMAPJ	Indicates whether the actual borehole location is shown on the topographic map
LITHFTJ	Top and bottom borehole depths, in ft, of sequence of core or rotary cuttings for which a lithologic log was prepared
PHOTOFTJ	Top and bottom borehole depths, in ft, of photographic record of drill core
ELECFTJ	Top and bottom depths, in ft, of electric log of borehole
GAMMAFTJ	Top and bottom depths, in ft, of gamma ray log of borehole
DENSFTJ	Top and bottom depths, in ft, of density log of borehole
SONICFTJ	Top and bottom depths, in ft, of sonic log of borehole
NEUTRONFTJ	Top and bottom depths, in ft, of neutron log of borehole
CALIPERFTJ	Top and bottom depths, in ft, of caliper log of borehole
RQDFTJ	Top and bottom borehole depths, in ft, of rock quality data log
TEMPFTJ	Top and bottom depths, in ft, of temperature log of borehole
OTHERLOGSJ	Top and bottom depths, in ft, of other geophysical logs
FISCHASSYJ	Top and bottom depths, in ft, of sequence analyzed by Fischer assays
LABJ	Name of laboratory where Fischer assays were performed
ALUMINAFTJ	Top and bottom depths, in ft, of sequence analyzed for alumina
NUMBASSYSJ	Number of Fischer assays that were made

Table A1. Column names and definitions of the Microsoft Access table CO_Tops_080115.—Continued

Column name	Column definition
USBMNUMBRJ	A number assigned to the report of Fischer assays made by the former U.S. Bureau of Mines
LOCATNOTEJ	Additional information, commonly used where there is a problem with the location
NAHCOLTFTJ	Top and bottom depths, in ft, of sequence analyzed for nahcolite
XRDFTJ	Top and bottom depths, in ft, of X-ray diffraction analyses made on samples from the borehole
ELEVNOTEJ	Additional information, commonly used where there is a problem with the elevation
MISCNOTEJ	Miscellaneous information, such as publications related to the borehole, and other data
REVISDATEJ	Date of last revision for original borehole data
NAME	Name of the borehole assigned by the company or agency that drilled it
TRSEC	Township, range, and section
EASTWEST	Distance, in ft, measured east or west from section line
NORSOU	Distance, in ft, measured north or south from section line
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
ELEVFT	A borehole reference elevation, such as ground surface, rotary bushing, or rotary table, from which down hole depths were measured
CHDH	Core hole or drill hole
ELEVDATUM	Elevation, in ft, for various reference surfaces including Kelly bushing, ground level, topographic map, and rotary table
USGSID	Unique ID assigned by staff geologist
JD76	Depth to top of Bed 76, in feet
JD74	Depth to top of Bed 74, in ft
JD72	Depth to top of Bed 72, in ft
JDTPPORCTF	Depth to top of Porcupine Creek tuff, in ft
JDBSPORCTF	Depth to base of Porcupine Creek tuff, in ft
JD70	Depth to top of Bed 70, in ft
JD68	Depth to top of Bed 68, in ft
JD67	Depth to top of Bed 67, in ft
JD66	Depth to top of Bed 66, in ft
JD64	Depth to top of Bed 64, in ft
JD62	Depth to top of Bed 62, in ft
JD60	Depth to top of Bed 60, in ft
JD58	Depth to top of Bed 58, in ft
JD56	Depth to top of Bed 56, in ft
JD54	Depth to top of Bed 54, in ft
JD52	Depth to top of Bed 52, in ft
JD50	Depth to top of Bed 50, in ft
JD48	Depth to top of Bed 48, in ft
JD46	Depth to top of Bed 46, in ft
JD44BIG3	Depth to top of Bed 44 of Big 3 oil shale beds, in ft
JD42BIG3	Depth to top of Bed 42 of Big 3 oil shale beds, in ft

Table A1. Column names and definitions of the Microsoft Access table CO_Tops_080115.—Continued

Column name	Column definition
JD40BIG3	Depth to top of Bed 40 of Big 3 oil shale beds, in ft
JD39	Depth to top of Bed 39, in ft
JD38STLWTR	Depth to top of Stillwater zone, in ft
JD37	Depth to top of Bed 37, in ft
JD36A	Depth to top of Bed 36A, in ft
JD36	Depth to top of Bed 36, in ft
JD34	Depth to top of Bed 34, in ft
JD32FRSENR	Depth to top of Bed 32 of the Four Senators, in ft
JD30	Depth to top of Bed 30 of the Four Senators, in ft
JD28FRSENR	Depth to top of Bed 28 of the Four Senators, in ft
JD26	Depth to top of Bed 26 of the Four Senators, in ft
JD25	Depth to top of Bed 25, in ft
JD24	Depth to top of Bed 24, in ft
JD22	Depth to top of Bed 22, in ft
JD21	Depth to top of Bed 21, in ft
JD20	Depth to top of Bed 20, in ft
JD18	Depth to top of Bed 18, in ft
JD16	Depth to top of Bed 16, in ft
JD14	Depth to top of Bed 14, in ft
OTPUPWAVY	Depth to top of Upper Wavy, in ft
OBSUPWAVY	Depth to base of Upper Wavy, in ft
JD12	Depth to top of Bed 12, in ft
JD10	Depth to top of Bed 10, in ft
JD08	Depth to top of Bed 8, in ft
JD06	Depth to top of Bed 6, in ft
JD04	Depth to top of Bed 4, in ft
JD02	Depth to top of Bed 2, in ft
JDAGROOV	Depth to top of A-groove, in ft
JDMAHOGZN	Depth to top of Mahogany zone, in ft
OMAHOGZN	Depth to top of Mahogany zone, in ft (space holder, not used in this assessment)
JDTPMAHOG	Depth to top of Mahogany bed (Donnell, USGS), in ft
OMAHOG	Depth to top of Mahogany bed (Johnson, USGS), in ft
JDBGROOV	Depth to top of B-groove, in ft
JDR6	Depth to top of R-6 zone, in ft
JDL5	Depth to top of L-5 zone, in ft
JDR5	Depth to top of R-5 zone, in ft
JDL4	Depth to top of L-4 zone, in ft
JDR4	Depth to top of R-4 zone, in ft
JDL3	Depth to top of L-3 zone, in ft
JDR3	Depth to top of R-3 zone, in ft
JDL2	Depth to top of L-2 zone, in ft
R2	Depth to top of R-2 zone, in ft
L1	Depth to top of L-1 zone, in ft

Table A1. Column names and definitions of the Microsoft Access table CO_Tops_080115.—Continued

Column name	Column definition
R1	Depth to top of R-1 zone, in ft
CLASTCR1TP	Depth to top of clastic wedge in R-1 zone, in ft
CLASTCR1BS	Depth to base of clastic wedge in R-1 zone, in ft
L0	Depth to top of L-0 zone, in ft
R0	Depth to top of R-0 zone, in ft
LPBS	Depth to base of Long Point, in ft
BMARKRTP	Depth to top of B Marker, in ft
BMARKRBS	Depth to base of B Marker, in ft (space holder, not used in this assessment)
CMARKRTP	Depth to top of C Marker, in ft
CMARKRBS	Depth to base of C Marker, in ft (space holder, not used in this assessment)
DMARKRTP	Depth to top of D Marker, in ft
DMARKRBS	Depth to base of D Marker, in ft (space holder, not used in this assessment)
FMARKR	Depth to top of F Marker, in ft
IMARKR	Depth to top of I Marker, in ft
TOPILES	Depth to top of Iles, in ft
TOPKMV	Depth to top of Kmv, in ft
TOPRLNS	Depth to top of Rollins, in ft
TOPCSGT	Depth to top of Castlegate, in ft
MHG2BGRV	Thickness of interval from the Mahogany bed to B-groove, in ft
MHGZN2BGRV	Thickness of interval from the Mahogany zone to B-groove, in ft
BGRV2R6	Thickness of interval from B-groove to the R-6 zone, in ft
R62L5	Thickness of interval from R-6 to the L-5 zone, in ft
L52R5	Thickness of interval from L-5 to the R-5 zone, in ft
R52L4	Thickness of interval from R-5 to the L-4 zone, in ft
L42R4	Thickness of interval from L-4 to the R-4 zone, in ft
R42L3	Thickness of interval from R-4 to the L-3 zone, in ft
L32R3	Thickness of interval from L-3 to the R-3 zone, in ft
R32L2	Thickness of interval from R-3 to the L-2 zone, in ft
L22R2	Thickness of interval from L-2 to the R-2 zone, in ft
R22L1	Thickness of interval from R-2 to the L-1 zone, in ft
L12R1	Thickness of interval from L-1 to the R-1 zone, in ft
R12L0	Thickness of interval from R-1 to the L-0 zone, in ft
L02R0	Thickness of interval from L-0 to the R-0 zone, in ft
R02LPBS	Thickness of interval from R-0 to the Long Point base, in ft
AGRV2MHGZN	Thickness of interval from A-groove to the Mahogany zone, in ft
B442AGRV	Thickness of interval from Bed 44 to A-groove, in ft
MGBS2R5	Thickness of interval from the Mahogany zone base to the R-5 zone, in ft
R52LPBS	Thickness of interval from R-5 to the Long Point base, in ft
JD762JD44	Thickness of interval from bed 76 to bed 44, in ft

Table A2. Column names and definitions of the Microsoft Access table CO_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 sandstone ("NO").

Table A3. 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. 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
BED76AVGPT	Bed 76 average gallons per ton oil yield
BED76AVMSIN	Bed 76 percent missing intervals from core, represented as a floating point value
BED76BPA	Bed 76 barrels per acre oil yield
BED44AVGPT	Bed 44 average gallons per ton oil yield
BED44AVMSIN	Bed 44 percent missing intervals from core, represented as a floating point value
BED44BPA	Bed 44 barrels per acre oil yield
AGVAVGPT	A-groove average gallons per ton oil yield
AGVAVMSIN	A-groove percent missing intervals from core, represented as a floating point value
AGVBPA	A-groove barrels per acre oil yield
MGZNAVGPT	Mahogany zone average gallons per ton oil yield
MGZNAVMSIN	Mahogany zone percent missing intervals from core, represented as a floating point value
MGZNBPA	Mahogany zone barrels per acre oil yield
BGVAVGPT	B-groove average gallons per ton oil yield
BGVAVMSIN	B-groove percent missing intervals from core, represented as a floating point value
BGVBPA	B-groove barrels per acre oil yield
R6AVGPT	R-6 average gallons per ton oil yield
R6AVMSIN	R-6 percent missing intervals from core, represented as a floating point value
R6BPA	R-6 barrels per acre oil yield
L5AVGPT	L-5 average gallons per ton oil yield
L5AVMSIN	L-5 percent missing intervals from core, represented as a floating point value
L5BPA	L-5 barrels per acre oil yield
R5AVGPT	R-5 average gallons per ton oil yield
R5AVMSIN	R-5 percent missing intervals from core, represented as a floating point value
R5BPA	R-5 barrels per acre oil yield
L4AVGPT	L-4 average gallons per ton oil yield
L4AVMSIN	L-4 percent missing intervals from core, represented as a floating point value
L4BPA	L-4 barrels per acre oil yield
R4AVGPT	R-4 average gallons per ton oil yield
R4AVMSIN	R-4 percent missing intervals from core, represented as a floating point value
R4BPA	R-4 barrels per acre oil yield
L3AVGPT	L-3 average gallons per ton oil yield
L3AVMSIN	L-3 percent missing intervals from core, represented as a floating point value
L3BPA	L-3 barrels per acre oil yield
R3AVGPT	R-3 average gallons per ton oil yield
R3AVMSIN	R-3 percent missing intervals from core, represented as a floating point value
R3BPA	R-3 barrels per acre oil yield
L2AVGPT	L-2 average gallons per ton oil yield
L2AVMSIN	L-2 percent missing intervals from core, represented as a floating point value
L2BPA	L-2 barrels per acre oil yield
R2AVGPT	R-2 average gallons per ton oil yield
R2AVMSIN	R-2 percent missing intervals from core, represented as a floating point value

Table A4. Column names and definitions of the Microsoft Access table OilShale_Holes_pts.—Continued

Column name	Column definition
R2BPA	R-2 barrels per acre oil yield
L1AVGPT	L-1 average gallons per ton oil yield
L1AVMSIN	L-1 percent missing intervals from core, represented as a floating point value
L1BPA	L-1 barrels per acre oil yield
R1AVGPT	R-1 average gallons per ton oil yield
R1AVMSIN	R-1 percent missing intervals from core, represented as a floating point value
R1BPA	R-1 barrels per acre oil yield
L0AVGPT	L-0 average gallons per ton oil yield
L0AVMSIN	L-0 percent missing intervals from core, represented as a floating point value
L0BPA	L-0 barrels per acre oil yield
R0AVGPT	R-0 average gallons per ton oil yield
R0AVMSIN	R-0 percent missing intervals from core, represented as a floating point value
R0BPA	R-0 barrels per acre oil yield
BD76MXMISS	Bed 76 maximum thickness of records missing from core
BD76CNTMISS	Bed 76 number of records missing from core
BD44MXMISS	Bed 44 maximum thickness of records missing from core
BD44CNTMISS	Bed 44 number of records missing from core
AGVMXMISS	A-groove maximum thickness of records missing from core
AGVCNTMISS	A-groove number of records missing from core
MGZNMXMISS	Mahogany zone maximum thickness of records missing from core
MGZNCNTMISS	Mahogany zone number of records missing from core
BGVMXMISS	B-groove maximum thickness of records missing from core
BGVCNTMISS	B-groove number of records missing from core
R6MXMISS	R-6 maximum thickness of records missing from core
R6CNTMISS	R-6 number of records missing from core
L5MXMISS	L-5 maximum thickness of records missing from core
L5CNTMISS	L-5 number of records missing from core
R5MXMISS	R-5 maximum thickness of records missing from core
R5CNTMISS	R-5 number of records missing from core
L4MXMISS	L-4 maximum thickness of records missing from core
L4CNTMISS	L-4 number of records missing from core
R4MXMISS	R-4 maximum thickness of records missing from core
R4CNTMISS	R-4 number of records missing from core
L3MXMISS	L-3 maximum thickness of records missing from core
L3CNTMISS	L-3 number of records missing from core
R3MXMISS	R-3 maximum thickness of records missing from core
R3CNTMISS	R-3 number of records missing from core
L2MXMISS	L-2 maximum thickness of records missing from core
L2CNTMISS	L-2 number of records missing from core
R2MXMISS	R-2 maximum thickness of records missing from core
R2CNTMISS	R-2 number of records missing from core
L1MXMISS	L-1 maximum thickness of records missing from core
L1CNTMISS	L-1 number of records missing from core

Table A4. Column names and definitions of the Microsoft Access table OilShale_Holes_pts.—Continued

Column name	Column definition
R1MXMISS	R-1 maximum thickness of records missing from core
R1CNTMISS	R-1 number of records missing from core
L0MXMISS	L-0 maximum thickness of records missing from core
L0CNTMISS	L-0 number of records missing from core
R0MXMISS	R-0 maximum thickness of records missing from core
R0CNTMISS	R-0 number of records missing from core

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