Chapter 1

An Assessment of In-Place Oil Shale Resources in the Green River Formation, Piceance Basin, Colorado



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Volume Title Page

By Ronald C. Johnson, Tracey J. Mercier, Michael E. Brownfield, Michael P. Pantea, and Jesse G. Self

Chapter 1 of 7

Oil Shale and Nahcolite Resources of the Piceance Basin, Colorado

By U.S. Geological Survey Oil Shale Assessment Team

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An Assessment of In-Place Oil Shale Resources in the Green River Formation, Piceance Basin, Colorado

By Ronald C. Johnson, Tracey J. Mercier, Michael E. Brownfield, Michael P. Pantea, and Jesse G. Self

Abstract

A comprehensive assessment of in-place oil, regardless of richness, in oil shales of the Green River Formation of the Piceance Basin of western Colorado is presented here. A considerable amount of oil-yield data was collected after the previous in-place assessment was published in 1989, and these data have been incorporated into this new assessment. About twice as many oil-yield data points (2,178 versus 1,083) were used in this assessment. Estimated total in-place oil in the Piceance Basin is about 1.5 trillion barrels, or about 50 percent larger than the previous in-place assessment of about one trillion barrels. Almost all of this increase is due to (1) new areas being assessed that had too little data to assess in the previous assessment, and (2) new intervals being assessed that were not assessed previously. Much of this previously unassessed resource is of low grade and is unlikely to be developed. The Radial Basis Function (RBF) extrapolation method was used to generate isopach maps, isoresource maps, and to calculate resources. The RBF method created more geologically reasonable models than kriging, and a comparison of the two methods using the same data points showed little difference in the results.

Introduction

This report presents an in-place assessment of the oil shale resources of the Green River Formation in the Piceance Basin of western Colorado (fig. 1). The Piceance Basin is one of three large structural and sedimentary basins that contain vast amounts of oil shale resources in the Green River Formation of Eocene age. The other two basins, the Uinta Basin of eastern Utah and westernmost Colorado, and the Greater Green River Basin of southwest Wyoming, northwestern Colorado, and northeastern Utah also contain large resources of oil shale in the Green River Formation (fig. 2), and these two basins will be assessed separately. The previous assessment of the Piceance Basin by the U.S. Geological Survey (USGS) estimated that there was about 1 trillion barrels of oil-in-place (Pitman and Johnson, 1978; Pitman, 1979; Pitman and others, 1989), based on Fischer assay results from coreholes drilled to evaluate oil shale, making it the largest known oil shale deposit in the world (Dyni, 2003).

The Fischer assay method is a standardized laboratory test for determining the oil yield from oil shale that has been almost universally used to determine oil yields for Green River Formation oil shales (Stanfield and Frost, 1949; ASTM, 1980). The Fischer assay standard method consists of heating a crushed and screened (-8 mesh (2.38-mm mesh) 100-gram sample in a small aluminum retort to 500° C at a rate of 12° C per minute and then held at that temperature for 40 minutes. The volatile vapors of shale oil, gas, and water pass through a condenser cooled with ice water (about 5° C) and collected in a graduated centrifuge tube. The oil and water are then separated by centrifuging and weighed. The quantities reported in the original sample are the weight percentages of shale oil, water, shale residue (contains carbon char), and "gas plus loss" (noncondensable gas yield) by difference. The specific gravity of the shale oil is measured and used to calculate the oil yield in gallons per ton (GPT).

The Fischer assay method does not determine the total amount of hydrocarbons in an oil shale sample and the method does not measure the amount or composition of the gases released during the heating of the sample. These gases—chiefly light hydrocarbons, hydrogen, and carbon dioxide—are reported as the "gas plus loss."

Fischer assay does not necessarily measure the maximum amount of oil that an oil shale can produce, and there are retorting methods that yield more than the Fischer assay yield (see Dyni, 2003, p. 196 for a discussion of methods to determine oil yields). However, the oil yields achieved by other technologies are typically reported as a percentage of the Fischer assay oil yield, and thus Fischer assay is still considered the standard by which other methods are compared.

Fischer assay analysis was done on cuttings from a significant number of rotary holes drilled for oil and gas in the basin. These analyses are quite old, mainly from the 1950s and 1960s, and were done to supplement the limited core hole data available at the time. There are many unresolved issues with the cuttings data, and no cuttings data were used in the assessment of Pitman and Johnson (1978), Pitman (1979), and Pitman and others (1989) or the assessment presented here.

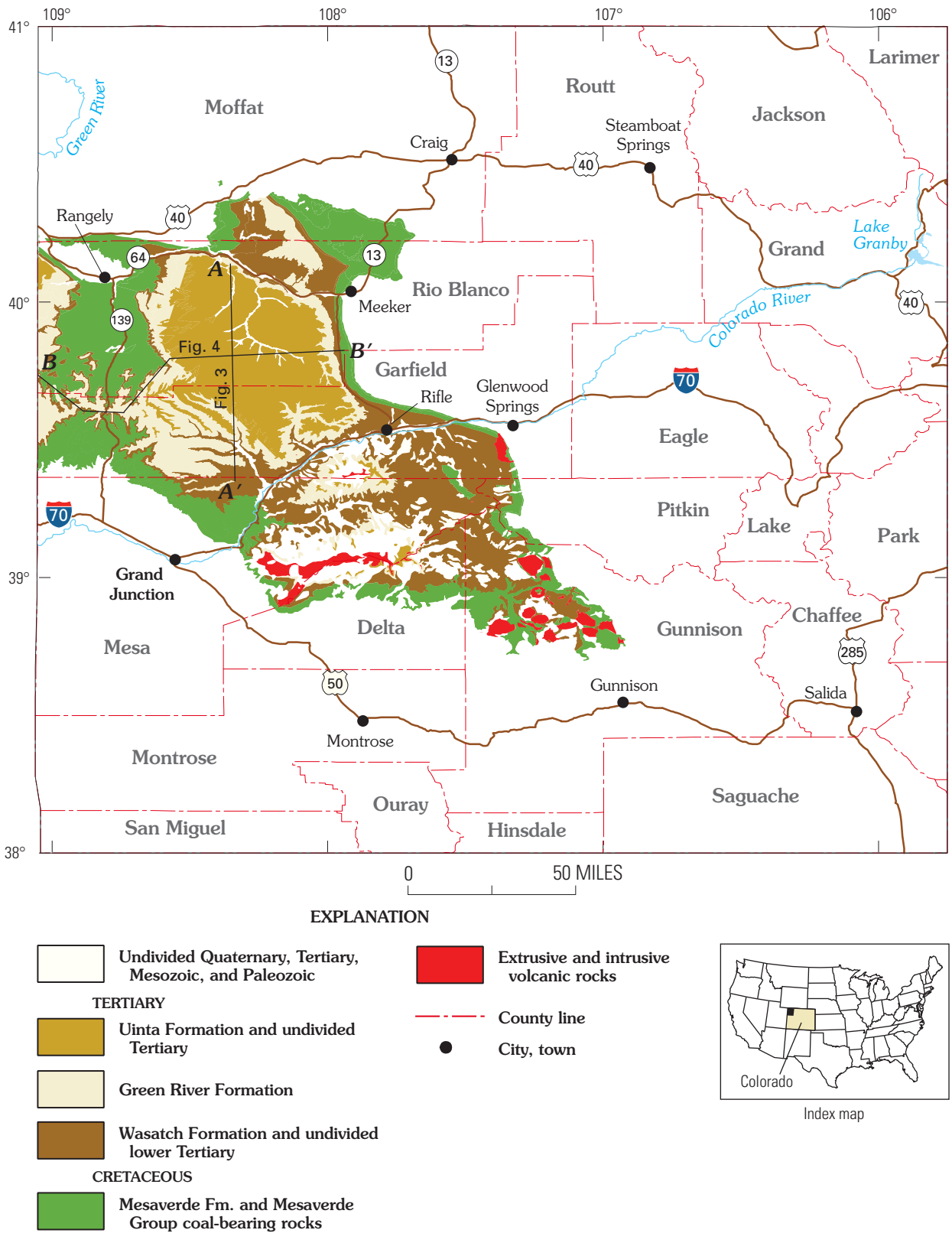


Figure 1. Geologic map of the Piceance Basin, northwest Colorado showing Upper Cretaceous and Lower Tertiary stratigraphic units. Locations of figures 3 and 4 are shown.

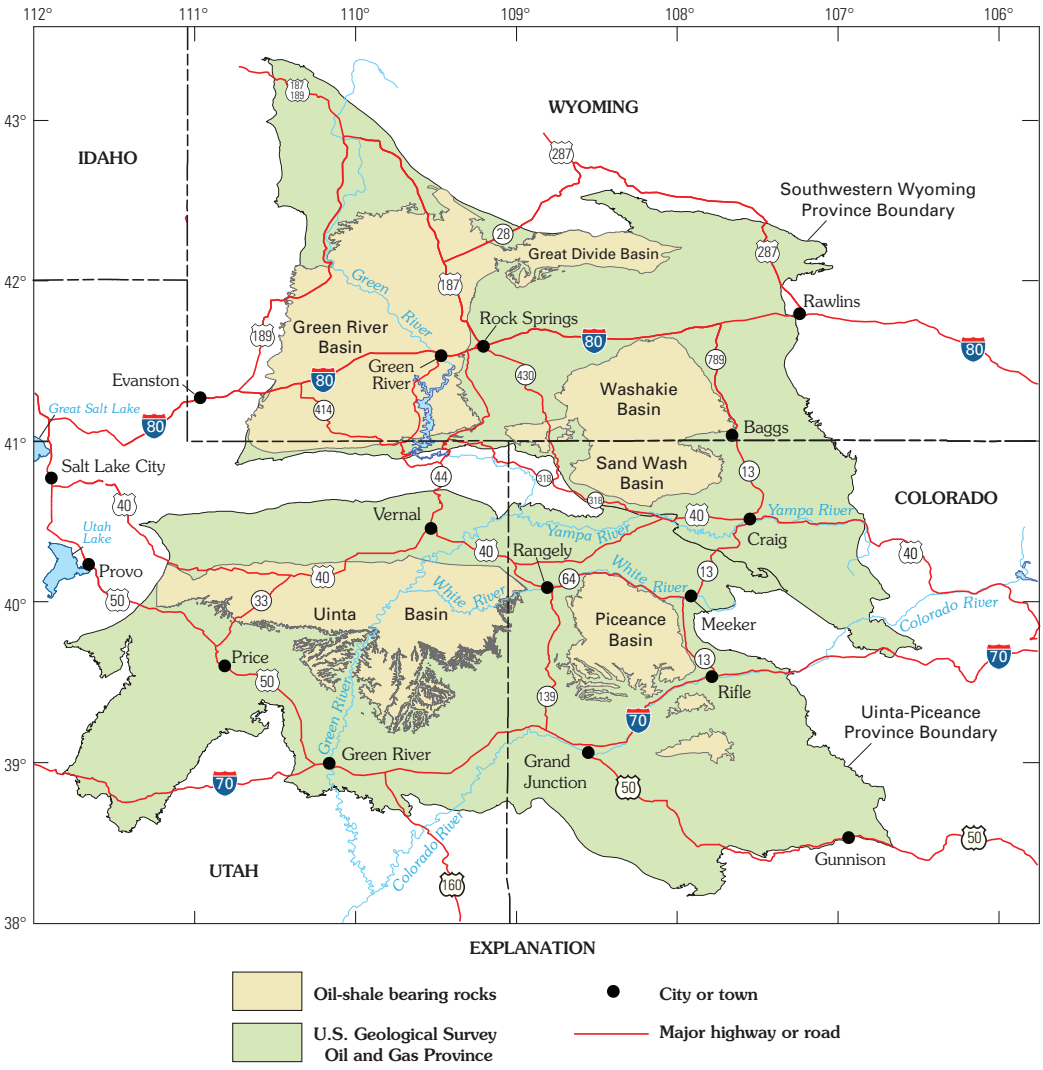


Figure 2. Map showing extent of Uinta and Piceance Basins and Greater Green River Basin, and approximate extent of oil shale in the Green River Formation. Extent of the Uinta and Piceance Basins is the same as the Uinta-Piceance Province boundary (Uinta and Piceance Assessment Team, 2003). Extent of the Greater Green River Basin is the same as the Southwest Wyoming Province boundary (Southwest Wyoming Province Assessment Team, 2005). For the extent of oil shale in the Piceance Basin, the base of the Parachute Creek Member as mapped by Tweto (1979) was used for all but the northwest part of the basin where the base of the lower member of the Green River Formation is used. For the extent of oil shale in the eastern part of the Uinta Basin, the base of the Parachute Creek Member of the Green River Formation as mapped by Cashion (1973) and Rowley and others (1985) was used. In the western part of the basin the top of the Mahogany bed, as mapped by Witkind (1995), was used. In the northern part of the Uinta Basin, only those areas where oil shale occurs at a depth of 6,000 ft or less are shown. This area was determined using a structure contour map of the top of the Mahogany oil shale bed compiled by Johnson and Roberts (2003). For the Sand Wash, Washakie, Great Divide, and southeastern part of the Green River Basin, the base of the Tipton Shale Member, as mapped by Tweto (1979) and Love and Christiansen (1985), was used as the extent of oil shale. For the western part of the Green River Basin, the base of the Wilkins Peak Member of the Green River Formation, and for the northern part of the Green River Basin, the base of the Laney Shale Member of the Green River Formation, as mapped by Love and Christiansen (1985), was used.

A considerable amount of oil-yield data was collected subsequent to this previous assessment, and these data have been incorporated into the present oil shale assessment. About twice as many data points (2,178 versus 1,083) were used in this assessment when compared with the previous one. Much of this additional data was donated by private industry after interest in developing oil shale waned in the 1980s. In addition, five oil shale intervals that were not included in the previous assessment are assessed here.

This effort has been hampered by difficulties in recovering the digital files that were used in the previous assessments by the USGS and the former U.S. Bureau of Mines (USBM). Much of the data that was used by the USGS was stored on outdated digital mediums that had either degraded to a point that they were no longer readable, or a suitable computer or software that could read the data could not be found. The USBM was disbanded in 1996, and the considerable amount of oil shale data stored on their computers is, at present, not accessible. In many cases, only computer printouts of the data remained that had to be scanned and tediously rectified.

The previous USGS assessment (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 could be traced across most of the basin (Cashion and Donnell, 1972), and each zone was assessed separately. We attempted to use the same set of rich and lean zones in order to make the two assessments comparable. Only a computer printout of part of the file listing the tops for these rich and lean zones in the drill holes that were used in the previous assessment was recovered, and this information was incorporated into our new digital tops file. In addition, a considerable amount of core hole information was collected subsequent to the previous assessment, and tops had to be picked for these additional holes. A series of stratigraphic cross sections was constructed to aid in this effort, and these are published separately (Self and others, chapter 5, this CD-ROM). Different workers in the past have used slightly different picks for the tops of some of the rich and lean zones. An attempt was made to use the same stratigraphic contacts for the rich and lean zones that were used in the previous USGS assessment, to make the two assessments as comparable as possible. In some isolated instances, we corrected minor errors in the tops file used in the previous assessment.

There have been considerable advances in computational power and computer programming since the last assessment was published, and this current assessment tries to take full advantage of these advancements. Pitman and others (1989) used geostatistical interpolation by kriging in part to generate their resource maps and resource numbers. Pitman and others (1989) found that kriging gave good results in areas with large numbers of control points but calculated unreasonable resource numbers with unreasonably large error limits in areas with little control, and they resorted to hand contouring and hand calculating resources in these areas. In this assessment we tried two extrapolation methods for spatial interpolation and extrapolation, the Radial Basis Function (RBF) method, and the Inverse Distance Weighted (IDW) method. Both methods gave similar results and we ultimately decided that the RBF method produced the most geologically reasonable results. The RBF method has been shown to give comparable results to those from kriging (Rusu and Rusu, 2006). We also compared the results using the RBF method with those from kriging for the same set of data points used in the previous assessment and found that the two methods calculated similar resource numbers.

The area underlain by Green River Formation oil shale occupies only a very small portion of the north-central part of the Piceance Basin structural and sedimentary basin (fig. 2). The isopach maps and assessment maps generated for this assessment cover only that portion of the Piceance structural and sedimentary basin that is underlain by Green River oil shale excluding Grand Mesa (fig.2). The oil shale resources on Grand Mesa are limited and were not assessed here. When describing the various oil shale zones, we will be referring to only that part of the Piceance structural and sedimentary basin that is underlain by Green River oil shale. For instance, if we refer to the depocenter in the north-central part of the basin we are referring to the north-central part of the overall Piceance structural and sedimentary basin that is underlain by Green River oil shale.

Additional core data acquired since the previous assessment helped considerably with this present assessment, but there was still insufficient core data in many marginal areas of the basin to establish oil-shale-richness trends. A large number of surface stratigraphic sections have been measured and described in detail in these marginal areas in the past (for example, see Johnson and others, 1988), and a reasonably good idea of how oil shale richness varies in these marginal areas was obtained from these sections. Much of this surface information was published after the previous assessment and was not used in that assessment. In addition, a number of previously unpublished surface sections, described by the authors, were included in this assessment. These sections are included in another publication on this CD-ROM (Self and others, chapter 5).

All of the Fischer assay data, corehole-location data, and oil shale zone tops file have been assembled into one Access database (see Mercier and others, chapter 3, this CD-ROM). Due to the number of data records (approximately one-half million) and the complexity of the spatial data involved in the assessment, Microsoft Access database management software and ESRI ArcGIS software were used to combine, store, and analyze the raw data. The ability to create custom forms in Access was a crucial element in the assessment methodology as it allowed staff to write Visual Basic scripts and SQL statements to filter subsets of the data and perform the necessary calculations using Access form controls. The public benefits from this process as the original forms used to calculate resources also serve as the end-user interface to view the raw data in a more simplified and meaningful manner. After resources were calculated for each core hole, the resultant Access tables were linked seamlessly with ESRI ArcGIS

software to model, extrapolate, and quantify the data spatially. The end product is a large database of tables (spreadsheets), forms to view the data, and a series of maps quantifying the results of those calculations. A complete description of how to use this database is presented in Mercier (chapter 3, this CD-ROM).

This assessment does not attempt to estimate the amount of oil that is economically recoverable, largely because there has not been an economic method developed to recover oil from Green River oil shale. In a recent report published by the RAND Corp. concerning the prospects for oil shale development in the United States, Bartis and others (2005, p. 5) state that: "Usually, estimates of recoverable resources are based on an analysis of the portion of the resources in place that can be economically exploited with available technology. Because oil shale production has not been profitable in the United States, such estimates do not yield useful information. Instead, calculations of recoverable resources have generally been based on rough estimates of the fraction of the resources in place that can be accessed and recovered, considering mining methods and processing losses."

Previous estimates of the amount of oil shale that is technically recoverable without considering economics are 45 percent (Taylor, 1987) and 55 to 75 percent (Prien, 1974) of the oil in place using room-and-pillar mining methods, whereas estimates of technically recoverable resource using open-pit mining are as much as 80 percent of the oil in place (Taylor, 1987). At present, there are no estimates of the percent of the resource that could be recovered using the in-situ methods that are currently being developed, however, Taylor (1987) stressed that the amount of oil that can be recovered from any in-situ process depends on both the percent of oil that can be recovered from within the retort and the amount of oil left behind in the areas between retorts. There are currently no estimates of the percent of in-place oil that can be recovered using in-situ methods currently being developed.

Although we cannot estimate recoverable shale oil at this time, one of our goals here is to lay the groundwork so that estimates of economically recoverable shale oil can be made in the future once suitable extraction methods are developed. For instance, Mercier (chapter 6, this CD-ROM) calculates cubic meters of overburden on the Mahogany oil shale zone throughout the basin. These calculations can be compared with estimates of in-place oil to generate "strip ratio" maps for strip mining the oil shale. Brownfield and others (chapter 2, this CD-ROM) estimates the in-place nahcolite resource in the basin, and for the first time, breaks down the resources into discrete zones. The presence of nahcolite (sodium bicarbonate) is a major concern for in-situ oil shale processes, because it breaks down to sodium carbonate (natrite) and carbon dioxide at temperatures from about 120° C to 350° C, depending on the fugacity of carbon dioxide, or significantly below retort temperatures. Nahcolite is considered a leasable mineral thus must be recovered either by solution mining prior to retorting or by solution mining the natrite after retorting and recombining it with carbon dioxide to again produce nacholite.

Acknowledgments

The authors would like to thank Jim Otton of the U.S. Geological Survey and Jerry Boak of the Colorado School of Mines for their many thoughtful and helpful comments. The authors would also like to acknowledge the tireless and mostly thankless work by Jack Dyni and John Donnell over the past 25 years to preserve oil shale data for the Eocene Green River Formation during a period when there was little to no interest in developing the oil shale resources in the United States. This assessment would not have been possible without their efforts.

Previous Assessments

Winchester (1916) published the first estimate of oil in the Green River Formation in the Piceance Basin, and he estimated that the basin could produce about 20 billion barrels of oil. After further study, Winchester (1928, p. 13) increased his estimate to 79.6 billion barrels of oil with 47.6 billion barrels "recoverable." Until recently, it was believed that mining and surface retorting of oil shale would be the predominant method of extraction, thus there were many attempts to separate out that part of the resource that could be potentially mined by eliminating intervals that were too lean to be mined. Only oil shale that exceeded minimum cutoffs, such as 15 ft of 15 gallons per ton (GPT) was assessed. The USGS in 1951 estimated that the Piceance basin contained 750 billion barrels of oil-in-place in shale yielding 15 gallons per ton (GPT) or greater (U.S. Congress, Senate Committee on Interior and Insular Affairs, 1951). Donnell (1961) divided the oil shale resources of the Piceance Basin into "indicated" and "inferred," with indicated resources generally occurring within 6 miles of a core hole and inferred resources occurring at greater than 6 miles from a core hole. Donnell (1961) estimated total in-place oil averaging 15 GPT or more in continuous sequences of 15 ft or more thick was 292.2 billion barrels of indicated and 666.9 billion barrels of inferred resource for a total of 959.1 billion barrels. Pitman and Donnell (1973) assessed an interval in the uppermost part of the oil shale interval, above the Mahogany zone, and estimated that it contained 128.5 billion barrels of oil-in-place. Duncan and Swanson (1965) and Donnell (1979) both estimated that the Piceance Basin contained about 1.1 trillion barrels of oil-in-place in sequences averaging 15 GPT or greater. Smith (1980) estimated about 1.0 trillion barrels of total resource. Pitman and others (1989) estimated the in-place resources, including all grades of oil shale of 1,008 billion barrels.

Several resource estimates have been made of just the Mahogany zone. The Mahogany zone has received considerable attention because it is one of the richest oil shale zones in the basin, and because it crops out around the margins of the basin where it can easily be mined. Donnell (1961) estimated that oil shale "in and adjacent to the Mahogany zone" contained indicated reserves of 6.8 billion

barrels and another 0.7 billion barrels of inferred reserves in sequences averaging 45 GPT in a continuous section and 5 ft or more thick. Using an average of 30 GPT in an interval 25 ft thick or greater, Donnell (1961) estimated that there were 36.8 billion barrels of indicated reserves and 54.7 billion barrels of inferred reserves. Using a 25 GPT and 15 ft cutoff, he estimated that there were 55.2 billion barrels of indicated reserves and 99.2 billion barrels of inferred reserves. Donnell and Blair (1970) estimated 164 billion barrels of oil in the Mahogany in intervals 10 ft thick or greater with an average yield of 15 GPT or greater. Pitman and Johnson (1978) estimated total resources in the Mahogany, regardless of grade, at 173 billion barrels, while Pitman and others (1989) estimated 178 billion barrels regardless of grade.

Computer programs written in FORTRAN were constructed in the 1970s and 1980s to calculate gallons per ton and barrels per acre (BPA) from Fischer assay analysis for any specified interval in a core hole. Although it was seldom stated, it is believed that these programs were used in most if not all the assessments made during that period. In addition, some of these programs included special algorithms to identify the longest sequence in an assayed core or section that maintained a specified average yield of oil in GPT. This was done to identify specific intervals thick enough and rich enough to be potentially mined. The algorithm could be used, for example, to determine the total amount of oil in intervals averaging at least 15 ft thick and 15 GPT or averaging at least 25 ft thick and 25 GPT. The algorithm also could exclude too much low-grade oil shale in these intervals. For example, intervals that average less than 10 GPT and were greater than 10 ft thick could be excluded.

Recent evaluation of the software by the authors has revealed some problems, the most significant being that the software will not function if zero values for oil yields are present in the Fischer assay tables. There are typically many missing core intervals in oil shale core holes, and these are listed in the Fischer assay tables as zero values for oil yields. Although it was never stated in any of the previous assessments, oil-yield values had to be assigned to all the missing intervals in order to make the FORTRAN programs function. It is unclear how values were assigned to all of the missing intervals, and it is possible that no consistent method was used. According to Janet Pitman (written commun., 2008) a missing interval was assigned the average of the oil-yield values of the intervals immediately above and below the missing interval. John R. Donnell (oral commun., 2008) recalls that values were assigned to missing intervals by comparing with nearby core holes where the intervals were not missing. We recovered a large number of computer printouts of oil-yield histograms that appear to date from the period when the last assessment was made and found examples of each. However, because the original files from the last assessment were not recovered, we are unable to ascertain which method of handling missing intervals was ultimately used.

Making estimates of thicknesses of oil shale that fit a set of criteria may not have the importance that it once had. Such estimates are a critical first step to determining the amount of oil shale that can be economically mined in underground or open-pit mines under various scenarios. But such estimates are less important for in-situ processes of retorting oil shale, the favored method being considered today, as all oil shale in a thick column would be heated and retorted regardless of grade.

Stratigraphy of the Green River Formation and Definition of the Rich and Lean Zones that Comprise the Oil Shale Section

The rich oil shale interval in the Green River Formation of the Piceance Basin was deposited in Eocene Lake Uinta, a large, internally drained lake that extended across both the Piceance Basin and the Uinta Basin to the west. The Green River Formation oil shales of the Greater Green River Basin (fig. 2) were deposited in a separate but largely contemporaneous lake, Lake Gosiute. Lake Uinta, which started out as a fresh or near freshwater lake, became increasingly saline through time and ultimately vast quantities of the potentially valuable sodium bicarbonate mineral nahcolite ($NaHCO_3$) and halite were deposited during periods when the lake receded into a comparatively small area in the middle of the Piceance Basin. The nahcolite deposits in the Piceance Basin are assessed in another report in this CD-ROM (Brownfield and others, chapter 2). Nahcolite is used as a raw material in the manufacture of a variety of basic industrial chemicals and to remove sulfur dioxide from power-plant emissions, and it is presently being solution mined in the basin. Dawsonite, a hydrated aluminum carbonate mineral ($NaAl(OH)_2CO_3$), which can be used as a source of aluminum, also occurs in vast quantities in the middle of the basin. These nahcolite and dawsonite deposits are disseminated in and interbedded with some of the richest oil shale deposits in the basin, and in the 1970s and 1980s, plans to exploit the oil shale resources of the saline depocenter of the Piceance Basin commonly included plans to recover the nahcolite and dawsonite resources as well (see for example, Nielson, 1969; Beard and others, 1974).

Several members of the Green River Formation are recognized, although the member designations have not always been applied the same way by all workers (figs. 3 and 4). In the oil shale section deposited in the offshore areas of the lake, the name Garden Gulch Member is generally applied to the illitic oil shales that were deposited in the early history of Lake Uinta, and the name Parachute Creek Member is applied to the dolomitic oil shales deposited later. The name Douglas Creek Member is applied to marginal lacustrine rocks along the west and southwest margins, and the name Anvil Points Member is applied to marginal lacustrine rocks along the east and southeast margins of the Piceance Basin. The names Garden Gulch Member, Parachute Creek Member, and Douglas Creek Member were first used by Bradley (1931),

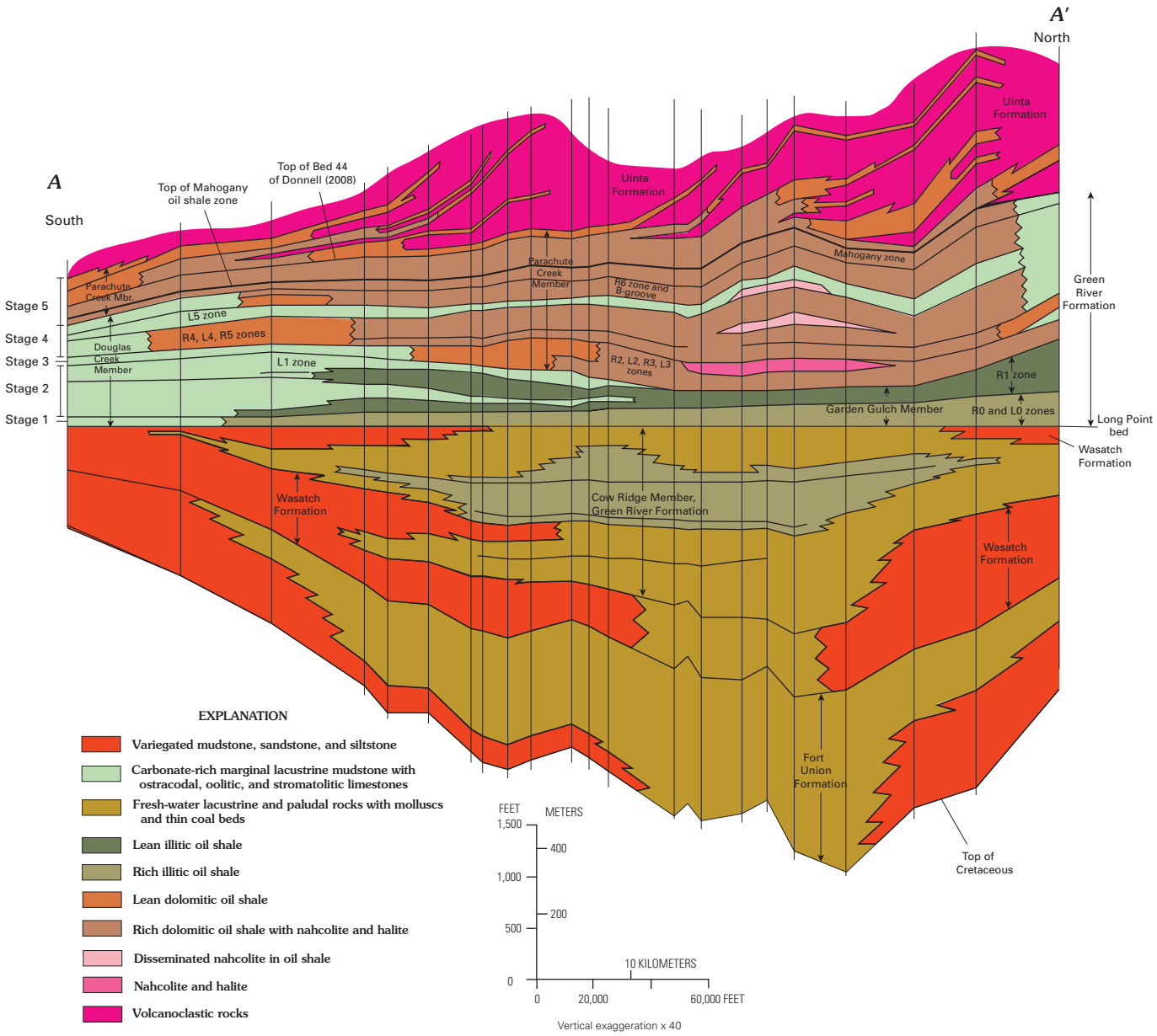


Figure 3. North-south cross section through the Piceance Basin, northwest Colorado showing member subdivisions, stages of Lake Uinta as defined by Johnson (1985), and some of the rich and lean zones defined by Cashion and Donnell (1972).

whereas Donnell (1953) was the first to use the name Anvil Points Member. The name Uinta Formation is applied to a sequence of sandstones and siltstones containing abundant volcanic debris that interfinger with the upper part of the Green River Formation (Cashion and Donnell, 1974).

Johnson (1985) subdivided the history of Lake Uinta into five roughly time-stratigraphic periods or stages with the change from one stage to the next corresponding to a significant change in conditions in the lake (figs. 3 and 4). The first two stages are generally equivalent to the Garden Gulch Member, and the last three are generally equivalent to the Parachute Creek Member. The beginning of stage 1 is marked by the initial transgression of Lake Uinta, the Long Point transgression that caused two comparatively small freshwater lakes, one in the Piceance Basin and one in the Uinta Basin to form one large lake that spanned across the intervening Douglas Creek arch. The illitic-rich oil shales from this stage deposited in the offshore areas of the lake generally average less than 15 GPT, and because of their great depth and low grade, there has been little interest in their development.

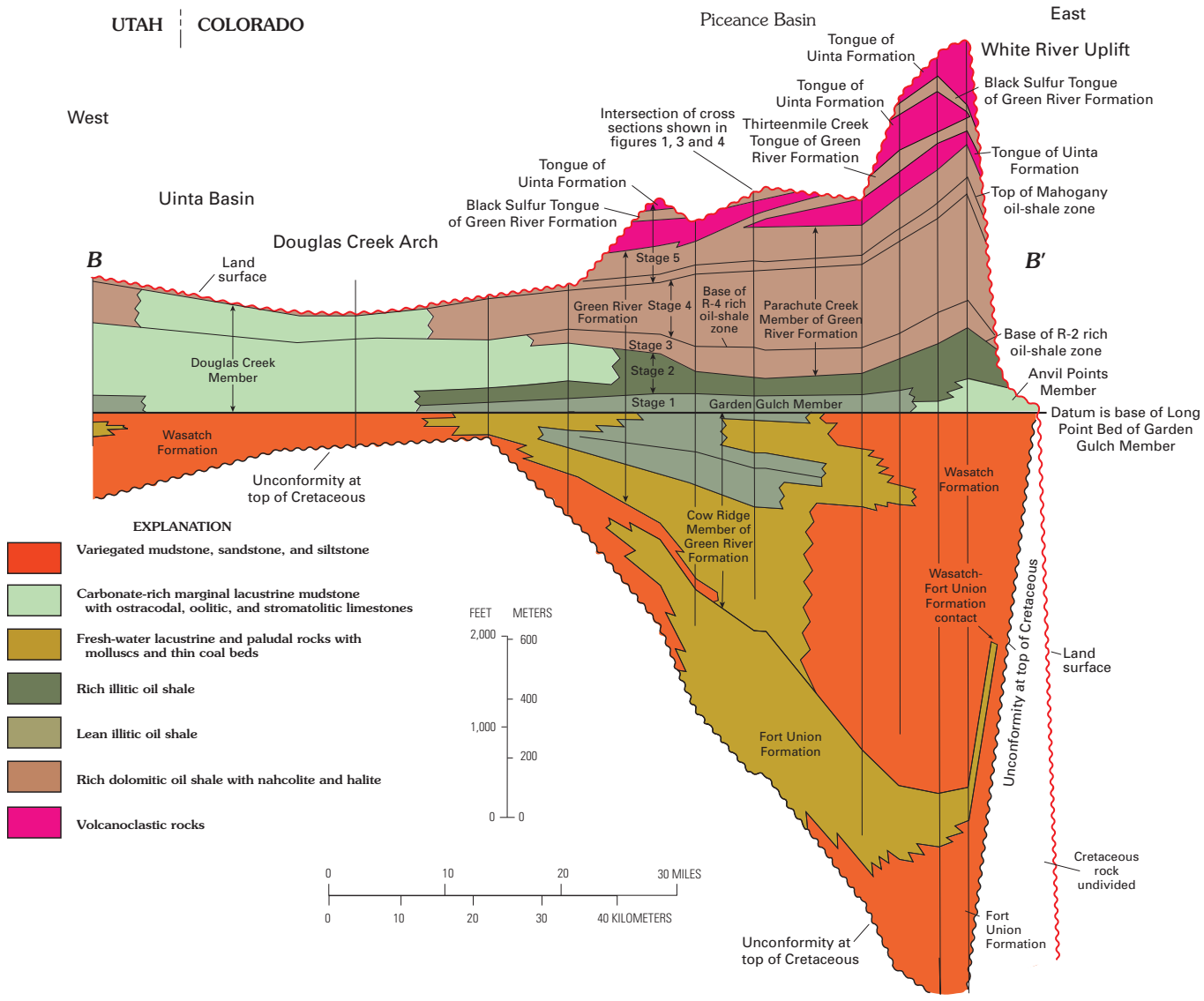


Figure 4. East-west cross section through the Piceance Basin, the Douglas Creek arch, and the eastern part of the Uinta Basin showing member subdivisions, stages of Lake Uinta as defined by Johnson (1985), and some of the rich and lean zones defined by Cashion and Donnell (1972).

Average oil yield increases abruptly at the beginning of the second stage, to a maximum of about 27 GPT averaged for the entire interval in the central part of the Piceance Basin, with thin beds averaging nearly 60 GPT. There has been some interest recently in exploiting these shales using an in-situ method.

A gradual shift from illitic-rich to carbonate-rich oil shales occurred at the beginning of the third stage, and for the first time nahcolite was deposited near the center of the lake. Nahcolite occurs disseminated in oil shale, as aggregates, and as beds (Dyni, 1974; 1981). Bedded nahcolite grades laterally into halite beds towards the middle of the saline depocenter. All oil shales deposited after the beginning of stage 3 are carbonate-rich with dolomite being the dominant carbonate (Robb and Smith, 1974). The fourth and fifth stages are marked by expansions of Lake Uinta. The fourth stage began with a relatively minor transgression that may have been caused by increased outflow from Lake Gosiute in the Greater Green River Basin into Lake Uinta (Johnson, 1985; 2007). The transgression at the start of the fifth stage was almost certainly related to increased outflow from Lake Gosuite, as volcaniclastic sediments thought to be derived from the Absaroka volcanic field in northwest Wyoming reached the north margin of Lake Uinta shortly after maximum transgression (Surdam and Stanley, 1980). The Mahogany zone (Mahogany ledge where exposed) was deposited during the early part of the fifth stage. These volcaniclastic sediments

could only have reached Lake Uinta once Lake Gosiute was largely filled in, as prior to its infilling, Lake Gosiute would have acted as a sediment sink. The volcaniclastic sediments gradually filled in the Piceance Basin part of Lake Uinta thus ending oil shale deposition (Johnson, 1985).

Individual oil shale units in the Piceance Basin can be traced great distances. Bradley (1931) traced the Mahogany ledge throughout most of the Piceance and Uinta Basins (fig. 5). In general, the oil shales are well bedded and on a small scale display fine laminations or "varves" (fig. 6) that have been attributed by many workers to seasonal variations in amount of organic matter and mineral matter raining down and settling on the bottom of the lake (see for example: Bradley, 1929). Cashion and Donnell (1972) recognized that the entire Parachute Creek Member and Garden Gulch Member could be subdivided into a sequence of oil-rich zones (R-zones) and oil-lean zones (L-zones) that could be recognized throughout much of the central part of the Piceance Basin and eastern part of the Uinta Basin (fig. 7). These zones appear to roughly form time-stratigraphic units representing changing rates of organic matter production and preservation that occurred simultaneously throughout Lake Uinta. The rich- and lean-zone stratigraphy formed the basis of the previous USGS assessment with in-place resources in each of the zones being assessed separately (Pitman and Johnson, 1978; Pitman, 1979; and Pitman and others, 1989). The lower zones, from the L-0 zone through the L-1 zone are clay rich and contain little carbonate, and comprise the Garden Gulch Member. All zones above the L-1 zone are dolomitic and comprise the Parachute Creek Member. On a finer scale many individual rich and lean beds within each rich and lean zone can be traced for great distances as well. Donnell (2008) traced individual oil shale beds above the Mahogany zone across large areas of the Piceance and Uinta Basins, and many beds within and below the Mahogany zone can also be traced for great distances.

All of these oil shale zones grade into marginal lacustrine rocks towards the margins of the basin. Johnson and others (1988) were able to trace many of the oil shale zones into marginal lacustrine equivalents around the west and southwest margins of the basin. Many of the oil shale zones have been subsequently traced into marginal lacustrine equivalents along the northern and eastern margins of the basin as well (Self and others, chapter 5, this CD-ROM). One of the biggest issues with the previous resource assessment (Pitman and others, 1989) was that oil-shale-richness trends were poorly constrained around the basin margins leading to poor results in these areas. Tracing rich and lean zones into marginal lacustrine equivalents allowed us to better constrain richness trends towards the margins of the basin leading to better estimates of oil shale richness in these areas.

The distinctive vertical pattern of rich and lean beds and rich and lean zones breaks down somewhat in the saline depocenter, making exact correlation more difficult. Here a rich bed can be present in one core hole and seemingly absent in another core hole nearby, and the overall patterns of rich and lean beds used elsewhere to define the zones is somewhat muted. Part of the problem is that the diameter of the core may be too small to obtain a representative sample in the saline interval where nahcolite aggregates as much as 40 cm across (fig. 8) are scattered throughout much of the section (Dyni, 1981, p. 30). Another problem is that many of the thick beds of nahcolite and halite that were once present in the saline depocenter have been leached out by relatively recent groundwater activity causing widespread collapse and rubblization. The exact vertical and lateral extent of the saline zone prior to leaching is not known. There are no saline minerals or persistent breccias preserved today above the lower part of the L-5 zone (fig. 7), indicating that thick beds of nahcolite and halite may never have been present in that interval (Dyni, 1974). There are, however, vugs that were presumably once filled with saline minerals in this interval (Trudell and others, 1970; Pipiringos and Johnson, 1976).

A major cause of correlation problems near the depocenter of the lake is mass-movement processes prior to lithification. Evidence for this mass movement includes contorted "breccias" or "blebby" oil shale (Bradley, 1931; Dyni, 1981: Dyni and Hawkins, 1981) (fig. 9) and disrupted bedding (fig. 10). Brecciated or "blebbly" oil shale beds from a few centimenters to 11-m thick have been described (Dyni, 1981). They consist of organically lean marlstone clasts floating in a darker organic-rich matrix (fig. 9). Typically, these blebby oil shales are higher in kerogen content than laminated marlstones (Bradley, 1931; Dyni, 1981), suggesting that high amounts of organic matter contributed to instability in the lake sediments. Dyni (1981) and Dyni and Hawkins (1981) believed that the blebby oil shale beds were transported across the floor of the lake by turbidity currents and traced one of these beds over an area of 175 square km. Dyni and Hawkins (1981) estimated that as much as 50 percent of the oil shale deposited in the depocenter of the lake consists of the blebby type, suggesting that redistribution of the most organic-rich sediments in Lake Uinta occurred on a massive scale.

A significant interval of oil shale occurs above the Mahogany zone in about the southern half of the basin (fig. 3). Pitman and Donnell (1973) subdivided this interval into four oil shale units and estimated the in-place oil shale resources in gallons per ton and barrels per acre for each of the four units. Individual oil shale beds in this interval are extremely persistent and can be traced over great distances (Donnell, 2008). Towards the north this oil shale interval intertongues and grades into sandstones of the Uinta Formation, a sandy unit consisting largely of volcaniclastic sediments sourced by the Absaroka volcanic field in northwest Wyoming (Johnson, 1981a). Unlike the continuous oil shale section to the south, the intertonguing interval has been highly affected by mass-movement processes prior to lithification (Johnson, 1981a) (fig. 11), and correlation of individual oil shale beds is only rarely possible. One slump block covering several square kilometers was mapped by Johnson (1981b).

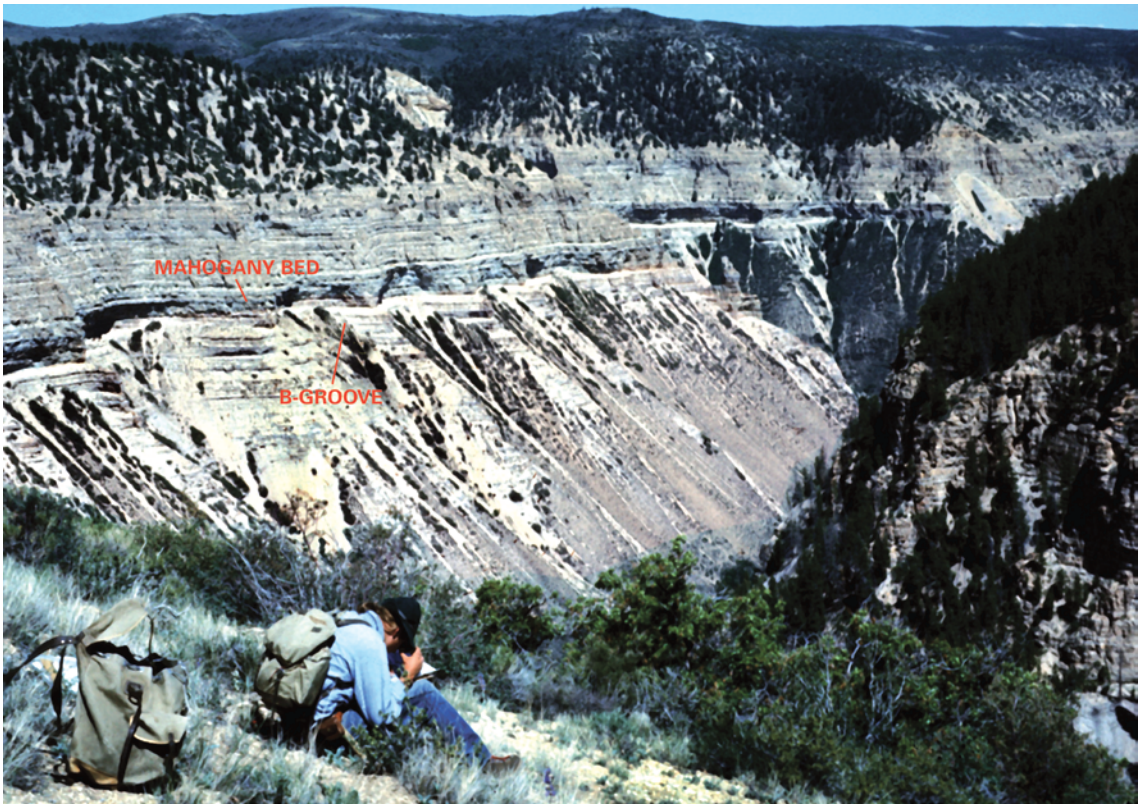


Figure 5. Outcrop of the Mahogany ledge in the south-central part of the Piceance Basin (sec. 16, T. 5 S., R. 98 W.). The Mahogany bed is the most persistent bed in the middle of the ledge. B-groove is the buff re-entrant at the base of the cliff.

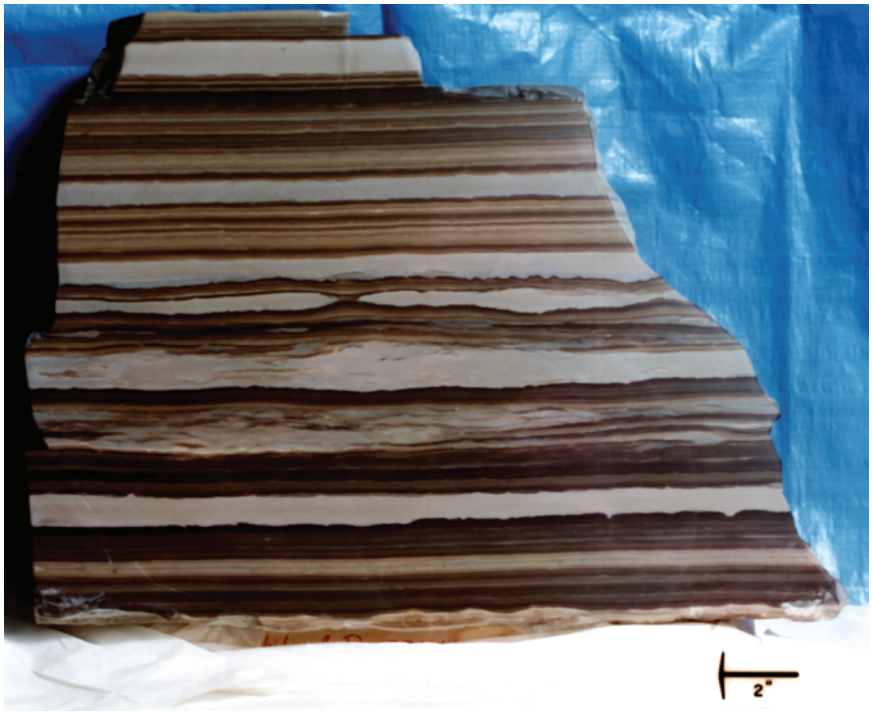
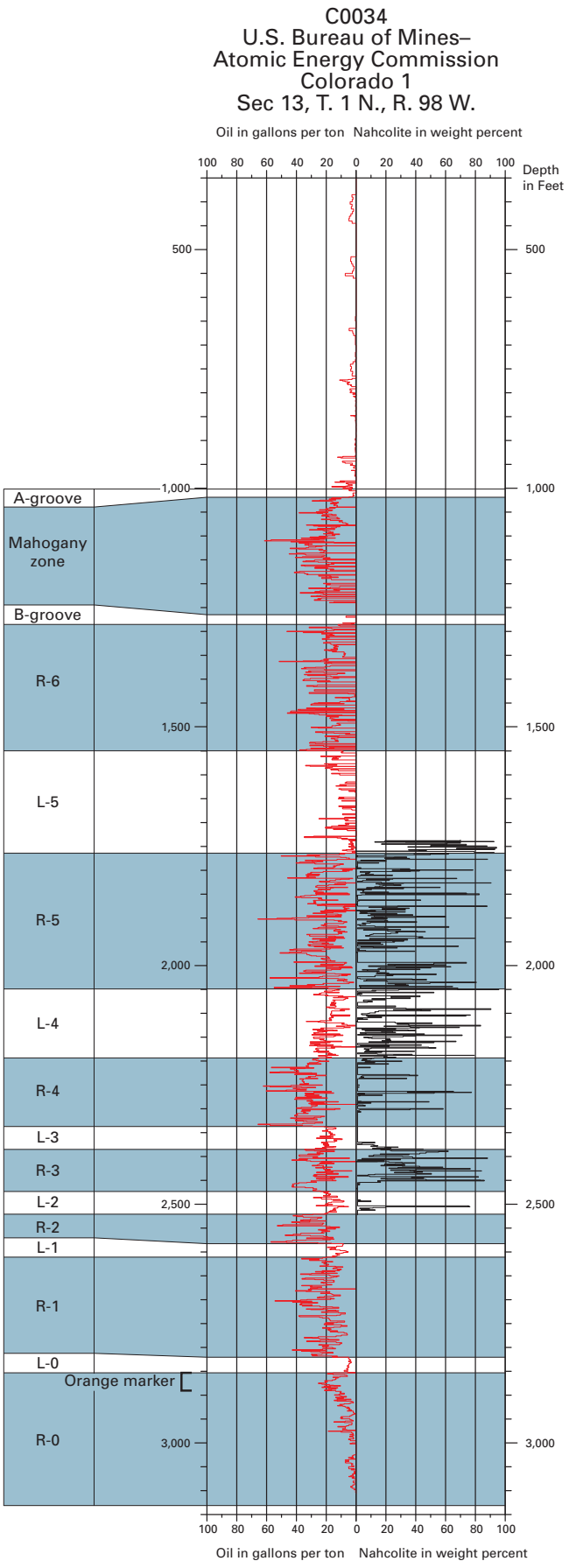


Figure 6. A typical sample of oil shale in the Parachute Creek Member displaying organic-rich layers (dark brown) and organic-lean layers (white).



Factors Affecting the Precision of Oil-Yield Measurements

Determining the Volume of Oil in a Given Volume of Rock

Determining gallons per ton from a Fischer assay is a straightforward calculation as the weight of the original sample is known and the volume of oil generated is known. Unfortunately, the density of the sample prior to retorting is not routinely measured, as this density must be known in order to calculate the amount of oil present in a prescribed interval over a prescribed area. Typically in-place oil in the Green River Formation is given in the rather arcane unit of barrels of oil per acre (BPA). The method used to convert GPT into BPA in the previous assessment (Pitman and others, 1989) was not discussed in their publication. An equation that computes BPA was recovered with the FORTRAN program that was used at the time of the previous assessment. The equation was isolated from the rest of the program, and it does seem to generate reasonable results. But there was no reference to where the equation came from and how the many constants used in the equation were generated, and thus we decided not to use it.

For this report, the determination of oil shale resource numbers in BPA for the Piceance Basin were generated from average GPT data from oil-yield Fischer assay analyses from core holes in the basin. Stanfield and others (1954) report summary data on volume-weight oil-yield relationships from about 20,500 USBM oil-yield analyses (table 1). Smith (1956) reported that oil-yield values were related to the specific gravity of the oil shale. Table 1 contains original values for oil yield, gallons per ton, as well as specific gravity, and was regenerated using

Figure 7. Rich and lean zones for the Green River Formation originally defined by Cashion and Donnell (1972) for the Piceance Basin, western Colorado and the Uinta Basin of eastern Utah and western Colorado. Graphs show oil in gallons per ton (red lines) and nahcolite in weight percent (black lines). The upper part of the R-0 zone is marked in the central part of the basin by a distinctive increase in resistivity on electric logs known informally as the orange marker, named for the color of pen used to mark it on geophysical logs (Chancellor and others, 1974; Ziemba, 1974). The orange marker, which comprises about the upper 30 ft of the R-0 zone, is caused by a slight increase in carbonate in the illitic sediments. The orange marker is equivalent to the carbonate marker in the Uinta Basin part of Lake Uinta, which also represents a temporary increase in carbonate precipitation (Johnson, 1989).



Figure 8. Nahcolite aggregates in rich oil shale, Piceance Basin, Colorado.

Microsoft Excel and values for weight of oil shale, volume of oil shale, and oil yield per unit volume were updated using currently accepted formulas (table 2). A third-order trendline with a R^2 value of 0.9998 was generated comparing oil yield versus specific gravity (fig. 12). As the original table contained only integer values for GPT, new records were inserted to fill in values to one decimal place (0.1 ft) creating a new look-up table. A linear trend series fill function in Microsoft Excel 2007 was then used to calculate specific-gravity values for each 0.1 ft value for the GPT column. A third-order trendline was then regenerated comparing 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 then calculated using the new values for oil yield and specific gravity. The final lookup table contained records for oil yield (GPT), specific gravity, and oil yield per unit volume for interval thicknesses from 1.0 to 80.0 ft.

Shale-oil-resource numbers in BPA were calculated using the formula: oil shale interval thickness * 43,560 (sq. ft/acre) *oil yield per unit volume (from the final look-up table, containing values on a 0.1 GPT basis /42 (gals/barrel of oil).

Broken Core and Missing Core Intervals

As previously discussed, oil-yield values were assigned to all of the missing intervals in order to make the FORTRAN program function. There are 15,805 missing intervals in the Fischer assay data file for the Piceance Basin, and because of time constraints, a simple method of dealing with these intervals had to be devised. The method used here simply calculates an average oil yield for all core recovered in a particular core hole for an oil shale zone in question, and that average is assigned to all the missing intervals in the zone. A brief discussion of some of the problems posed with missing intervals is presented here.

Core can be moderately to severely broken by the coring process itself, and a quantity of rubble is recovered instead of a complete core. The onsite geologist might decide that the rubble is more or less representative of the entire interval and spread the rubble out in the core boxes between whole pieces of recovered core. Because the rubble was largely homogenized, the original variation in oil yield through the interval is lost. In addition, it is possible that the recovered rubble is not representative of the average oil yield for the entire interval. For instance, leaner oil shale may be more



Figure 9. Outcrop of "blebby" oil shale displaying organically lean marlstone clasts in rich oil shale matrix. The sediment was transported laterally on the floor of Lake Uinta by mass-movement processes (NW ¼ sec. 16, T. 5 S., R. 98 W., approximately 200 ft below top of Mahogany ledge). Lens cap for scale.



Figure 10. Outcrop of oil shale displaying disrupted bedding due to movement of the floor of Lake Uinta prior to lithification (sec. 15, T. 6 S., R. 99 W., approximately 500 ft above top of Mahogany ledge). Pencil for scale.



Figure 11. Intertonguing of volcaniclastic sandstones of the Uinta Formation (brown) and marlstones of the Green River Formation (white). The sandstones underwent slumping on the floor of Lake Uinta prior to lithification (sec. 14, T. 3 S., R. 99 W).

prone to disintegration than rich oil shale resulting in the recovered rubble being skewed towards the richer oil shale in the interval. If the amount of rubble is small and the rubblized interval is quite long, the geologist might decide to assign the rubble to only part of the interval and assume that the rest of the interval is missing. In either case, oil-yield values obtained are compromised, and the distinctive pattern of rich and lean beds that characterize the oil shale zones in the Piceance Basin is lost for the core being studied.

The missing core problem also affects the isopach maps to some degree. When calculating GPT, we had to place the top of a rich or lean zone at the top or base of an actual assayed interval. For instance, if the top of the Mahogany zone occurs within a 30-ft missing interval, we had to place the contact at either the top or the base of the overlying or underlying assayed interval in order to construct the isopach maps and make the resource calculations. Thus, the uncertainty of each data point will be different depending on whether or not the contact of the rich or lean zone in question occurs within a thick missing interval. This problem would not only affect the uncertainty of points on the isopach maps but also the uncertainty of points on the resource maps, because the BPA maps were constructed by multiplying average GPT by the thickness of the zone. Thus if the thickness is off because there is a thick missing interval at the contact, then the point on the BPA map will be affected as well.

Figures 13–26 plot the percent missing interval in each oil shale zone in each core hole. The number of missing intervals (in red) and thickest single missing interval in each zone (in blue) is also shown. The percent missing intervals for individual oil shale zones range to as high as 62 percent. Clearly missing intervals are a major source of uncertainty in the precision of each data point.

A detailed analysis of 13 closely spaced core holes from a four-square-mile area in the northwest part of the basin (table 3, fig. 27) was undertaken to test the validity of applying the average of the recovered core to the missing intervals. The average oil yield for all oil shale zones from the L-0 zone through the Mahogany zone was plotted along with the percent of missing interval in figure 28. There are not enough data points for the R-0 zone to make a plot. Distance between the core holes needed to be kept to a minimum to limit the effect of regional variations in oil-yield values. Even though the core holes are closely spaced, there is still a noticeable decrease in oil yields towards the west across the study area. Average oil yields are lower overall in the two westernmost core holes in the study area, C261 and C265 (fig. 28). For most of the oil shale zones, this decrease is minimal, but it is significant in the L-3 oil shale zone, which decreases from 17.7 GPT in C283 in the eastern part of the study area to 9.5 GPT in C265 in the western part. With the exception of the L-3 zone, there is remarkably little correlation between the percentage of missing core and the average oil yield. For example, oil yields vary little for the Mahogany zone between the core holes despite the missing core totals varying from 0 to over 40 percent. One major concern was that richness of the oil shale affected the probability of it being preserved during coring. For instance, if rich beds were more likely to be preserved than lean beds, then the average oil yield for a zone should go up as the percentage of missing core increases. These results suggest that, in

Table 1. Original volume-weight oil-yield relationships of Green River Formation oil shale. From Stanfield and others (1954).

[GPT, gallons per ton; gm/cc, grams per cubic centimeter; 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 (gm/cc)	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 1. Original volume-weight oil-yield relationships of Green River Formation oil shale. From Stanfield and others (1954).—Continued

[GPT, gallons per ton; gm/cc, grams per cubic centimeter; 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 (gm/cc)	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	124.43	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 2. Recalculated volume-weight oil-yield relationships of Green River Formation oil shale. 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; gm/cc, grams per cubic centimeter]

Oil yield by assay, (GPT)	Specific gravity of oil shale, (gm/cc)	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 2. Recalculated volume-weight oil-yield relationships for Green River Formation oil shale. 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; gm/cc, grams per cubic centimeter]

Oil yield by assay, (GPT)	Specific gravity of oil shale, (gm/cc)	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

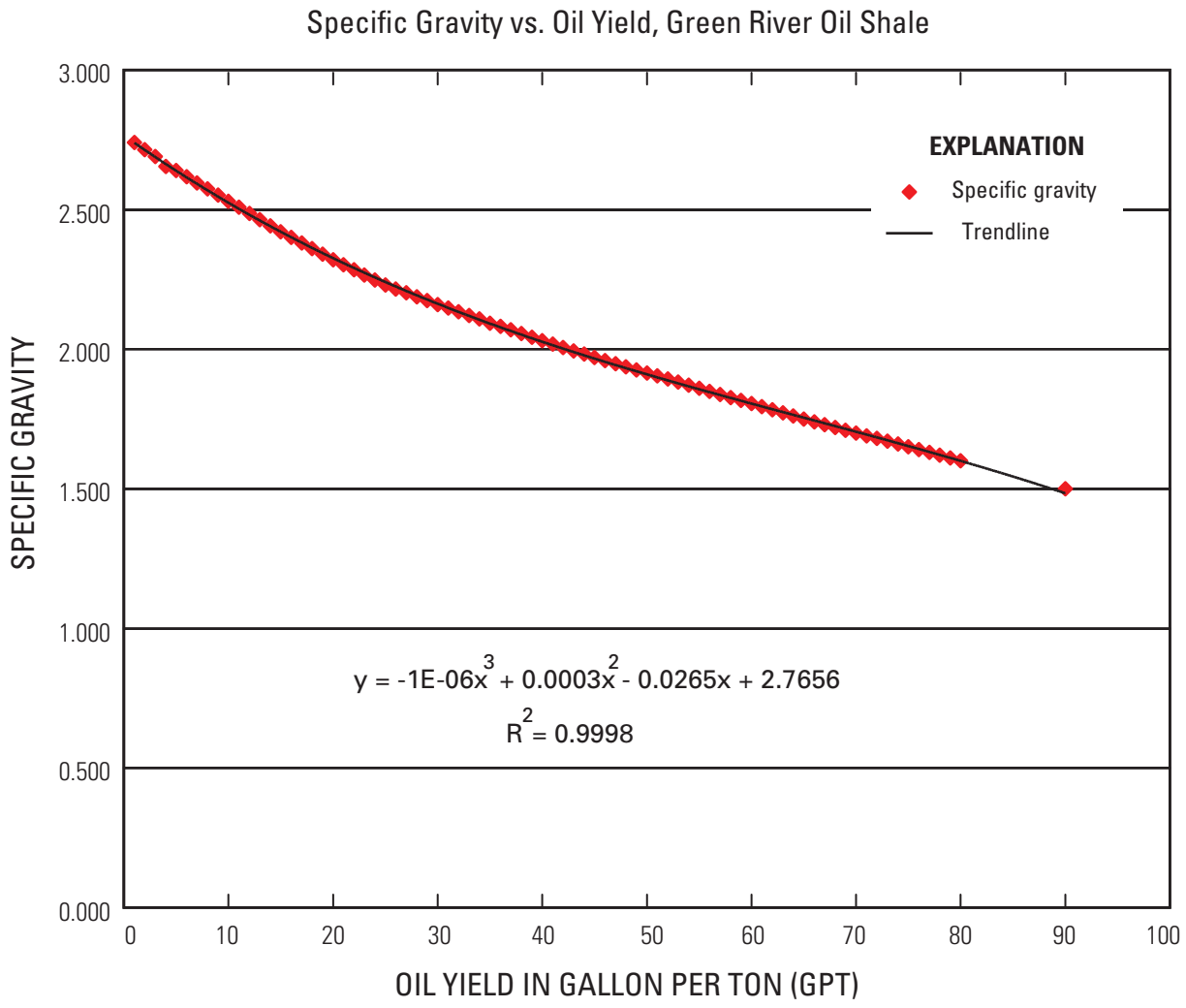


Figure 12. Graph showing the relationship between oil yield for Green River oil shales and specific gravity. Data from Stanfield and others (1954).

general, rich and lean oil shale is equally likely to go missing during the coring process.

Both the number of missing intervals and thickness of individual missing intervals in a zone are important because lots of thin missing intervals randomly distributed throughout an oil shale zone are less likely to affect the average for that zone than if most of the missing core is concentrated in a single or a few missing intervals. For instance, if 25 percent of a certain zone is missing and the missing intervals are numerous and fairly thin then the overall average of the zone will probably not be highly affected. However, if that 25 percent missing interval consists of a single interval, then the chances are much greater that the missing core will affect the average. Figure 29 shows oil-yield histograms for two closely spaced rotary holes in the east-central part of the basin and demonstrates the potential problem when an individual missing interval is thick. There are no missing intervals in the Mahogany zone in C0599R, and the average for the zone is 23.7 GPT. The second drill hole is missing one 70 ft thick interval in the Mahogany zone, but this missing interval includes the Mahogany bed, the richest part of the Mahogany zone. As a result, average oil yield for the Mahogany zone in this hole is only 16.4 GPT.

Figure 30 shows the oil-yield histograms for four of the 13 closely spaced core holes discussed previously. The average of 22.8 GPT for the Mahogany zone in C0265 (fig. 30*A*) should be close to the true average because there is no missing core. Core hole C0261 (fig. 30*B*), which had only 9.3 percent missing core in intervals no thicker than 3.6 ft, averages 22.6 GPT or similar to the complete core. Core hole C0273 (fig. 30*C*) has more missing core, 16.3 percent, but the individual intervals are relatively thin, no greater than 3.9 ft. Average oil yield for this core hole is somewhat greater than expected at 25.8 GPT. Core hole C0266 (fig. 30*D*) is missing 41.1 percent of the Mahogany zone, yet the average oil yield of 21.6 GPT is close to the expected value of 22.8 GPT from

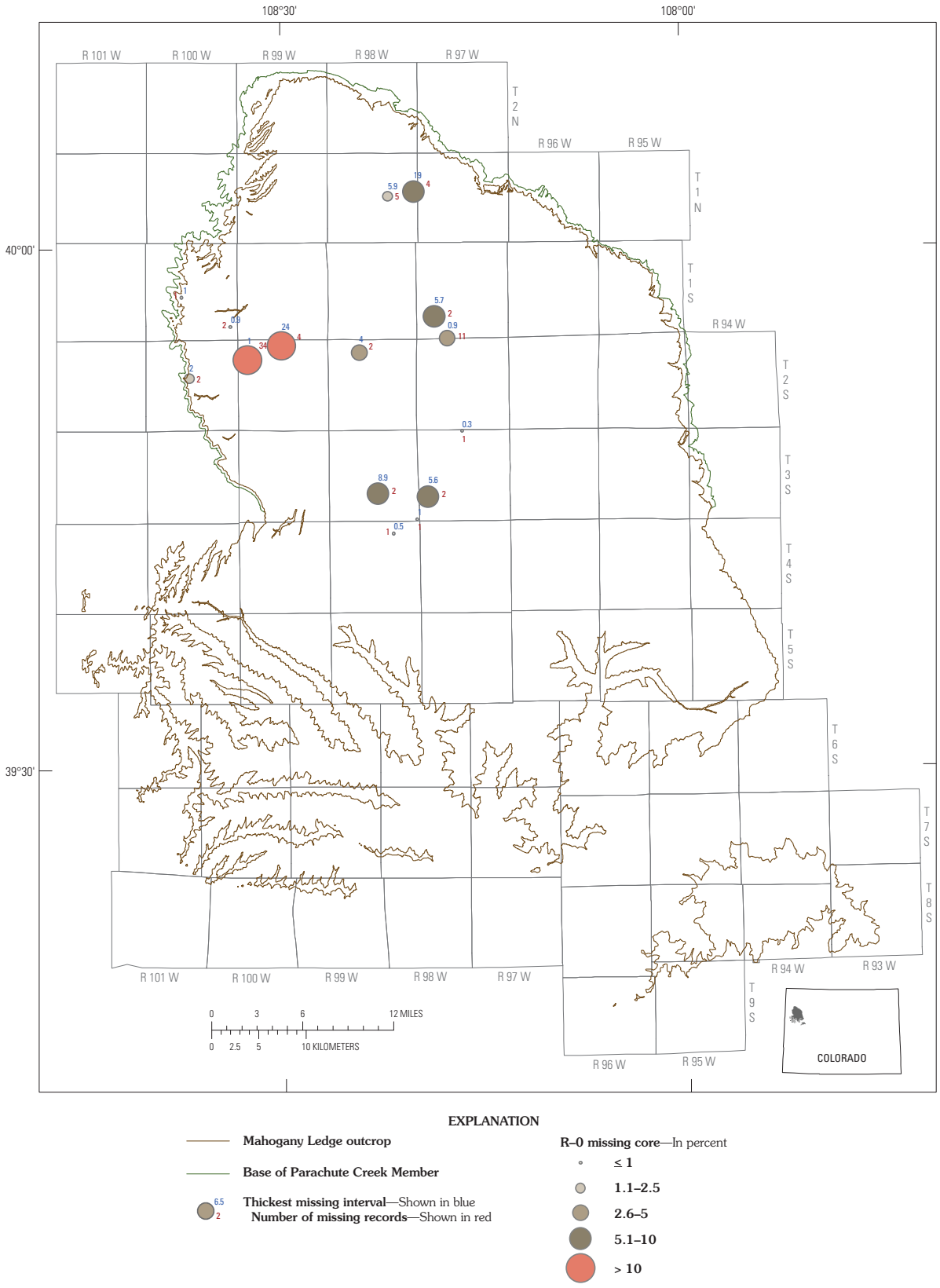


Figure 13. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the R-0 zone, Piceance Basin, Colorado.

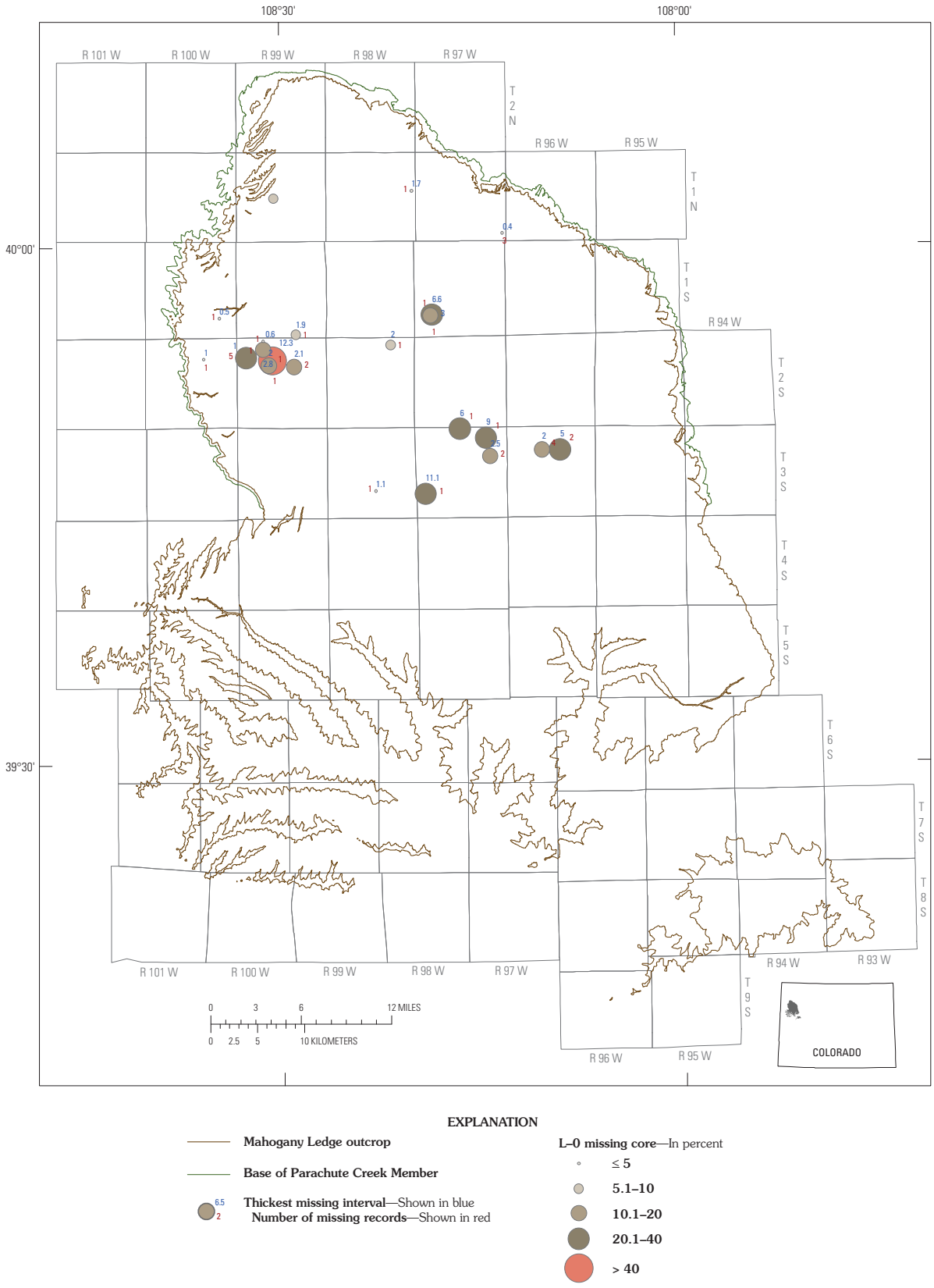


Figure 14. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the L-0 zone, Piceance Basin, Colorado.

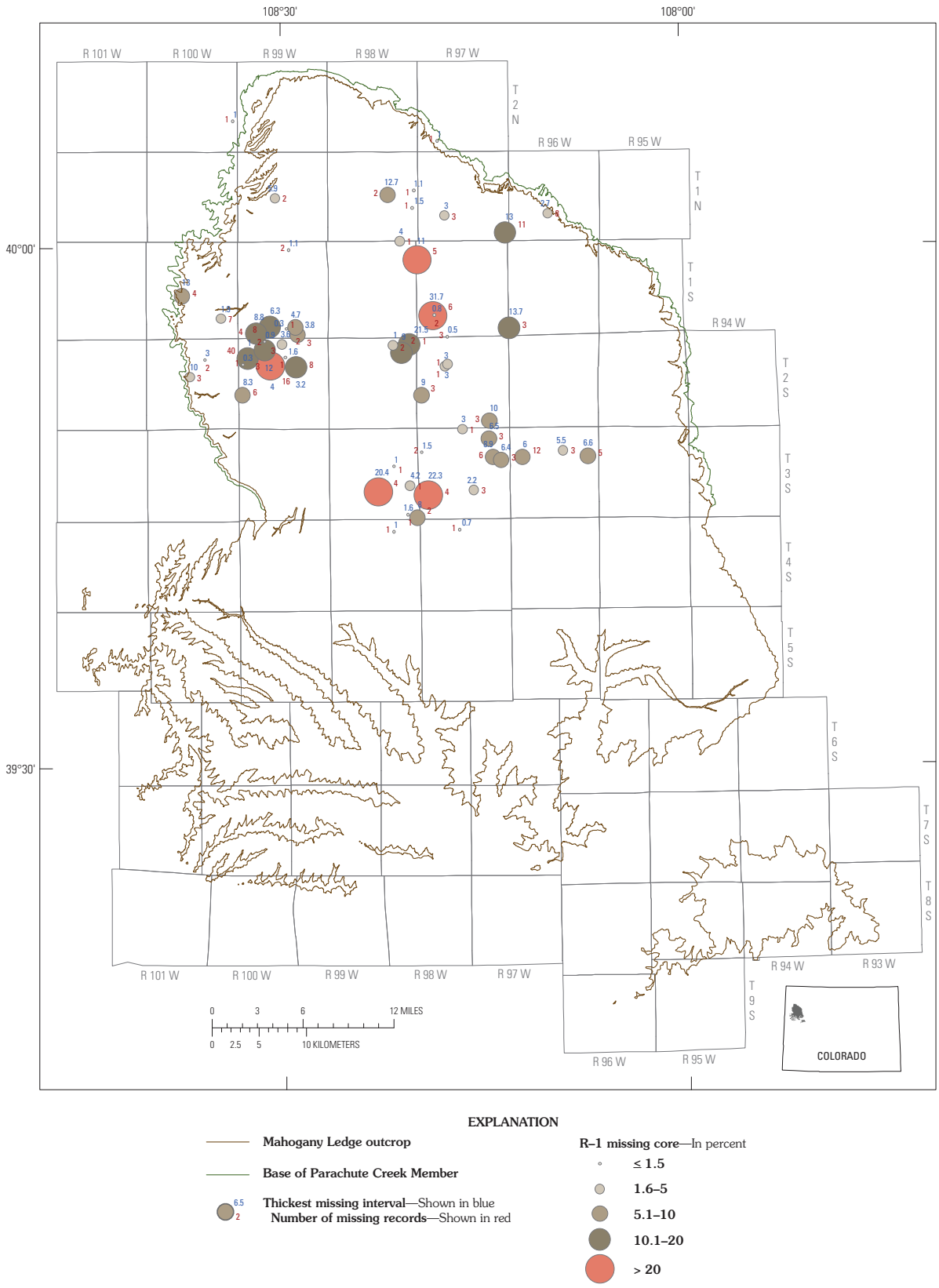


Figure 15. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the R-1, Piceance Basin, Colorado.

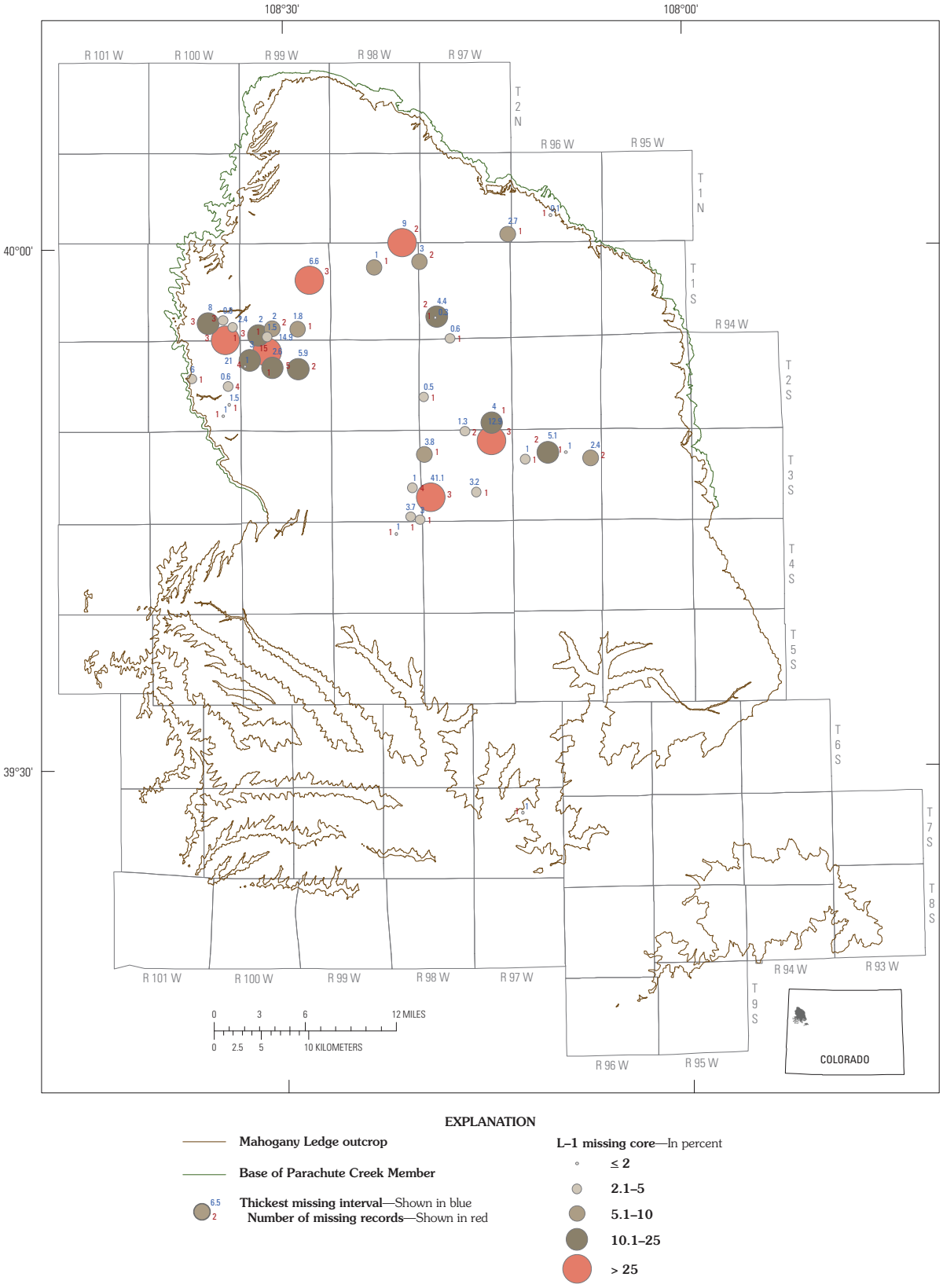


Figure 16. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the L-1 zone, Piceance Basin, Colorado.

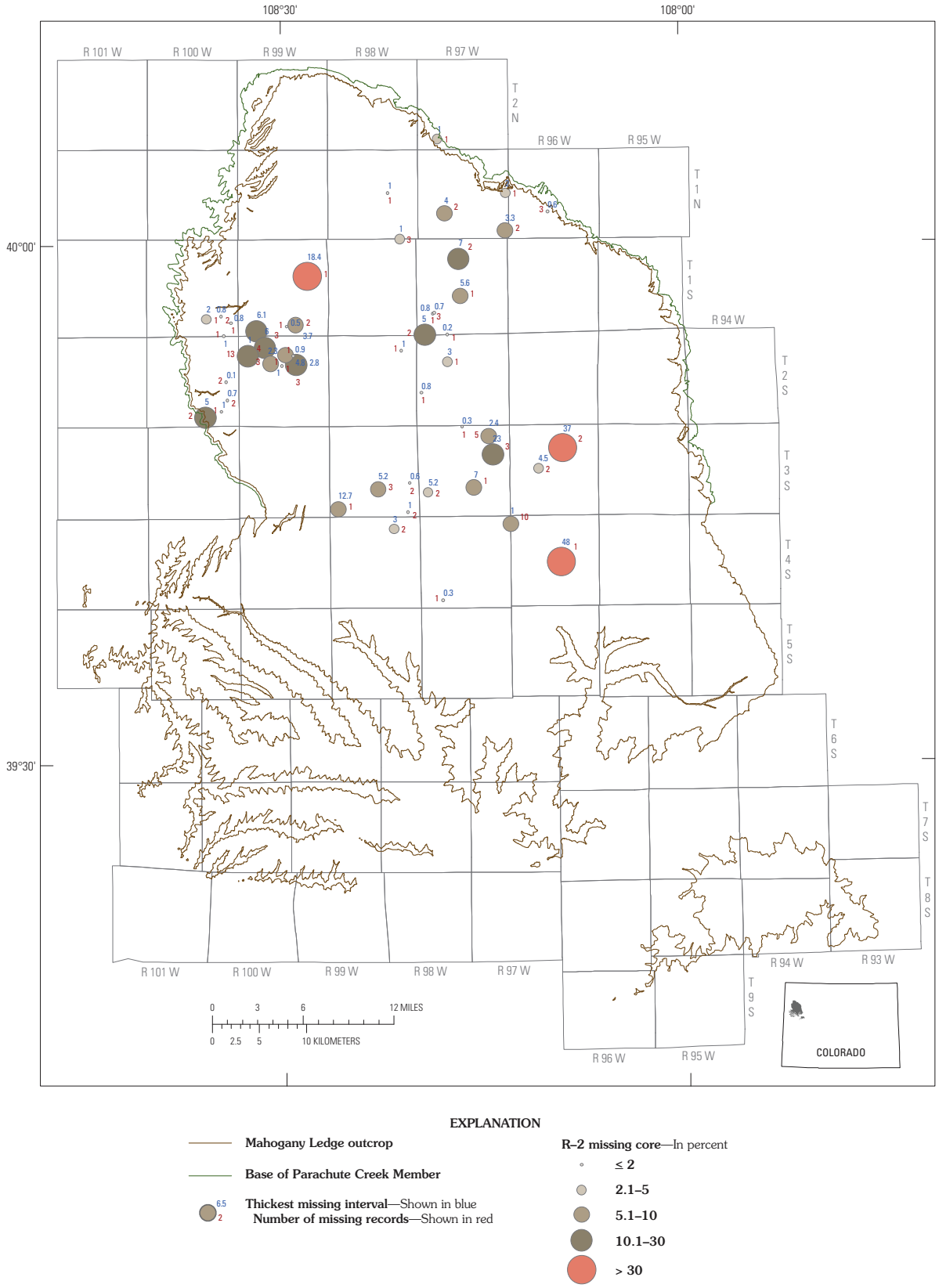


Figure 17. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for both core holes and rotary holes drilled through the R-2 zone, Piceance Basin, Colorado.

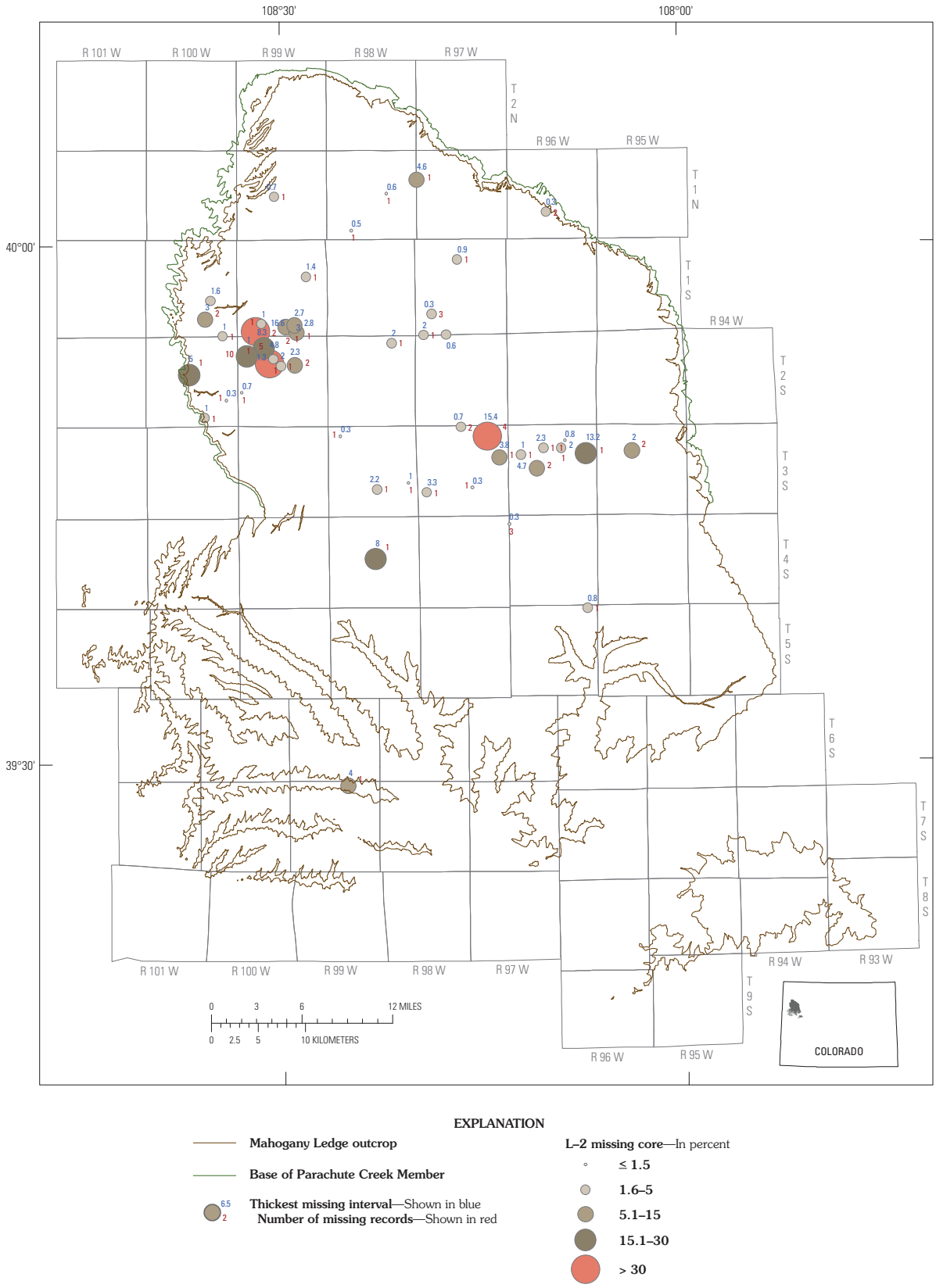


Figure 18. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for both core holes and rotary holes drilled through the L-2 zone, Piceance Basin, Colorado.

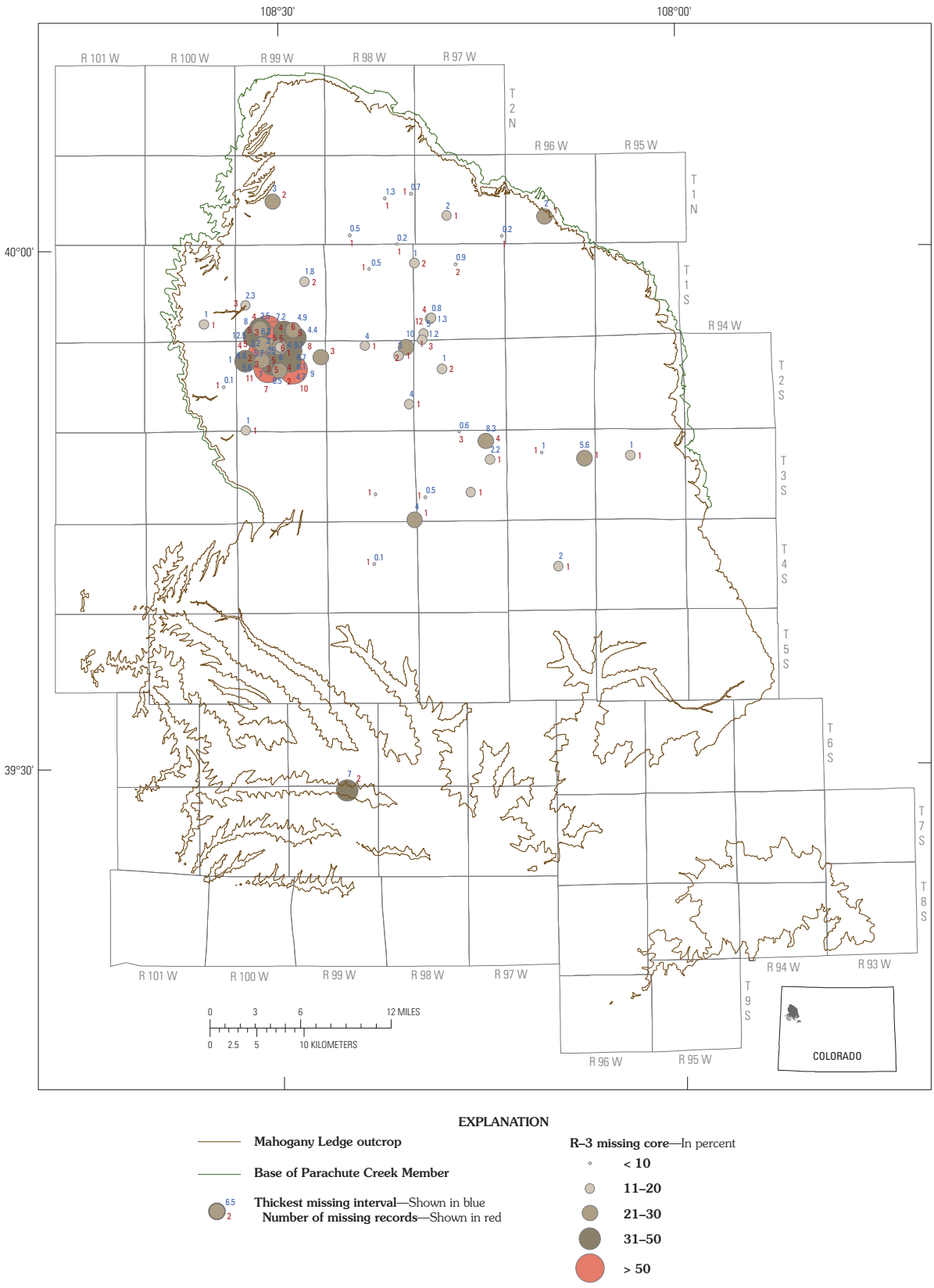


Figure 19. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the R-3 zone, Piceance Basin, Colorado.

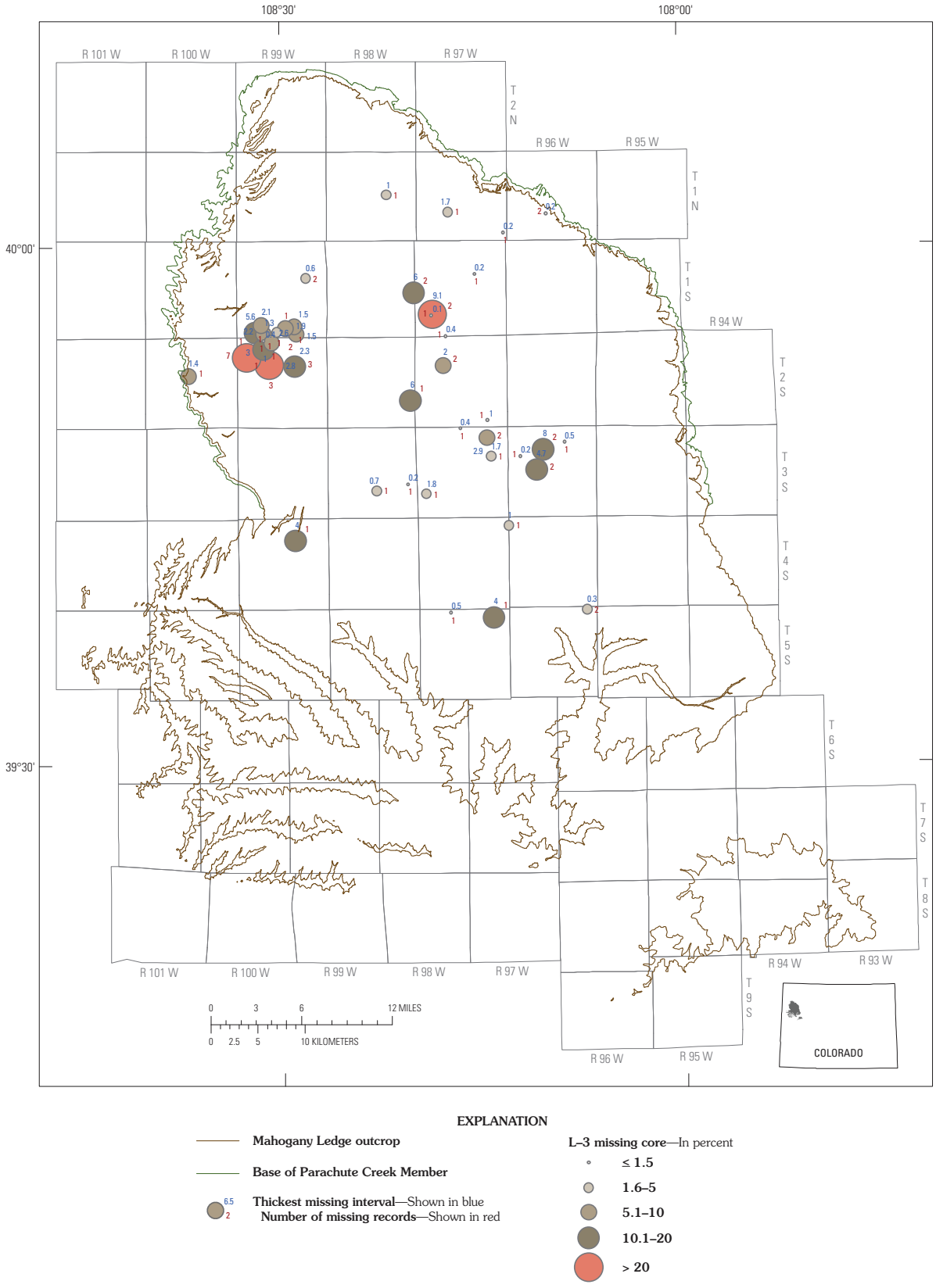


Figure 20. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the L-3 zone, Piceance Basin, Colorado.

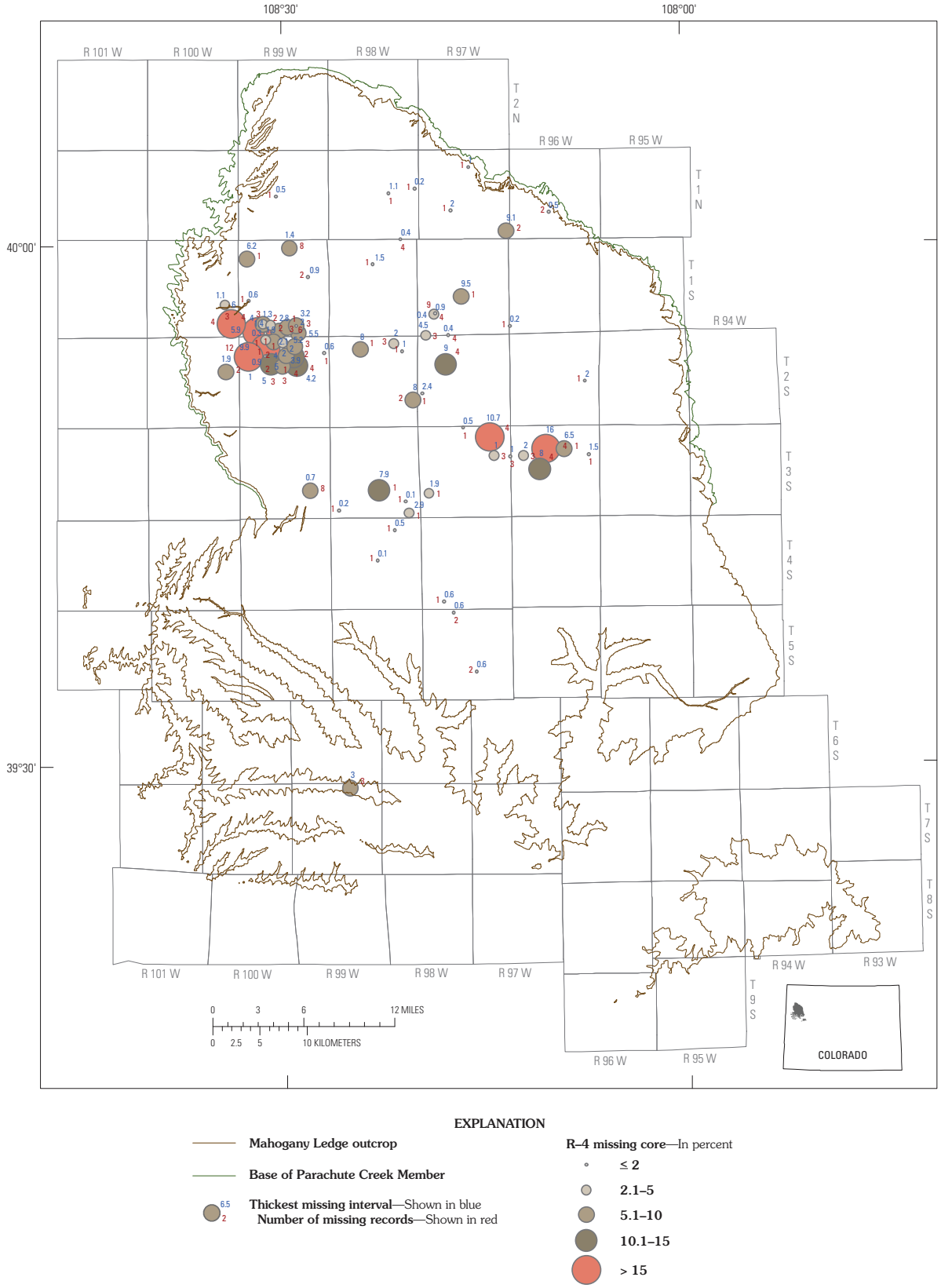


Figure 21. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the R-4 zone, Piceance Basin, Colorado.

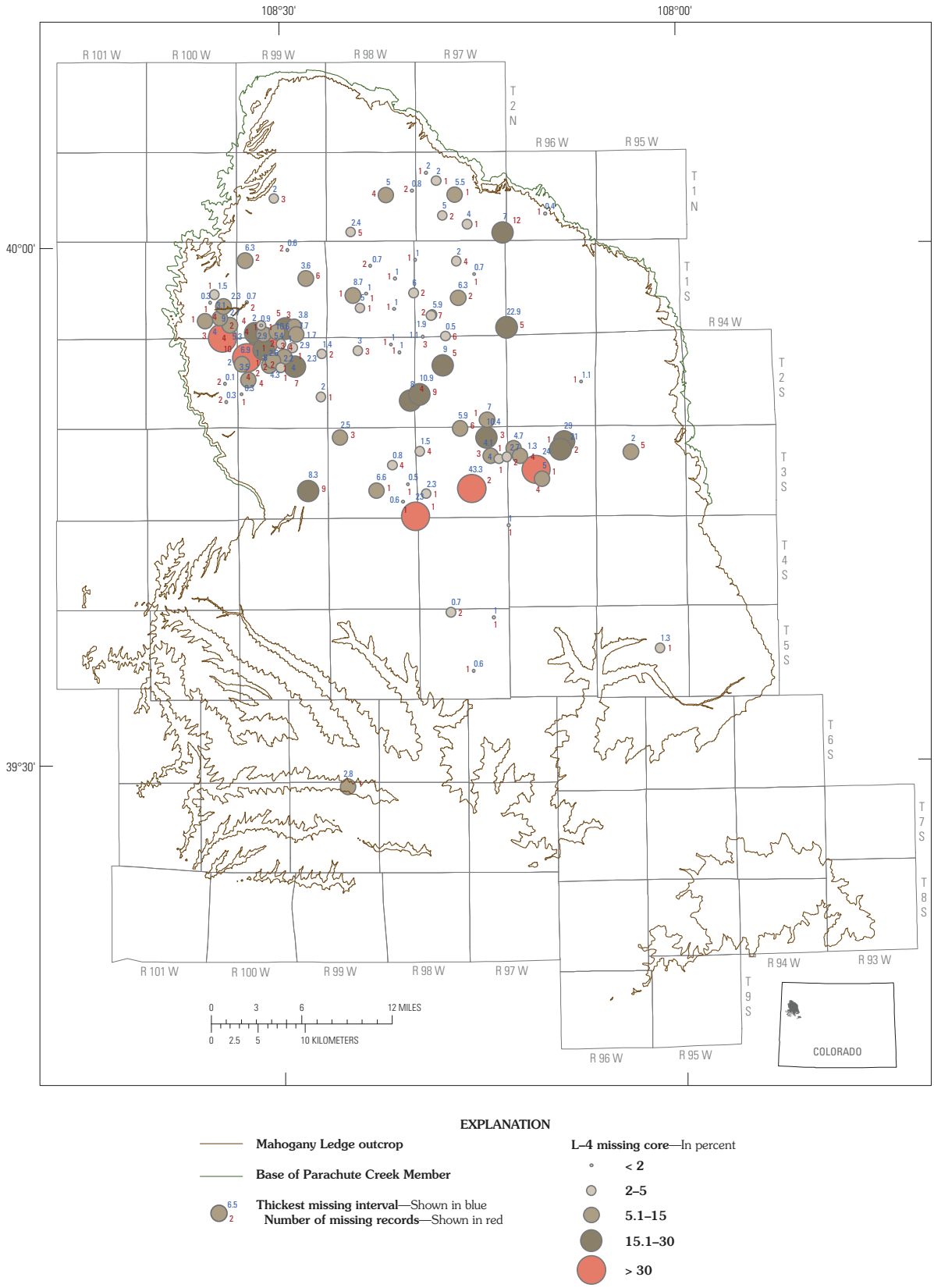


Figure 22. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the L-4 zone, Piceance Basin, Colorado.

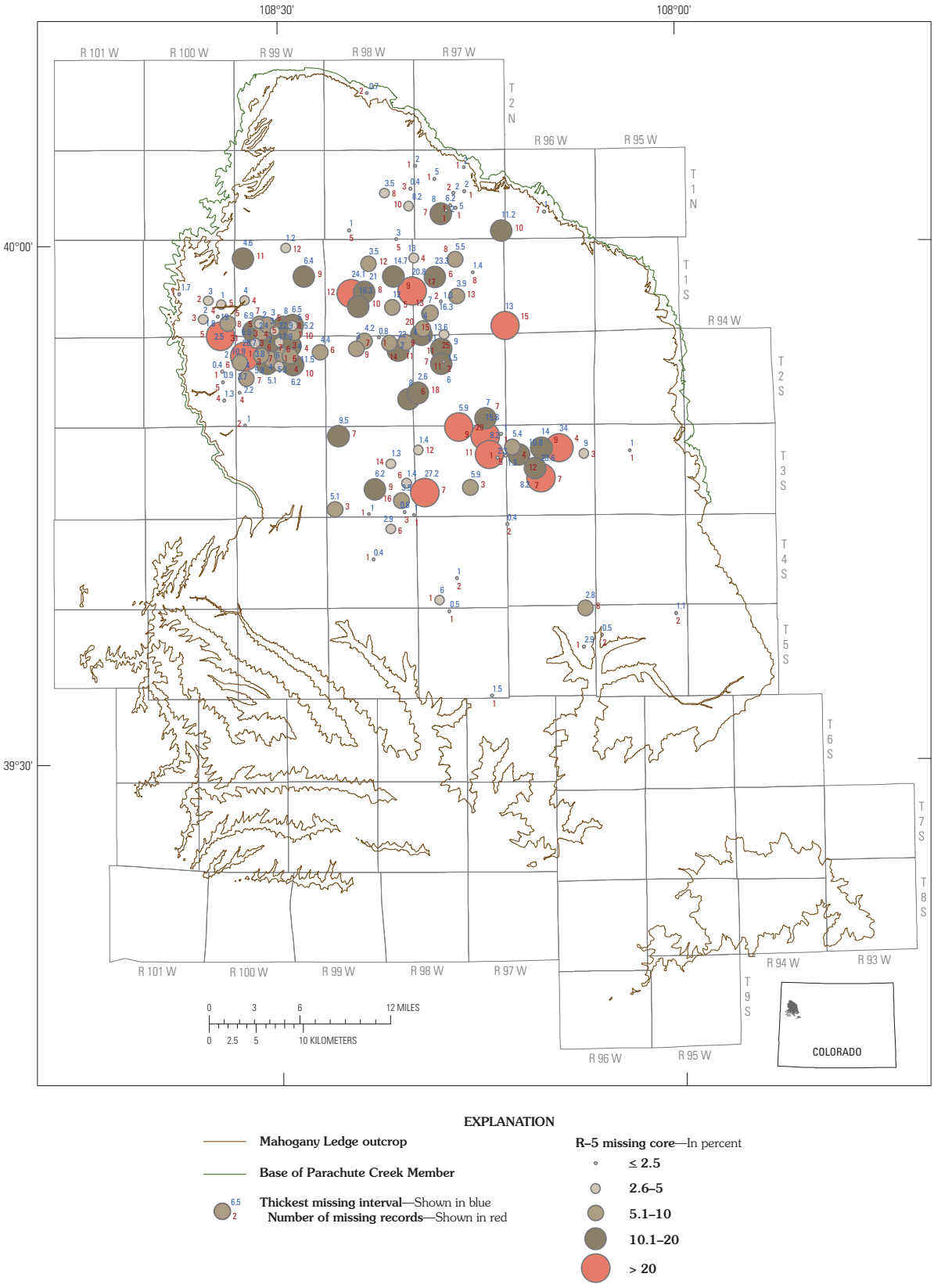


Figure 23. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the R-5 zone, Piceance Basin, Colorado.

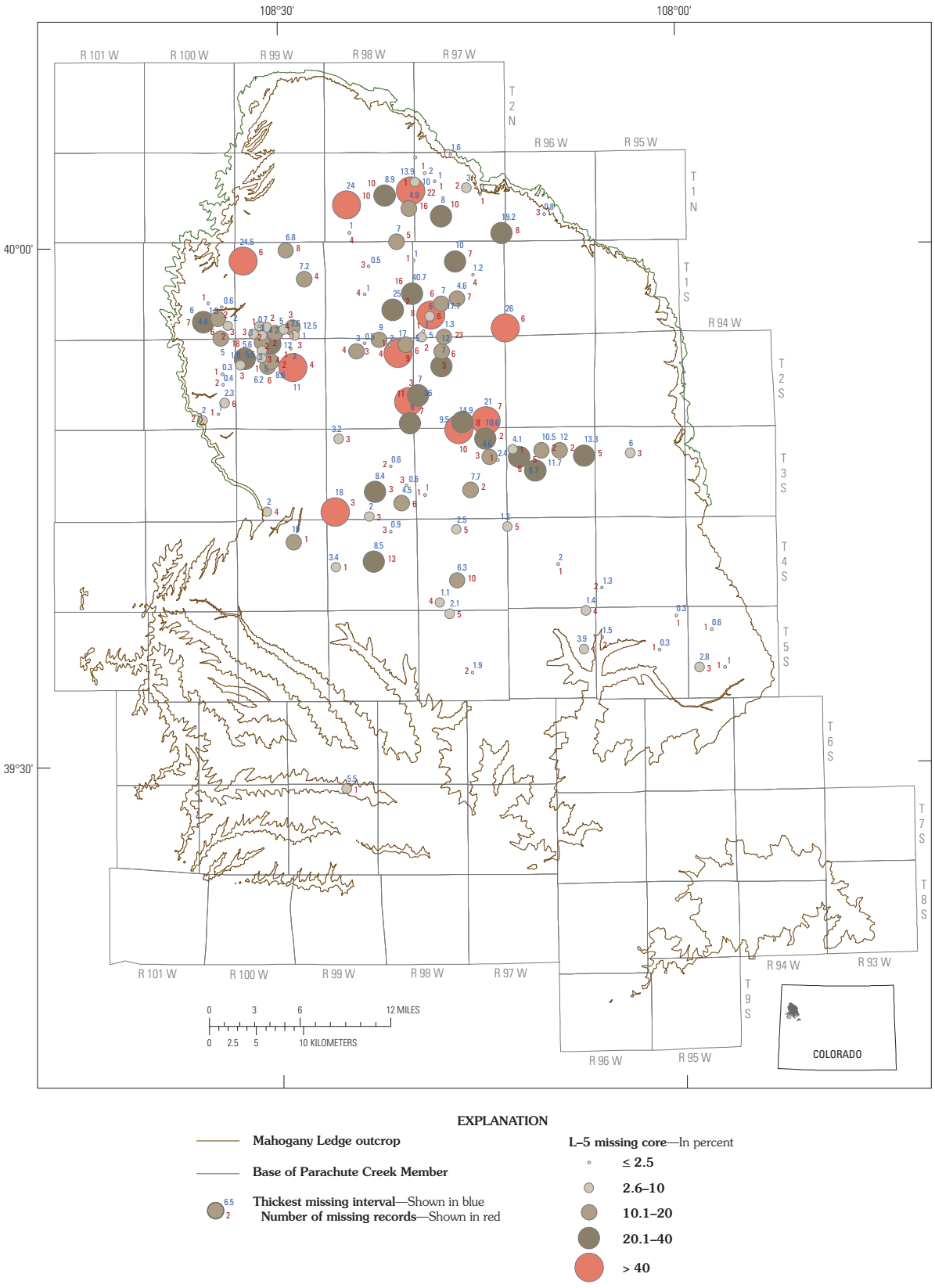


Figure 24. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the L-5 zone, Piceance Basin, Colorado.

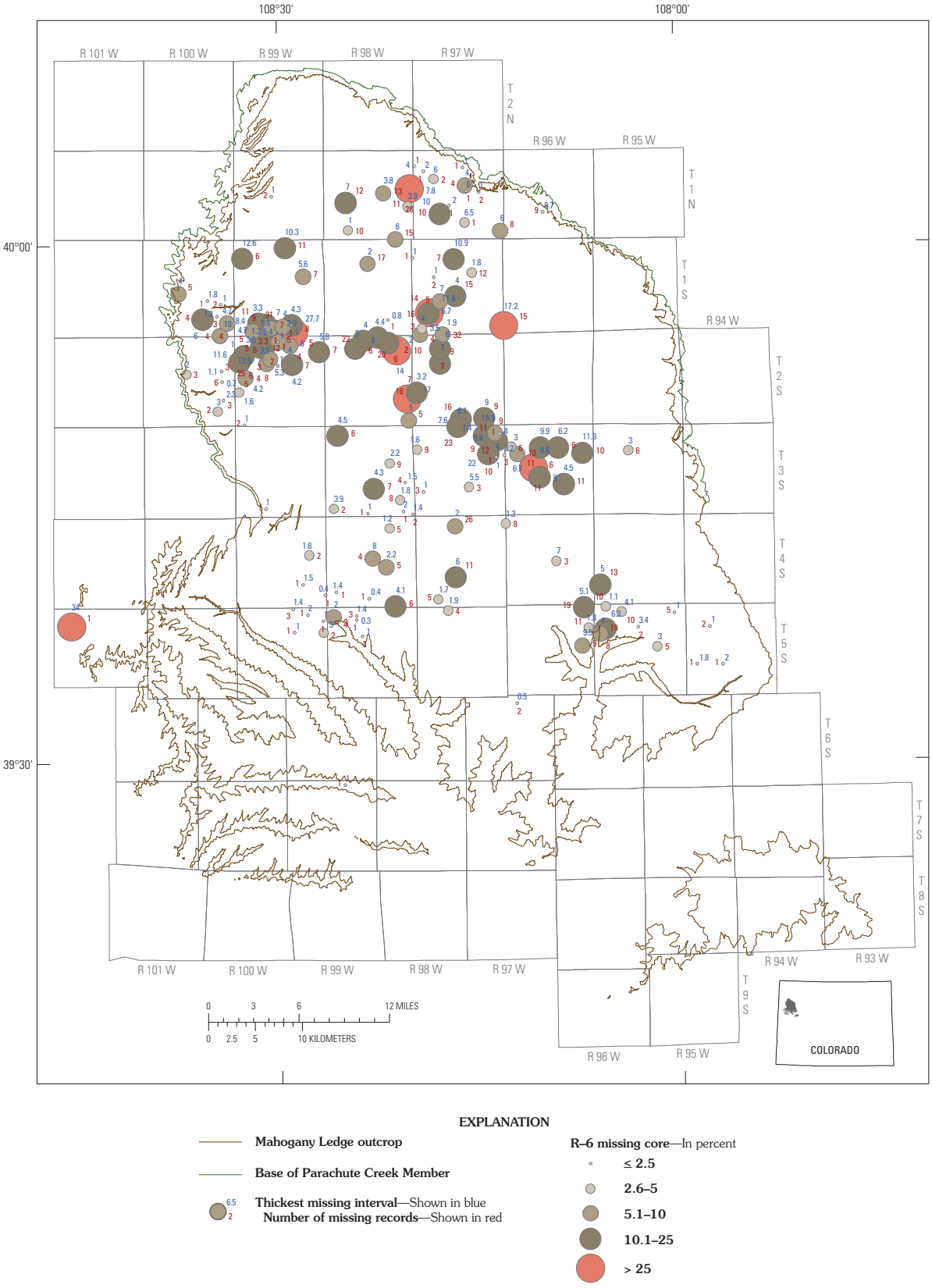


Figure 25. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for both core holes and rotary holes drilled through the R-6 zone, Piceance Basin, Colorado.

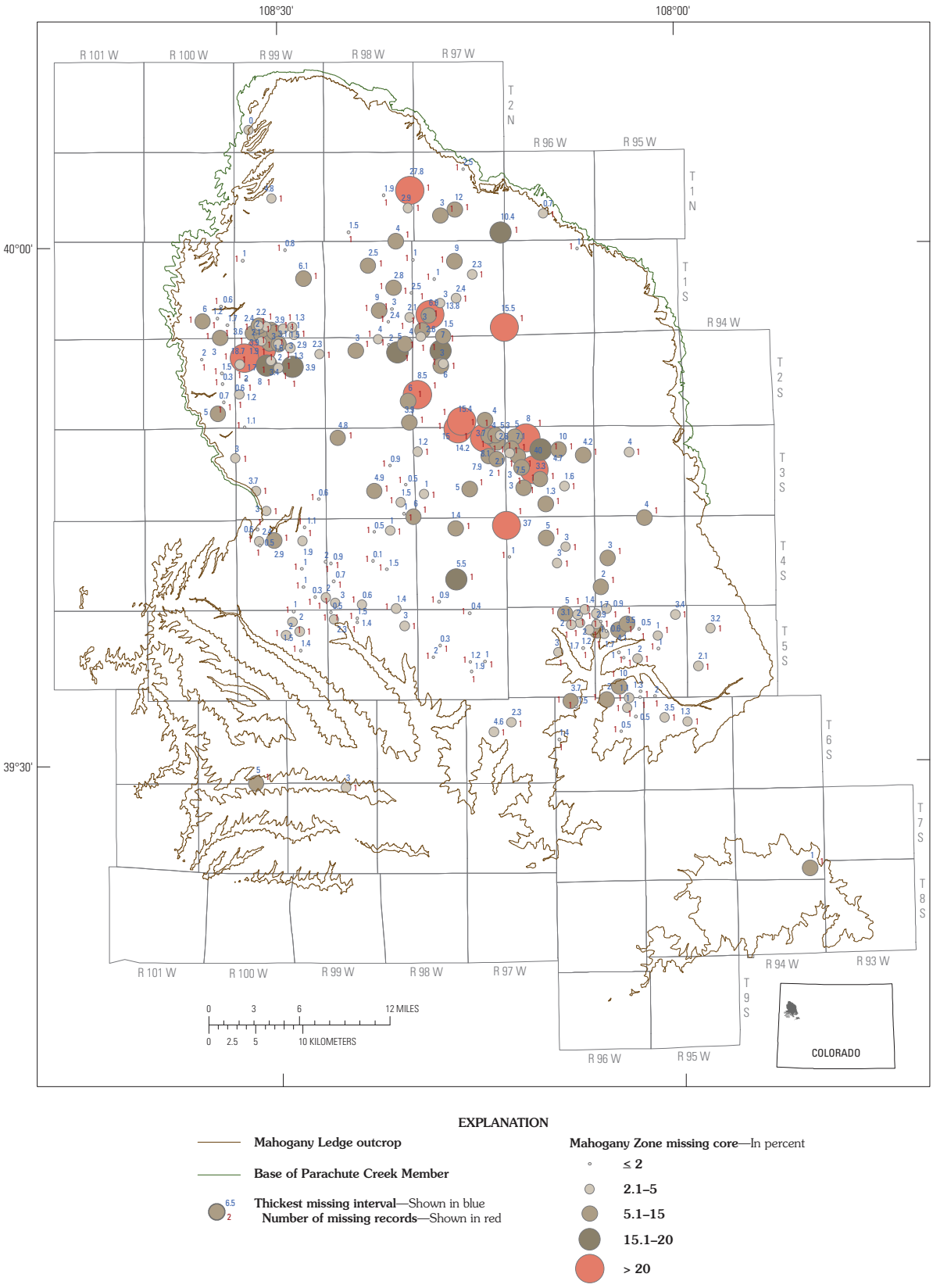


Figure 26. Map showing percent of missing intervals, number of missing intervals (red), and thickest missing interval (blue) for core holes drilled through the Mahogany zone, Piceance Basin, Colorado.

Table 3. Detailed analysis of 13 closely spaced core holes from a four-square-mile area in the northwest part of the basin showing variations in average gallons per ton and percent missing interval for all 13 oil shale zones assessed. Locations of core holes shown on figure 27.

USGS ID	Mahogany gallons per ton	Mahogany percent missing interval	R-6 gallons per ton	R-6 percent missing interal	L-5 gallons per ton	L-5 percent missing interval	R-5 gallons per ton	R-5 percent missing	L-4 gallons per ton	L-4 percent missing
C0206	23.4	6.9	20.6	13.4	13.4	0.7	28	3.6	21.9	1.3
C0207	24.6	2.7	19.9	0.7	12.5	0	31.7	17.5	21.6	0
C0214	23.4	8.1	22.3	13.3	11.9	6	28.2	6	19.8	8.7
C0217	26.5	5.7	22.2	14.8	13.4	13.9	31.6	3.5	24.7	8.7
C0237	24.7	5.5	20.9	5.1	12.7	0	32.1	5	24.2	3.3
C0238	23.3	3.2	20.4	10.8	12.4	4.2	29.3	7.5	21.7	3.1
C0261	22.6	9.3	17.9	9.5	10.7	5.5	27.3	15.3	18.4	24.8
C0262	23	4.4	20	15.1	12.5	3.8	30.3	5.8	22.1	0
C0265	22.8	0	15.4	0	15	0	24.7	2.6	19.9	0
C0266	21.6	41.1	17.8	10.2	10.2	8	26	24	18.4	22.3
C0267	24.1	7.5	19.2	12.8	14.8	36.3	28.7	16.6	20.7	0
C0273	25.8	16.3	19.8	11.1	12	41.8	30.7	18.7	23.1	19.4
C0384	26.7	13.4	22.2	9.3						

Table 3. Detailed analysis of 13 closely spaced core holes from a four-square-mile area in the northwest part of the basin showing variations in average gallons per ton and percent missing interval for all 13 oil shale zones assessed. Locations of core holes shown on figure 27.—Continued

USGS ID	R-4 gallons per ton	R-4 percent missing	L-3 gallons per ton	L-3 percent missing	R-3 gallons per ton	R-3 percent missing	L-2 gallons per ton	L-2 percent missing	R-2 gallons per ton	R-2 percent missing
C0206	33.7	2.9	13	6	25.8	6.1	15.4	0	29.2	0
C0207	33.5	2.3	16.5	0	28.8	6	16.5	0	32.6	0
C0214	33.8	0.4	11.1	6.5	26.2	26.7	14.4	0	28.7	0
C0217	35.4	8.5	16.1	3.5	30.9	30.1	18.1	0	30.1	0
C0237	36.3	0	16.4	0	29.4	4.7	18.3	0	31.7	0
C0238	34	9.1	11.8	0	26	16.5	15.4	3.7	30.2	0
C0261	32.6	22.8	10.3	17	23.7	18.1	15.1	53.7	27	28.9
C0262	36.3	2.9	15	0	31.1	47.8	15.5	0	29.1	0
C0265	29.6	0	9.5	0	20.7	0	10.9	0	26.7	0
C0266	36	21.4	12.5	11.1	22.7	32	9.7	28.6	27.4	22.5
C0267	32.5	7.6	13.2	6.5	26.8	14.3	18.1	0	29.7	0
C0273	36.3	12.9	17.7	15.7	28.7	35.6	18	9	31.2	14.4
C0384										

Table 3. Detailed analysis of 13 closely spaced core holes from a four-square-mile area in the northwest part of the basin showing variations in average gallons per ton and percent missing interval for all 13 oil shale zones assessed. Locations of core holes shown on figure 27.—Continued

USGS ID	L-1 gallons per ton	L-1 percent missing	R-1 gallons per ton	R-1 percent missing	L-0 gallons per ton	L-0 percent missing	R-0 gallons per ton
C0206							
C0207	8.4	0	17.7	3.1	6.4	0	12.4
C0214	8.4	4.4	19.2	0	4.9	0	
C0217							
C0237							
C0238							
C0261	6.5	18.2	17.5	11.7	5.1	0	
C0262	8.4	7.7	20.7	12	5.9	0	
C0265	8	0	17.9	0	5.5	0	
C0266	6.5	35.5	16.9	12.2	9.9	12.8	
C0267	6.4	0	16.2	0	13.4	0	
C0273	5.7	21.9	20.1	13.4	7.5	15.8	
C0384							

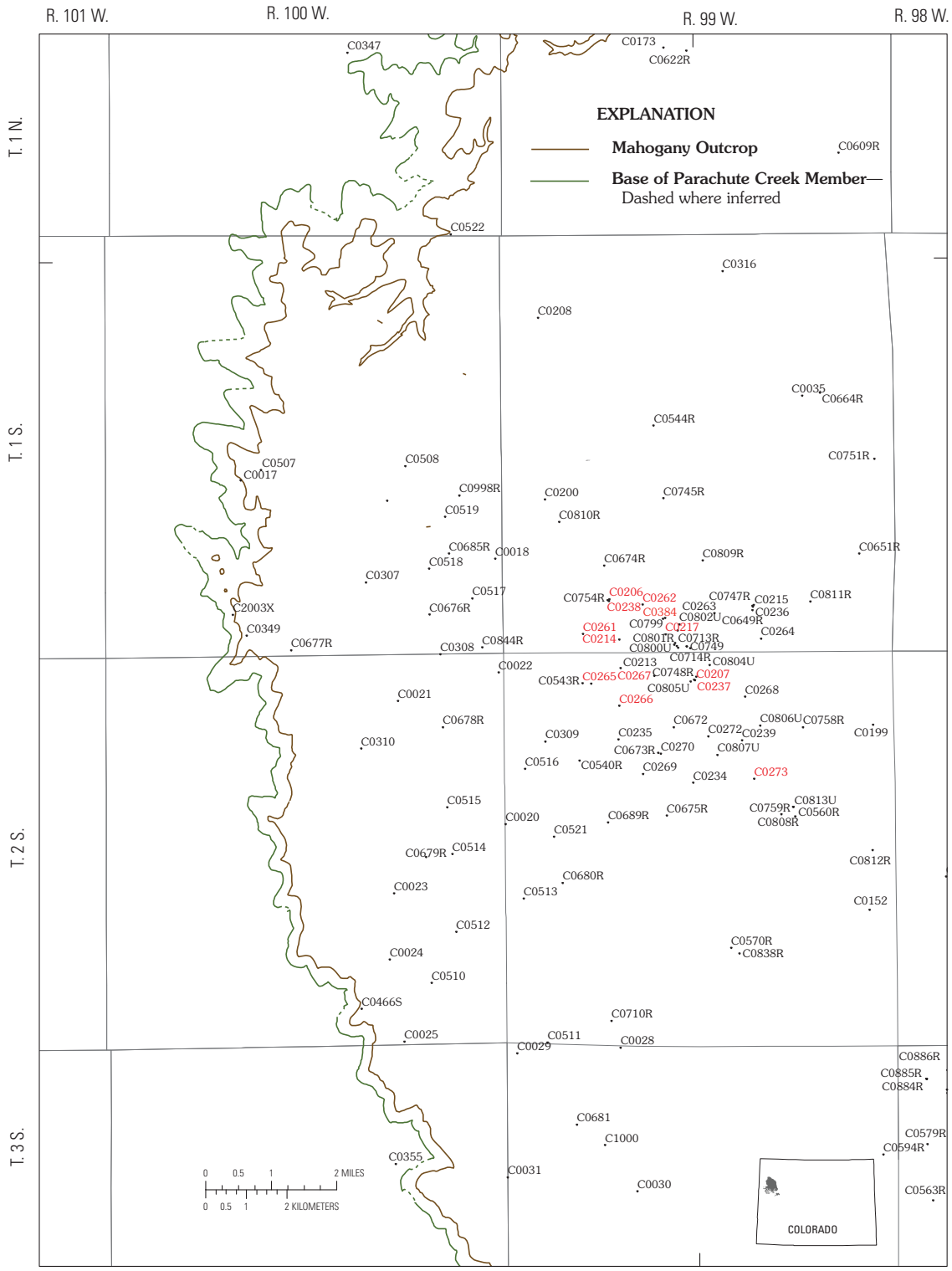


Figure 27. Map showing locations of 13 closely spaced core holes (red numbers) in the northwest part of the basin that were used to study effects of missing core intervals on the overall oil yields obtained from the core. Number designations are from Dyni (1998). Core holes and rotary holes not used in this comparison shown in black. Rotary holes are distinguished from core holes by the "R" at the end of the number. Brown line is top of Mahogany ledge as mapped by Hail and Smith (1994). Green line is base of Parachute Creek Member of the Green River Formation as mapped by Hail and Smith (1994).

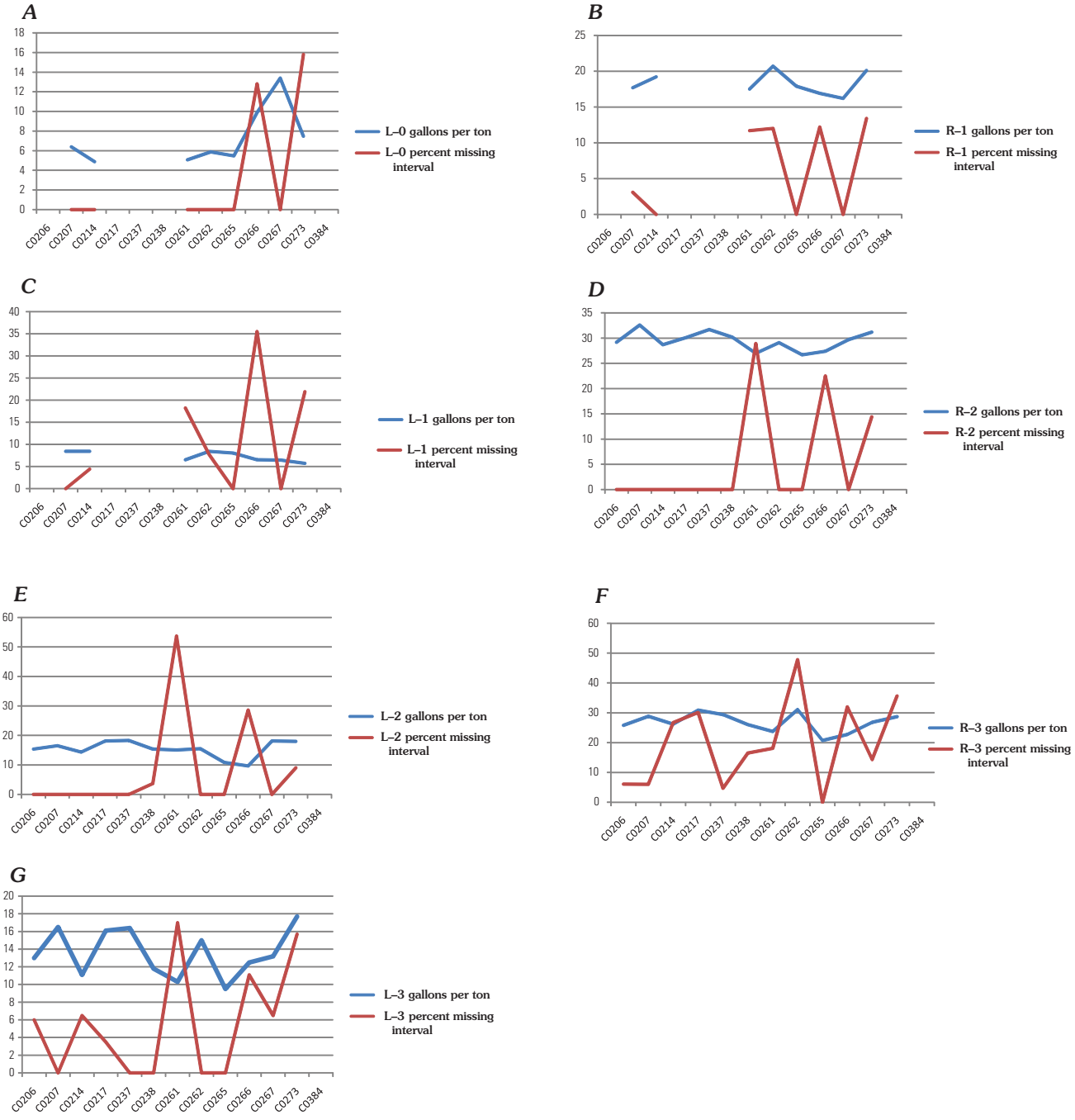


Figure 28. Percent missing interval versus average oil yield for the oil shale zones from the L-0 zone through Mahogany zone for 13 closely spaced core holes in the northwest part of the basin. Locations of core holes shown on figure 27.

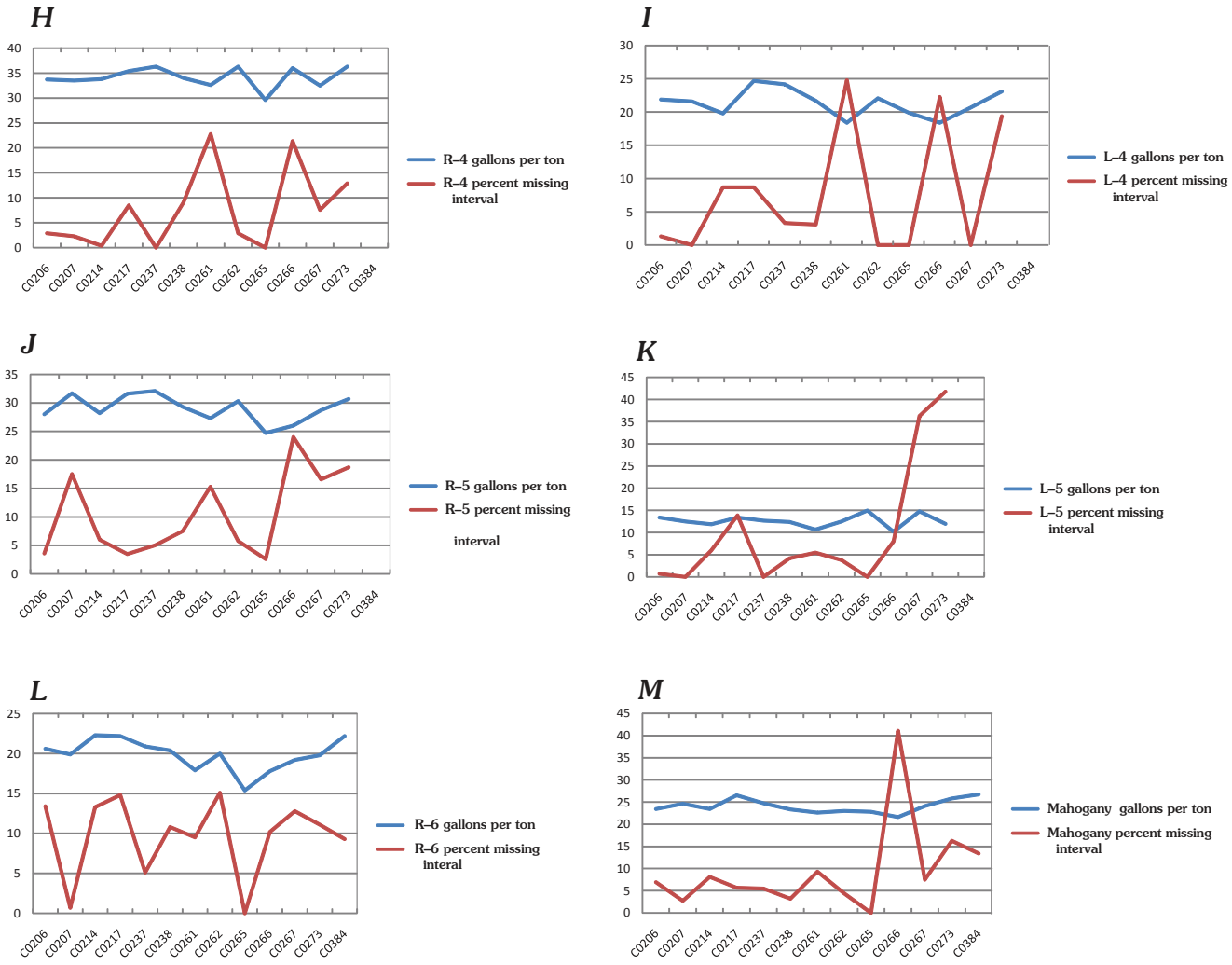


Figure 28. Percent missing interval versus average oil yield for the oil shale zones from the L-0 zone through Mahogany zone for 13 closely spaced core holes in the northwest part of the basin. Locations of core holes shown on figure 27.—Continued

the full core. One of the missing intervals is 18.7 ft thick, which represents 15.3 percent of the total thickness of the Mahogany zone.

What is clear from this discussion is that the reliability of each control point used to construct the resource maps varies depending on the amount of missing interval. The issue of missing intervals clearly warrants further study, but for this assessment, we did not eliminate any control points because of excessive amounts of missing intervals.

Comparing Gallons Per Ton Data Points From This Assessment With Those Used in the Previous Assessment

Although the computer files used in the previous assessment (Pitman and others, 1989) were not recovered, the thickness of oil shale zones, gallons per ton values, and barrels per acre values for each data point are shown on the isopach maps and assessment maps published with that assessment. In areas where core holes are widely spaced, we could, in many instances, identify the core holes used in the previous assessment and thus we could compare their results with ours. Figures 31–34 shows locations of selected core holes that were used to compare GPT and BPA determinations for the R-5 and L-5 zones in both this assessment and the assessment of Pitman and others (1989). The results are listed in tables 4 and 5 and graphed in figures 35–38. As expected, for core holes with no missing intervals, the GPT values are nearly the same for the two assessments except that the values used in the previous assessment were rounded off to the nearest integer (figs. 31, 33). As the percentage of missing interval increases, the ratio between GPT used here and GPT used in the previous assessment increases and there is an increase in scatter (figs. 35–38). In addition, most but not all of the BPA values used in this assessment are higher than those used in the previous assessment even when there were no missing intervals (figs. 31, 33, 34, 37). This difference is generally quite small but can be as much as 35 percent particularly for core holes in marginal areas. This indicates that our method for assigning values to missing intervals and for converting GPT into BPA overall produces slightly greater resource numbers than the method used in the previous assessment. Our method, however, is fully documented, and it would be relatively easy to use different formulas and generate a new set of resource numbers using the Access table presented in Mercier and others (chapter 3, this CD-ROM).

Reproducibility of Fischer Assay Analysis

Fischer assay has been the standard method to measure the oil potential of oil shale for almost 60 years (Stanfield and Frost, 1949). Dyni (2003) discusses the Fischer assay method and how it compares with other methods to determine oil yields in oil shales. Reproducibility of Fischer assay results has been studied by many workers in the past. Keighin (1980) studied variations in assay results on: 1) the same samples using the same analytical technique by the same lab, 2) the same samples analyzed by different labs using the same analytical technique, 3) the same samples run by different labs using slightly different analytical techniques, and 4) samples from two closely spaced holes run by two different labs using slightly different analytical techniques. Results were variable, with a correlation coefficient (r) of 0.9207 for the first scenario, r values of 0.9946 and 0.9604 for the second, r values of 0.9947 and 0.9973 for the third, and an r value of only 0.7994 for the fourth scenario. For the third case of two labs analyzing the same samples but using slightly different analytical techniques one lab gave consistently higher results than the other. The poor correlation for the fourth case of two laboratories using slightly different analytical techniques on two sets of samples from nearby core holes suggests that there may be significant problems with assigning values to missing core intervals based on results from a nearby core hole.

The analytical errors should be minimal for a typical oil shale zone that averages from 50 to about 200 ft thick that was sampled and analyzed for oil content every foot or so, as the errors should be averaged out by the relatively large number of analyses. No attempt was made here to identify assays that were run by the lab that gave consistently higher results, but this should be investigated in the future.

Problems Related to Saline Minerals

Much of the oil shale section in the saline depocenter contains the saline minerals nahcolite and halite. When nahcolite is dispersed in the oil shale or occurs as aggregates or thin beds, it is generally not removed prior to assaying. The presence of nahcolite in a sample can generally be detected from Fischer assay results because it breaks down producing carbon dioxide during retorting, increasing the amount of "gas plus loss" over that of nahcolite-free oil shale. In fact, this increase in "gas plus loss" due to the breakdown of nahcolite can be used to estimate the amount of nahcolite originally present in the sample (see Brownfield and others, chapter 2, this CD-ROM). The assay results are thus diluted by the presence of these minerals and lower GPT measurements are obtained than if the minerals had been leached prior to assaying. This dilution does not greatly affect the calculation of in-place oil as the diluted GPT value is applied to the entire section, including the nahcolite.

However, thick beds of nahcolite and halite are also present in the saline depocenter. These beds are generally not assayed and appear as zeros in the Fischer assay results. One bed of halite and nahcolite is as much as 65 ft thick (Dyni, 1974, p. 117). Missing intervals also appear as zeros in the assay results, and great care was taken to distinguish the zero assay results from these saline beds from zero results from missing intervals. As previously discussed, true missing intervals were assigned an oil yield value equivalent to the average

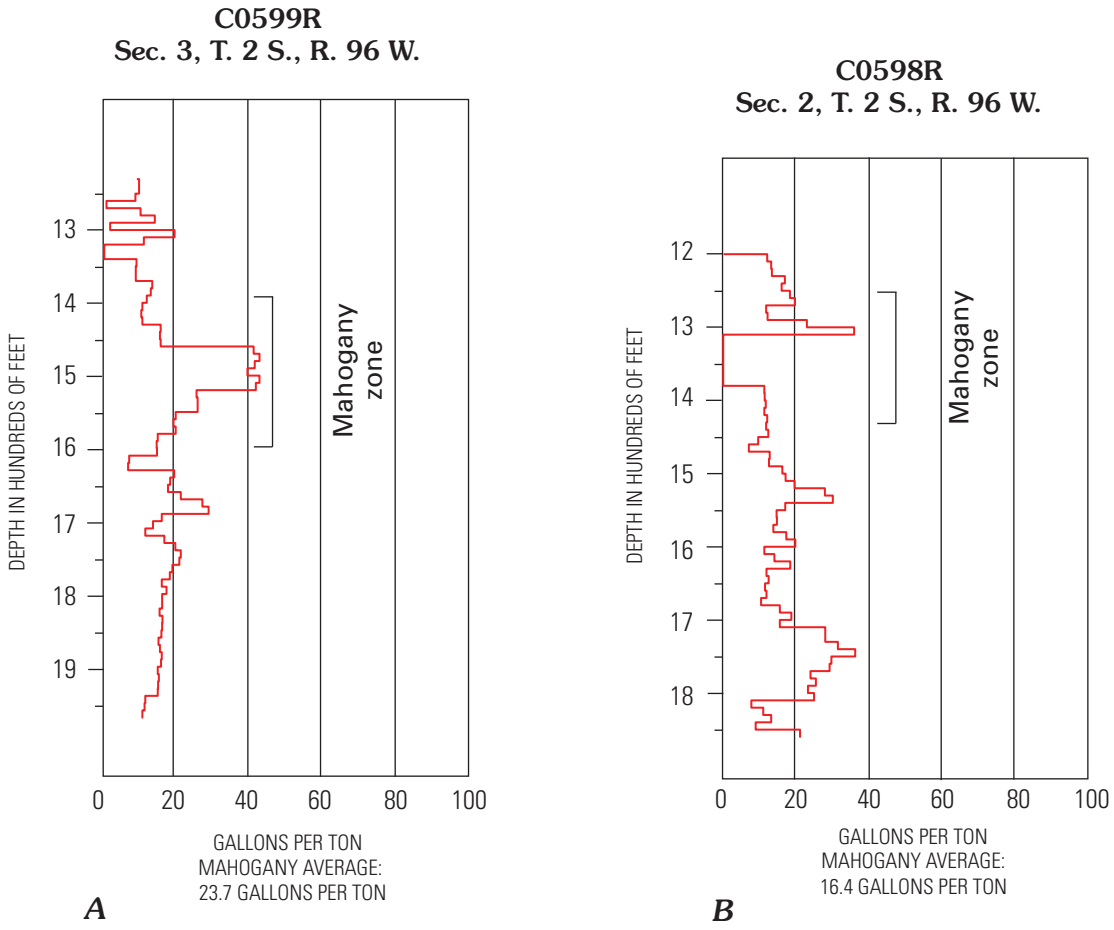


Figure 29. Oil-yield histograms for two closely spaced rotary holes in the eastern part of the basin. In the first hole (*A*), the Mahogany zone is complete and averages 23.7 gallons per ton. A 70 ft thick interval is missing in the second hole (*B*). The missing interval includes the Mahogany bed, the richest part of the Mahogany zone. Having the Mahogany bed missing depresses the average of the remaining core in the Mahogany zone to 16.4 gallons per ton.

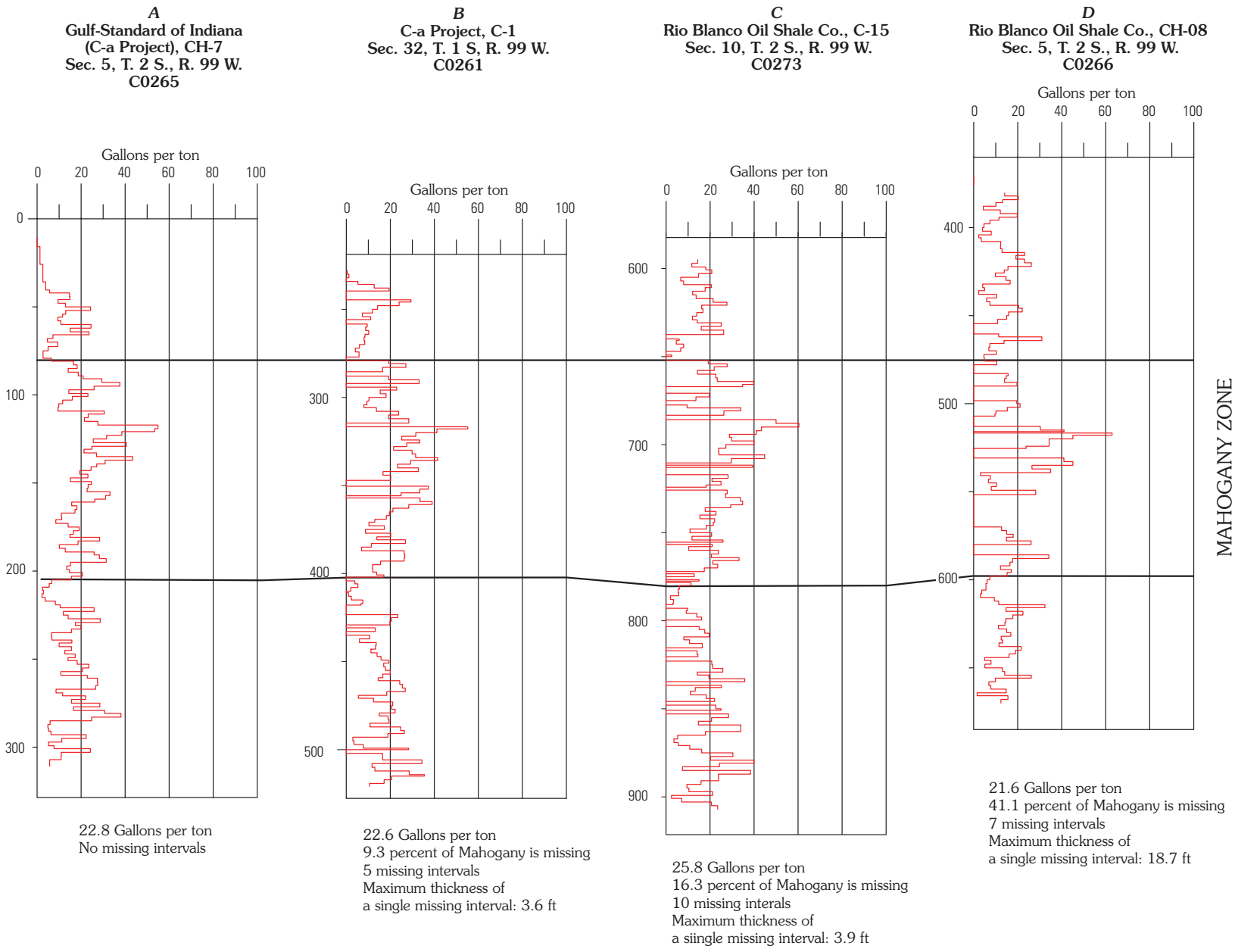


Figure 30. Oil-yield histograms listing percent missing intervals and average oil yield in gallons per ton for four core holes (*A*–*D*) in the northwest part of the basin. Black lines bracket the Mahogany zone. Locations are shown on figure 27.

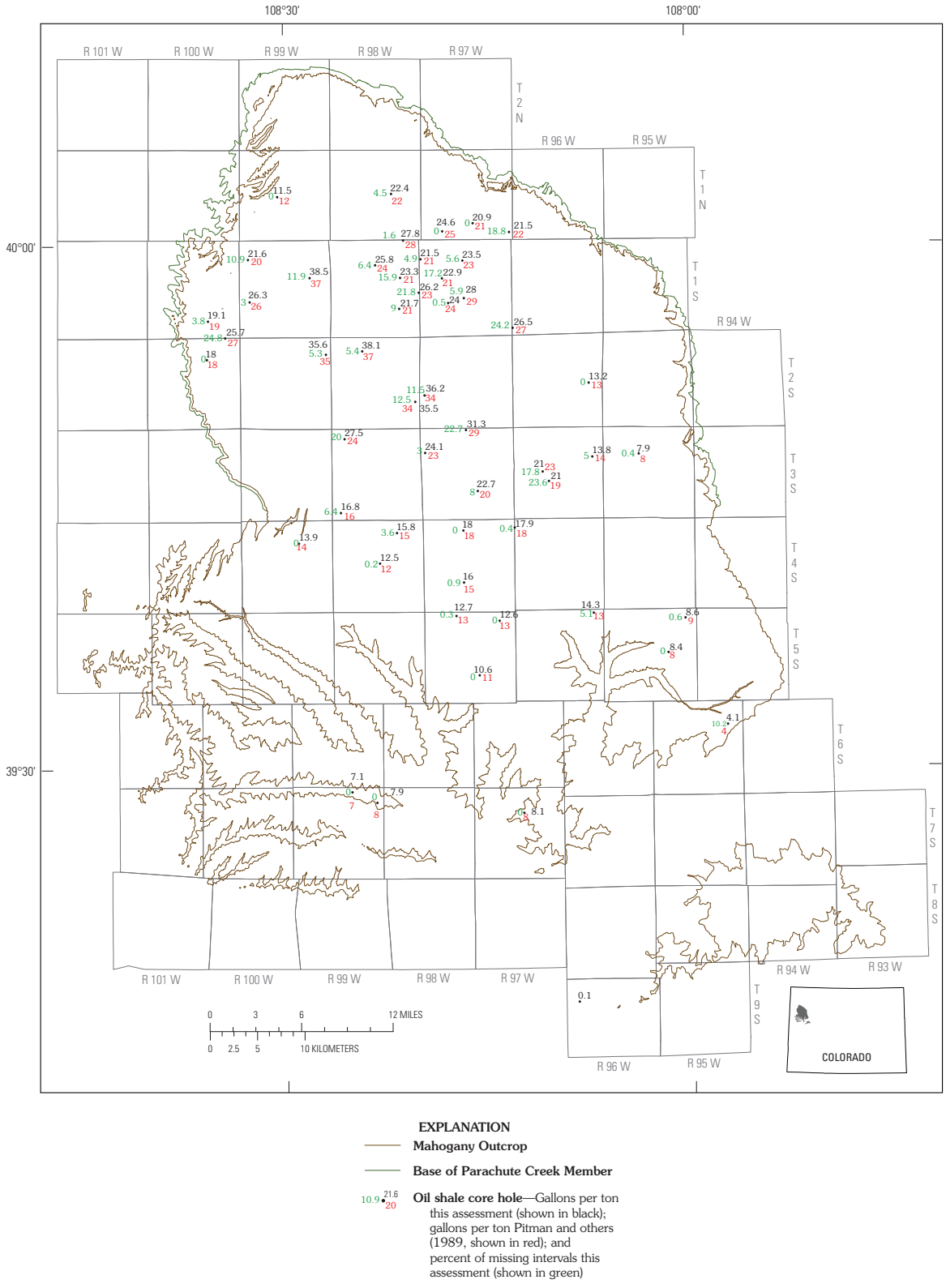


Figure 31. Map showing gallons per ton measurements used in both this assessment and the previous one to assess the R-5 zone. The black values are for this assessment, and the red values are from the previous assessment. The green numbers are the percent of missing interval in the R-5 zone. The brown line is the outcrop of the top of the Mahogany ledge, and the green line is the outcrop of the base of the Parachute Creek Member (digitized from Hail and Smith, 1994; 1997).

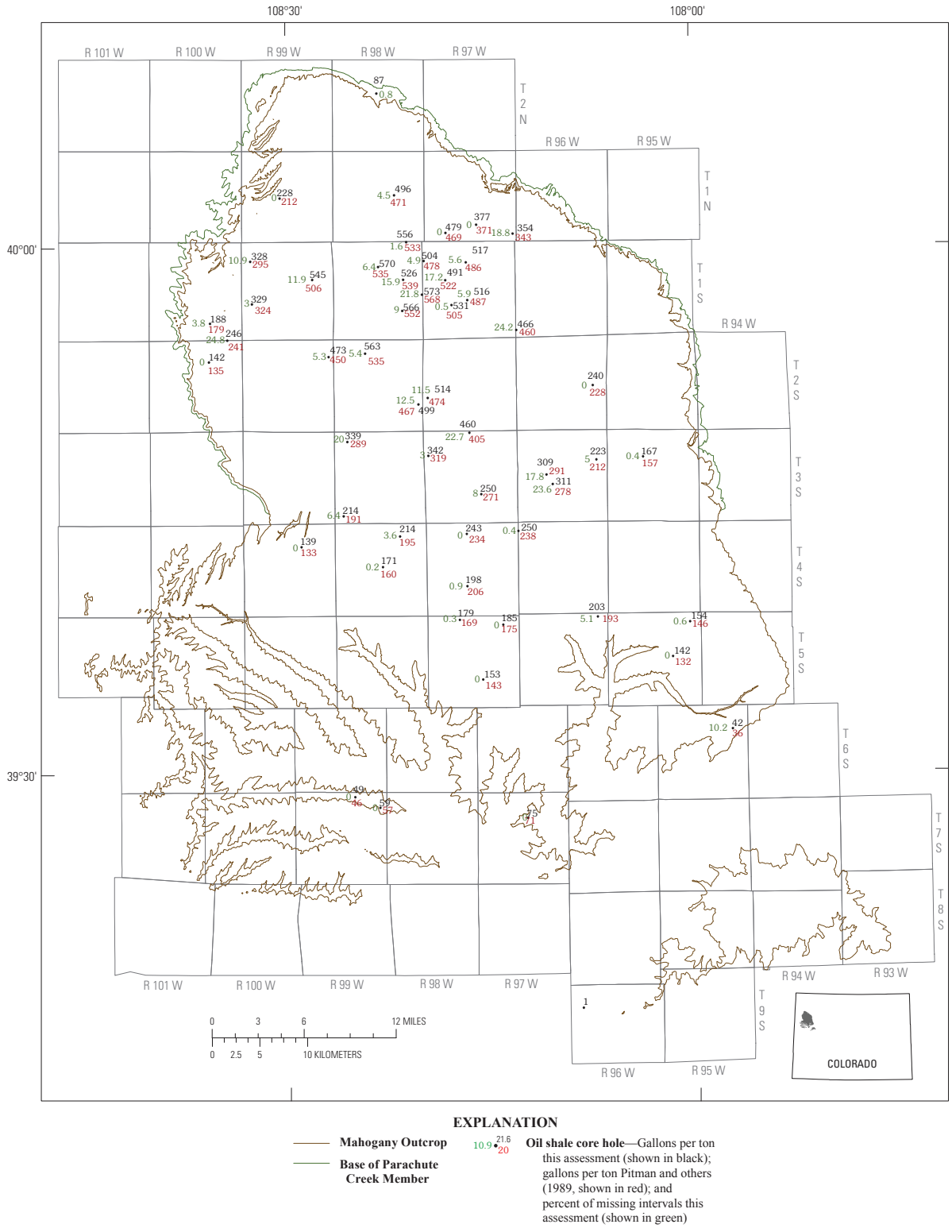


Figure 32. Map showing barrels per acre measurements used in both this assessment and the previous one to assess the R-5 zone. The black values are for this assessment and the red values are from the previous assessment. The green numbers are the percent of missing interval in the R-5 zone. The brown line is the outcrop of the top of the Mahogany ledge, and the green line is the outcrop of the base of the Parachute Creek Member (digitized from Hail and Smith, 1994; 1997).

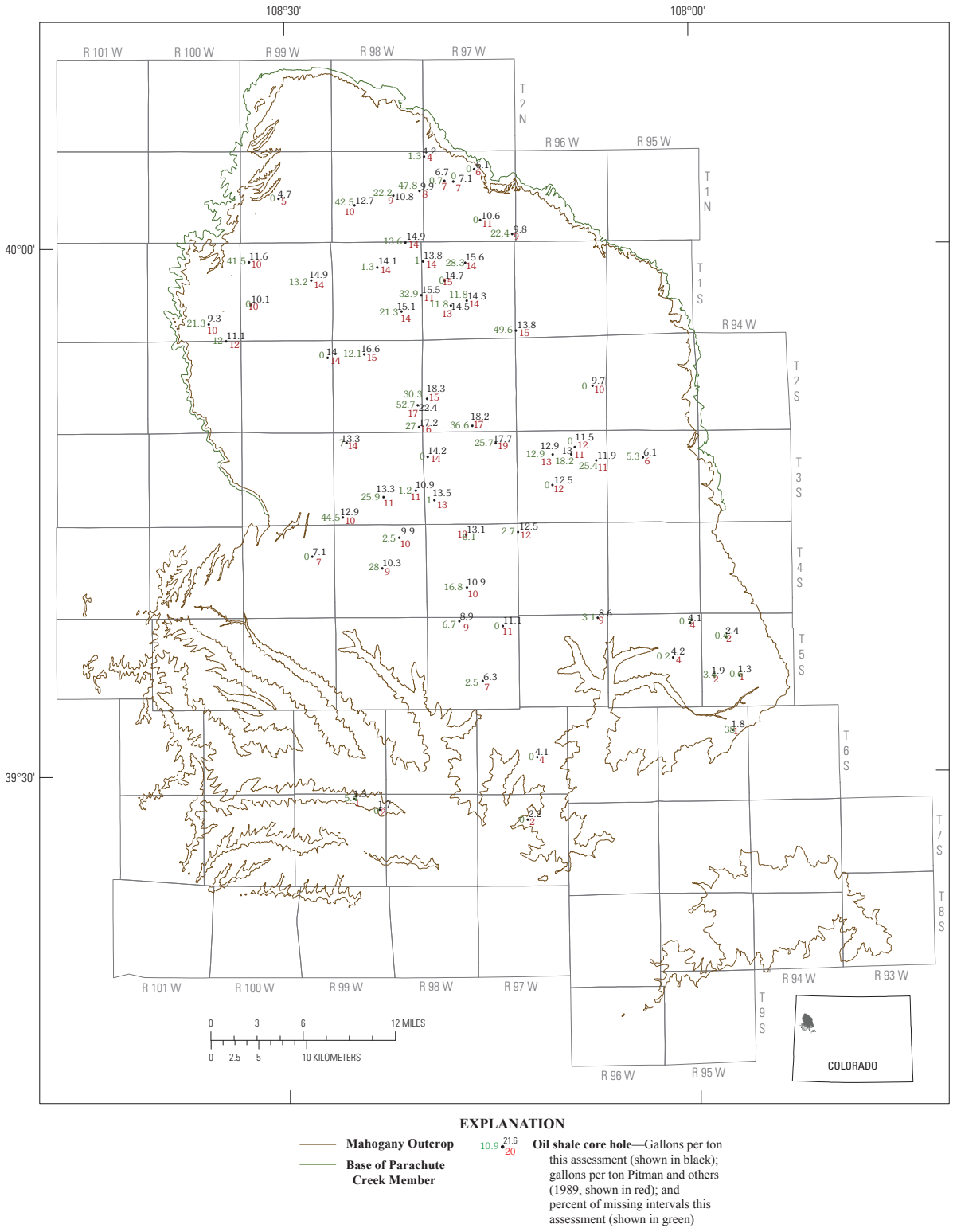


Figure 33. Map showing gallons per ton measurements used in both this assessment and the previous one to assess the L-5 zone. The black values are for this assessment, and the red values are from the previous assessment. The green numbers are the percent of missing interval in the L-5 zone. The brown line is the outcrop of the top of the Mahogany ledge and the green line is the outcrop of the base of the Parachute Creek Member (digitized from Hail and Smith, 1994; 1997).

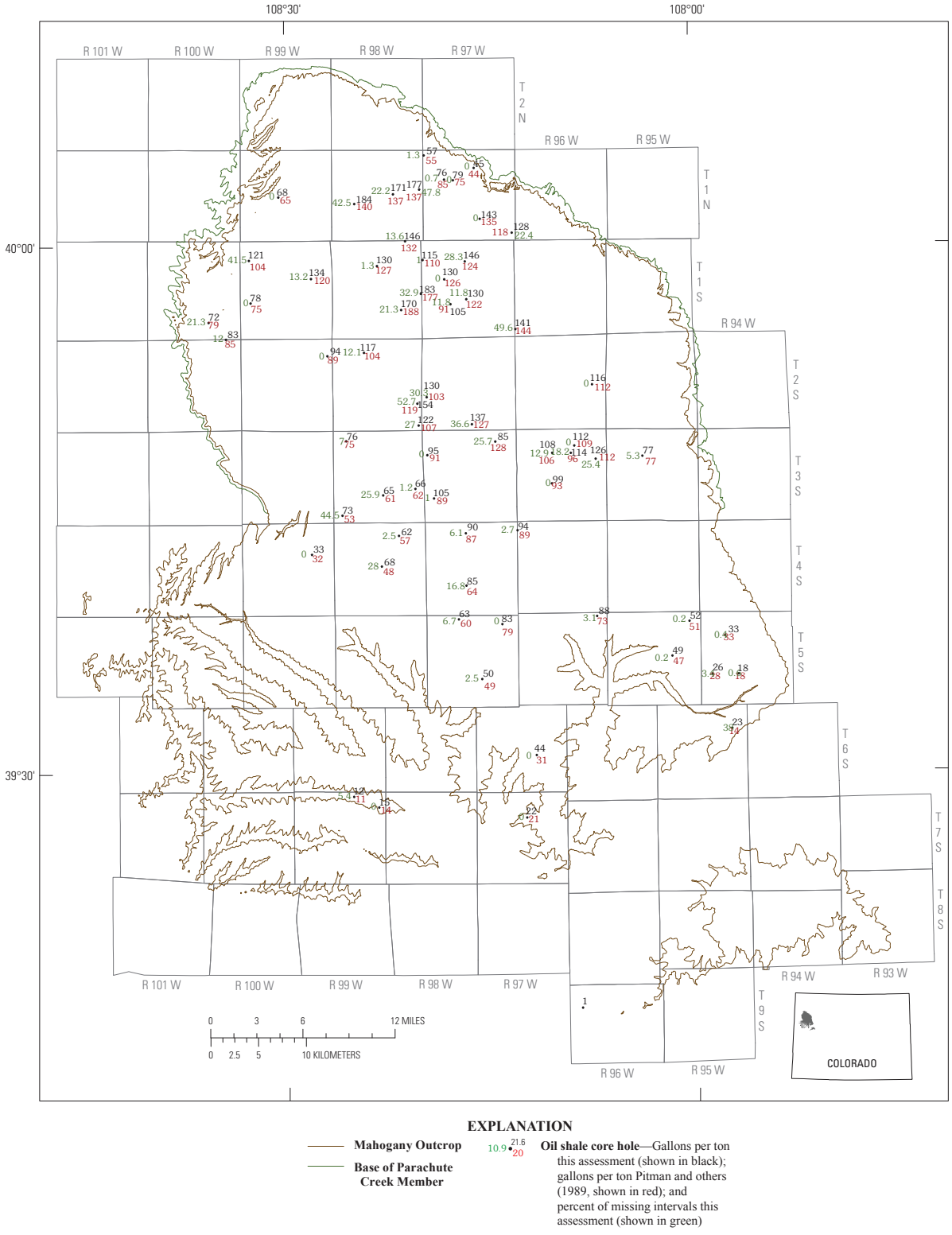


Figure 34. Map showing barrels per acre measurements used in both this assessment and the previous one to assess the R-5 zone. The black values are for this assessment and the red values are from the previous assessment. The green numbers are the percent of missing interval in the R-5 zone. The brown line is the outcrop of the top of the Mahogany ledge, and the green line is the outcrop of the base of the Parachute Creek Member (digitized from Hail and Smith, 1994; 1997).

Table 4. Gallons per ton, barrels per acre, and percent missing intervals for 49 selected core holes that were used to assess the R-5 zone in both this assessment and the assessment of Pitman and others (1989).

[GPT, gallons per ton; BPA, barrels per acre]

GPT here, R-5	GPT Pitman, R-5	BPA here, R-5	BPA Pitman, R-5	Percent missing	GPT here/GPT Pitman	BPA here/BPA Pitman
11.5	12	228	212	0	0.958	1.075
22.4	22	496	471	4.5	1.018	1.053
24.6	25	479	460	0	0.984	1.041
20.9	21	377	371	0	0.995	1.016
21.5	22	354	343	18.8	0.977	1.032
19.1	19	188	179	3.8	1.005	1.050
21.6	20	328	295	10.9	1.080	1.112
26.3	26	329	324	3	1.012	1.015
38.5	37	545	506	11.9	1.041	1.077
25.8	24	570	535	6.4	1.075	1.065
23.3	21	526	539	15.9	1.110	0.976
21.7	21	566	552	9	1.033	1.025
26.2	23	573	568	21.8	1.139	1.009
21.5	21	504	478	4.9	1.024	1.054
22.9	21	491	522	17.2	1.090	0.941
24	24	531	505	0.5	1.000	1.051
29	28	516	487	5.9	1.036	1.060
23.5	23	517	486	5.6	1.022	1.064
26.5	27	466	460	24.2	0.981	1.013
18	18	142	135	0	1.000	1.052
35.6	35	473	450	5.3	1.017	1.051
38.1	37	563	535	5.4	1.030	1.052
35.5	34	499	474	12.5	1.044	1.053
36.2	34	514	467	11.5	1.065	1.101
13.2	13	240	228	0	1.015	1.053
27.5	24	339	289	20	1.146	1.173
16.8	16	214	191	6.4	1.050	1.120
24.1	23	342	319	3	1.048	1.072
31.3	29	460	405	22.7	1.079	1.136
22.7	20	250	271	8	1.135	0.923
21	23	309	291	17.8	0.913	1.062
21	19	311	278	23.6	1.105	1.119
13.8	14	223	212	5	0.986	1.052
7.9	8	167	157	0.4	0.988	1.064

Table 4. Table listing gallons per ton, barrels per acre, and percent missing intervals for 49 selected core holes that were used to assess the R-5 zone in both this assessment and the assessment of Pitman and others (1989).—Continued.

[GPT, gallons per ton; BPA, barrels per acre]

GPT here, R-5	GPT Pitman, R-5	BPA here, R-5	BPA Pitman, R-5	Percent missing	GPT here/GPT Pitman	BPA here/BPA Pitman
13.9	14	139	133	0	0.993	1.045
12.5	12	171	160	0.2	1.042	1.069
15.8	15	214	195	3.6	1.053	1.097
18	18	243	234	0	1.000	1.038
16	15	198	206	0.9	1.067	0.961
17.9	18	250	238	0.4	0.994	1.050
12.7	13	179	169	0.3	0.977	1.059
12.6	13	185	175	0	0.969	1.057
11	10.6	153	143	0	1.038	1.070
14.3	13	203	193	5.1	1.100	1.052
8.4	8	142	132	0	1.050	1.076
8.6	9	154	146	0.6	0.956	1.055
7.1	7	49	46	0	1.014	1.065
7.9	8	59	57	0	0.988	1.035
8.1	8	75	71	0	1.013	1.056

Table 5. Gallons per ton, barrels per acre, and percent missing intervals for 61 selected core holes that were used to assess the L-5 zone in both this assessment and the assessment of Pitman and others (1989).

[GPT, gallons per ton; BPA, barrels per acre]

GPT here, L-5	GPT Pitman, L-5	BPA here, L-5	BPA Pitman, L5	Percent missing	GPT here/GPT Pitman	BPA here/BPA Pitman
4.7	5	68	65	0	0.940	1.046
12.7	10	184	140	42.5	1.270	1.314
10.8	9	171	137	22.2	1.200	1.248
9.9	8	177	137	4.7	1.238	1.292
4.2	4	57	55	1.3	1.050	1.036
6.7	7	76	85	0.7	0.957	0.894
7.1	7	79	75	0	1.014	1.053
6.1	6	45	44	0	1.017	1.023
10.6	11	143	135	0	0.964	1.059
9.8	9	128	118	22.4	1.089	1.085
9.3	10	72	79	21.3	0.930	0.911
11.6	10	121	104	41.5	1.160	1.163
10.1	10	78	75	0	1.010	1.040
14.9	14	134	120	13.2	1.064	1.117
14.1	14	130	127	1.3	1.007	1.024
14.9	14	146	132	13.6	1.064	1.106
15.1	14	170	188	21.3	1.079	0.904
15.5	11	183	177	32.9	1.409	1.034
13.8	14	115	110	1	0.986	1.045
14.7	15	130	126	0	0.980	1.032

Table 5. Gallons per ton, barrels per acre, and percent missing intervals for 61 selected core holes that were used to assess the L-5 zone in both this assessment and the assessment of Pitman and others (1989).—Continued

[GPT, gallons per ton; BPA, barrels per acre]

GPT here, L-5	GPT Pitman, L-5	BPA here, L-5	BPA Pitman, L5	Percent missing	GPT here/GPT Pitman	BPA here/BPA Pitman
14.3	14	130	122	11.8	1.021	1.066
15.6	14	146	124	28.3	1.114	1.177
11.1	12	83	85	12	0.925	0.976
14	14	94	89	0	1.000	1.056
16.6	15	117	104	12.1	1.107	1.125
22.4	17	154	119	52.7	1.318	1.294
17.2	16	122	107	27	1.075	1.140
18.3	15	130	103	30.3	1.220	1.262
18.2	17	137	127	36.6	1.071	1.079
9.7	10	116	112	0	0.970	1.036
14	13.3	76	75	7	1.053	1.013
12.9	10	73	53	44.5	1.290	1.377
13.3	11	65	61	25.9	1.209	1.066
11	10.9	66	62	1.2	1.009	1.065
14.2	14	95	91	0	1.014	1.044
13.5	13	105	89	1	1.038	1.180
17.7	19	85	128	25.7	0.932	0.664
12.5	12	99	93	0	1.042	1.065
12.9	13	108	106	12.9	0.992	1.019
11.5	12	112	109	0	0.958	1.028
13	11	114	96	18.2	1.182	1.188
11.9	11	126	112	25.4	1.082	1.125
6.1	6	77	77	5.3	1.017	1.000
7.1	7	33	32	0	1.014	1.031
10.3	9	68	48	28	1.144	1.417
13.1	13	90	87	6.1	1.008	1.034
10.9	10	85	64	16.8	1.090	1.328
12.5	12	94	89	2.7	1.042	1.056
8.9	9	63	67	6.7	0.989	0.940
11.1	11	83	79	0	1.009	1.051
6.3	7	50	49	2.5	0.900	1.020
8.6	9	88	73	3.1	0.956	1.205
4.2	4	49	47	0.2	1.050	1.043
4.1	4	52	51	0.2	1.025	1.020
2.4	2	33	33	0.4	1.200	1.000
1.9	2	26	28	3.4	0.950	0.929
1.3	1	18	18	0.6	1.300	1.000
2.2	2	44	31	0	1.100	1.419
1.3	1	12	11	5.4	1.300	1.091
1.7	2	15	14	8	0.850	1.071
2.2	2	22	21	10.4	1.100	1.048

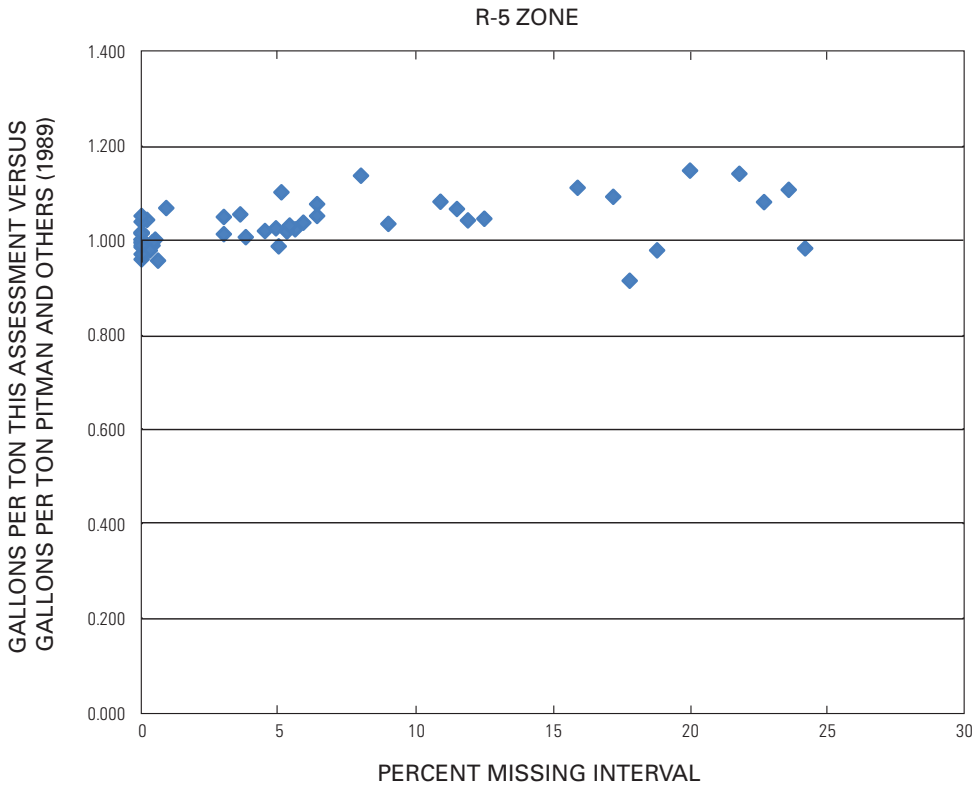


Figure 35. Ratio of gallons per ton calculated here with that calculated by Pitman and others (1989) for 49 core holes that penetrated the R-5 zone compared with percent missing intervals.

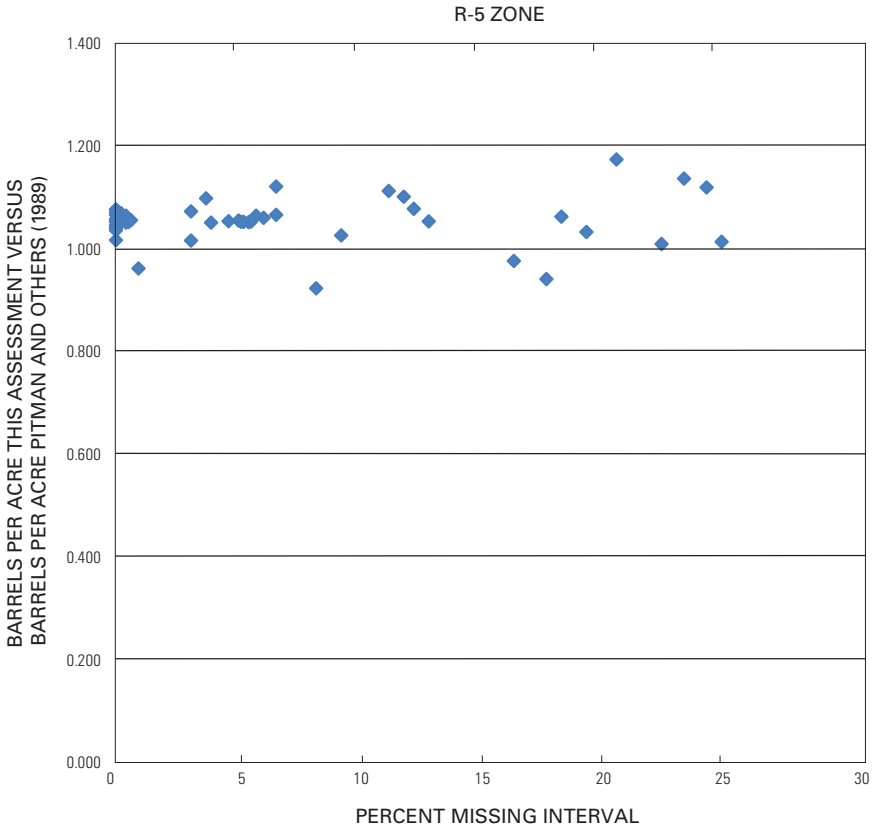


Figure 36. Ratio of barrels per acre calculated here with that calculated by Pitman and others (1989) for 49 core holes that penetrated the R-5 zone compared with percent missing intervals.

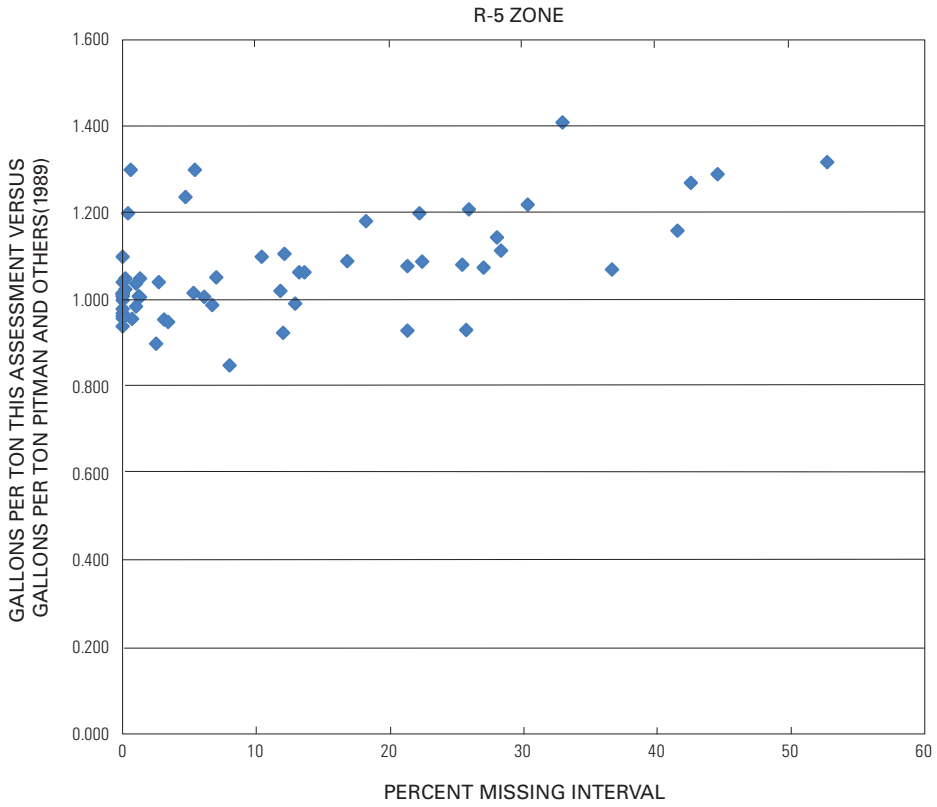


Figure 37. Ratio of gallons per ton calculated here with that calculated by Pitman and others (1989) for 61 core holes that penetrated the L-5 zone compared with percent missing intervals.

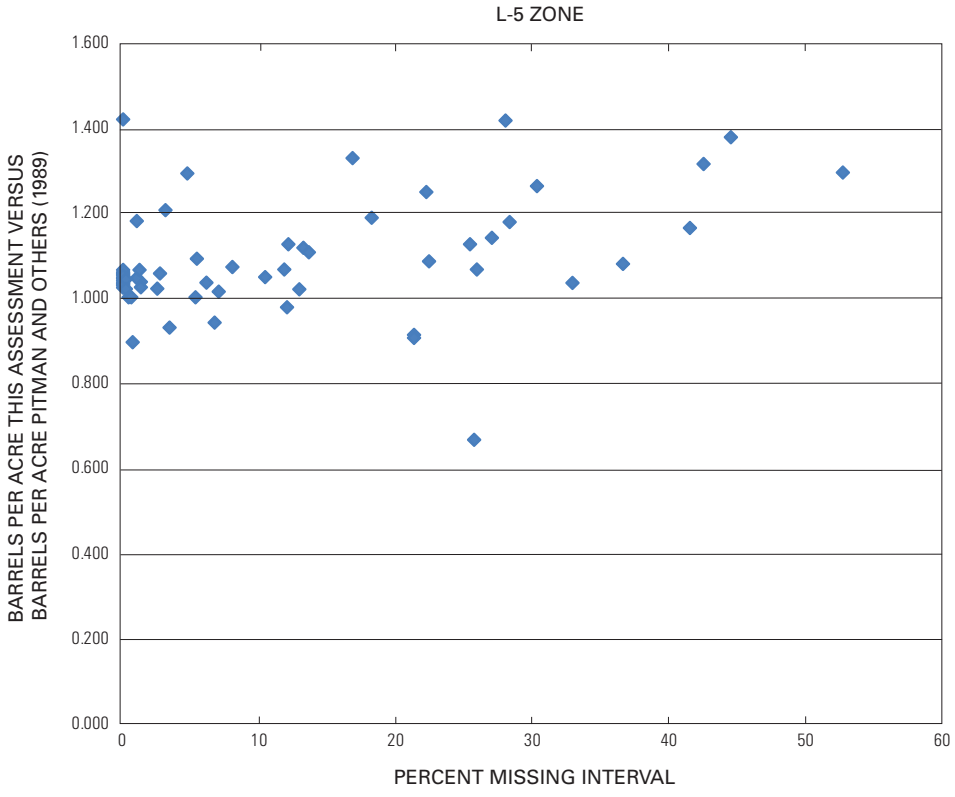


Figure 38. Ratio of barrels per acre calculated here with that calculated by Pitman and others (1989) for 61 core holes that penetrated the L-5 zone compared with percent missing intervals.

of the recovered core for that oil shale zone. We did not want to assign oil-yield values to unassayed saline beds as it would falsely increase the in-place oil shale calculations.

Leaching of nahcolite and halite beds in the R-5 and L-5 zones in the saline depocenter by relatively recent groundwater movement has created an unknown but significant amount of void space (Dyni, 1981). Void space occurs in collapse breccias, formed by the collapse due to leaching of thick halite and nahcolite beds, and in vugs and other spaces formed by the leaching of nahcolite aggregates and disseminated nahcolite. Leaching saline minerals out of a sample increases the GPT measured with Fischer assay, because the saline minerals no longer dilute the results. Applying this enhanced Fischer assay result to the entire interval including the void space results in an overestimation of the oil in place. This problem was not discussed in the previous assessment by Pitman and others (1989). However, descriptions of core taken in the leached zone rarely give estimates of the amount of void space, and thus it is unlikely that this problem has ever been systematically addressed. Thus, in-place oil estimates in the leached zone have probably been overestimated by an unknown amount in this assessment as well as the previous assessment. It should be possible to address this problem by careful core analysis and possibly by analyzing available geophysical logs, but strict time constraints did not allow us to pursue these possibilities at this time.

Methods Used to Generate Isopach Maps and Isoresource Maps

Pitman and others (1989) used geostatistical interpolation by kriging to generate their resource maps and resource numbers. According to Pitman and others (1989), statistical tests done prior to kriging determined that oil shale resource values were "statistically homogeneous" or that BPA resource values for oil shale core holes spaced a short distance apart tended to be more alike than values for core holes that were farther apart. Pitman and others (1989) used a computer program called BLUEPACK to determine that variations in oil yield were linear for all of the oil shale zones except the L-5 and R-2 zones. For these two zones there was a significant amount of variation that could not be predicted from available data and a "nugget-only" model was used to try to capture this variability. Pitman and others (1989) found that universal kriging gave good results in areas with good control, but in areas with little control such as basin margin areas universal kriging calculated very large error limits—as much as +1,298 percent, and several townships had insufficient control for universal kriging to calculate any resource numbers at all. Pitman and others (1989) manually determined in-place oil shale resources using isoresource contours and compared the results with the results from kriging. Pitman and others (1989) found that resource estimates determined by kriging compared favorably with resource values determined manually in areas with good control, however in areas with limited control, such as the basin margin areas, universal kriging dramatically overestimated resources. For example, in the township with the +1,298 percent error, kriging estimated 1.1 billion barrels of oil in place in the R-5 zone while hand contouring estimated only 219 million barrels.

As our study required close to 200 unique models to construct the isopach, GPT, BPA, and nahcolite assessments, we chose to use an RBF-multiquadric function instead of kriging as it facilitated the generation of quicker models while providing similar results. The RBF-multiquadric function in ESRI Geostatistical Analyst provided us with a quick, exact interpolator, and kept the model within our methodology's native software format (ESRI ArcGIS). Rusu and Rusu (2006) recently demonstrated that "soft computing methods" such as Radial Basis Functions (RBF) compare favorably with conventional "hard computing methods" such as kriging. In their study, they compared results when the RBF method and kriging were applied to the same data set. Rusu and Rusu (2006) cited a recent study where the Radioactivity Environmental Monitoring Group (REM) of the Institute for Environment and Sustainability at the Joint Research Center (JRC) of the European Commission invited participants to apply both RBF and kriging to a data set depicting variations in daily mean values of gamma-ray doses in southwest Germany. Part of the data points were hidden, and the participants were asked to estimate values at these hidden locations using the data points given. In general, both the RBF method and kriging were equally good at predicting the right results, except for areas with limited data where a proper variogram required for kriging is difficult to construct. In these areas, the RBF method gave better results. According to Rusu and Rusu (2006, p. 126) "The results and the execution time are quite similar for RBF and kriging, but the ease of use of RBF is overwhelming, compared to the use of kriging. When using RBF, the user has to choose only the radial functions type and the smoothing parameter. When using kriging, complex variogram modeling has to be done." The problems with generating a proper variogram with limited data may be in part why in the previous assessment kriging gave values with unacceptable margins of error for areas with limited data.

Some of the problems encountered with the previous assessment have largely been alleviated by the addition of a large number of new data points. Table 6 compares the number of data points used for each oil shale zone in the previous assessment with the number used in this assessment. In all, 2,178 data points are used here which compares with 1,083 used for the last. For the Mahogany zone, 396 data points were used this time as opposed to 131 in the previous assessment, whereas the number of data points used for the R-6 zone increased from 67 to 235. Despite these increases, there were still problems establishing trends in the marginal areas of the basin, and estimates from surface sections were added as a supplement to the core-hole data. The importance of having

detailed measured sections and good geologic mapping in these marginal areas to help fix regional oil-yield trends cannot be overemphasized.

Four maps were generated for each oil shale zone assessed here: 1) an isopach map, 2) a map showing variations in oil yield in GPT, 3) a map showing variations in BPA, and 4) a map showing total in-place oil in each 36-section township in the basin. We compared two methods for spatial interpolation, the RBF method discussed above, and the Inverse Distance Weighted (IDW) method. Resource models were created using ESRIs ArcGIS GeoStatistical Analyst extension. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding that location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance.

The RBF method in GeoStatistical Analyst (GA) is an exact interpolator that will honor all data points and not introduce any error at those locations unless a smoothing function is used. If a smoothing function is used, the RBF can also extrapolate values above or below the actual values outside the data-point locations. The final resource models were created with the RBF method using a sampling method containing eight moving window sectors with eight neighbors in each sector. No smoothing function was used. After numerous iterations, we found that the RBF method using these parameters yields surfaces that we believe best fit what was happening geologically. Both the RBF method and IDW method gave fairly similar results in areas with large numbers of control points, but the RBF method seemed to generate more reasonable results in marginal areas with little control.

Although the RBF method does not generate as complete an error estimate as kriging, it does give the difference between the predicted and measured value for each control point, and it does give an overall error for an entire map. 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 eight 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.

The barrels-per-township maps were generated by first intersecting the Piceance township polygon file with the outcrop polygon files. The resultant files included only those polygonal areas of each township that contained the desired zones to be assessed—one file for the Mahogany and those zones above the Mahogany, one file for B-groove and R-6, and one file for all zones below the R-6 (fig. 7). Using ESRIs Spatial Analyst's Zonal Statistics function, we were able to quantify each township in each barrels-per-acre resource model (1 acre = 63.615 meter cell size) by using each "clipped" township polygon (the result of intersecting the township polygon with the outcrop polygon) as the zone to quantify. In short, as the cell size in the model is one acre, the function sum totals all of the cells contained by each polygon to be assessed in the zone dataset. The resultant summary table contains a sum total of barrels for each township, as well as several other statistics. The maps were then generated by joining the summary table to each zone polygon file. For a more complete explanation

Table 6. Number of control points used to assess each oil shale zone in this assessment and the previous assessment by Pitman and Johnson (1978), Pitman (1979), and Pitman and others (1989). Oil shale zones from Cashion and Donnell (1972).

Oil shale zone	Number of control points	
	This assessment	Previous assessment
Mahogany zone	392	131
R-6 zone	235	67
L-5 zone	186	105
R-5 zone	176	107
L-4 zone	173	101
R-4 zone	171	104
L-3 zone	171	92
R-3 zone	158	93
L-2 zone	155	85
R-2 zone	148	85
L-1 zone	122	63
R-1 zone	91	50
Total	2178	1083

of this procedure see Mercier and others (chapter 3, this CD-ROM).

Here we compare the results of the RBF method and kriging using the same data sets that were used in Pitman and others (1989). Figures 39 and 40 are maps showing barrels per acre for the R-5 and L-5 zones generated using the RBF and using only the data shown on the kriged R-5 assessment map of Pitman and others (1989). The R-5 and L-5 zones were used for this comparison because they had the most data points of all the oil shale zones that were kriged (table 6). The Mahogany zone had more data points, but kriging was not used to assess it. Tables 7 and 8 list the barrels per acre for each township using the RBF method and kriging. A comparison was also made between only the best townships, those where kriging in the assessment of Pitman and others (1989) estimated an error of 20 percent or less at the 95 percent confidence level. For the R-5 zone, the overall results using RBF were 5.15 percent higher than the kriged results and only 0.13 percent higher when only the best townships were compared (table 8). For the L-5 zone, our overall results were 6.28 percent higher than kriged results and 7.50 percent higher for the best townships (table 9). Townships where kriging gave greater results are shown in red and those where the RBF method gave greater results are shown in blue on figures 39 and 40. For the R-5 zone, kriging gave higher results throughout much of the central part of the basin (fig. 39), whereas for the L-5 zone only a few scattered townships gave higher results using kriging (fig. 40). Some of the discrepancy in the marginal areas is because we used a new outcrop line that encompasses a larger area than the previous assessment.

Detailed Description and Assessment Results of Oil Shale Zones

This study presents an in-place assessment of the Green River Formation in the Piceance Basin and, for comparative purposes, this assessment uses the same two sets of maps used in the previous in-place assessment by Pitman and others (1989): 1) maps showing variations in oil yield measured in GPT, and 2) maps showing variations in BPA. A table was compiled that lists the in-place resource for each oil shale zone in each township in the basin similar to the one compiled by Pitman and others (1989). This allows us to compare our results with Pitman and others (1989) who estimated total oil in each township using both hand contouring and kriging.

The extent of each oil shale zone around the margins of the basin had to be estimated in order to define the limits of the assessed area. With the exception of the Mahogany zone, the oil shale zones have been incompletely mapped in outcrop around the margins of the basin because many of them have graded into largely marginal lacustrine rock and cannot be identified. Pitman and others (1989) did not specify what outcrop line was used to define the limits of their assessed areas. Only the outcrop of the Mahogany zone is shown on their assessment maps, and it is assumed that that line was used to define the limits of all their assessment areas. Two outcrop lines are shown in our assessment maps: the top of the Mahogany ledge, and the base of the Parachute Creek Member of the Green River Formation. The base of the Parachute Creek Member, as mapped around the basin margins, is variably placed at the base of the R-2 zone to the base of the R-4 zone, and the base of the Mahogany zone (see for example, Johnson and others, 1988). The contacts are from Hail and Smith (1994, 1997). For zones R-6 and above, we used the top of the Mahogany ledge as the limit of the assessed area, and for zones below the R-6, we used the base of the Parachute Creek Member. Using these two outcrop lines results in slightly underestimating the area underlain by the R-6 zone and higher, and slightly overestimating the areas of the zones below R-6.

As noted above, nahcolite that was present in either disseminated or aggregate form in a core was typically assayed along with the oil shale thus diluting the overall oil yield for the sample. This resulted in a lower gallons per ton measured for the assayed interval than if the nahcolite had been removed prior to assaying. However, a bed of almost pure halite or nahcolite or both that was encountered during coring in the saline depocenter was typically not assayed and shows up as a zero oil-yield value on the oil-yield histograms. These beds were not included when calculating the average GPT for the enclosing oil shale zone, and thus the average for the oil shale zone was not reduced by the presence of nearly pure nahcolite and (or) halite beds.

Oil-yield trends are poorly constrained in many of the marginal areas of the basin where core holes are sparse, and resource maps generated early in this project appeared to overestimate or underestimate oil yields in these areas based on our knowledge of the geology. To better constrain oil-yield trends in these areas we estimated oil yields in 14 of the 20 surface sections that were used to help construct the isopach maps of the oil shale zones (table 9). Without these surface sections, the RBF method extrapolated to negative values in many of these marginal areas. Many of the oil shale zones have graded into marginal lacustrine lithologies with little or no kerogen content in these surface sections. We could not assign zero values, however because the interpolation program required that these points have some minimal value. Oil yield was placed at 0.1 GPT and barrels per acre was placed at 1,000 for these sections (table 4).

We did not attempt to assess the amount of oil shale in the basin that adheres to a defined set of criteria such as the total amount of oil in intervals averaging at least 25 ft thick and 25 GPT, as some earlier assessments had done. This is, in part, because the FORTRAN program used for these calculations needs to be rewritten in modern computer code, but also because we need to seriously rethink the whole process used

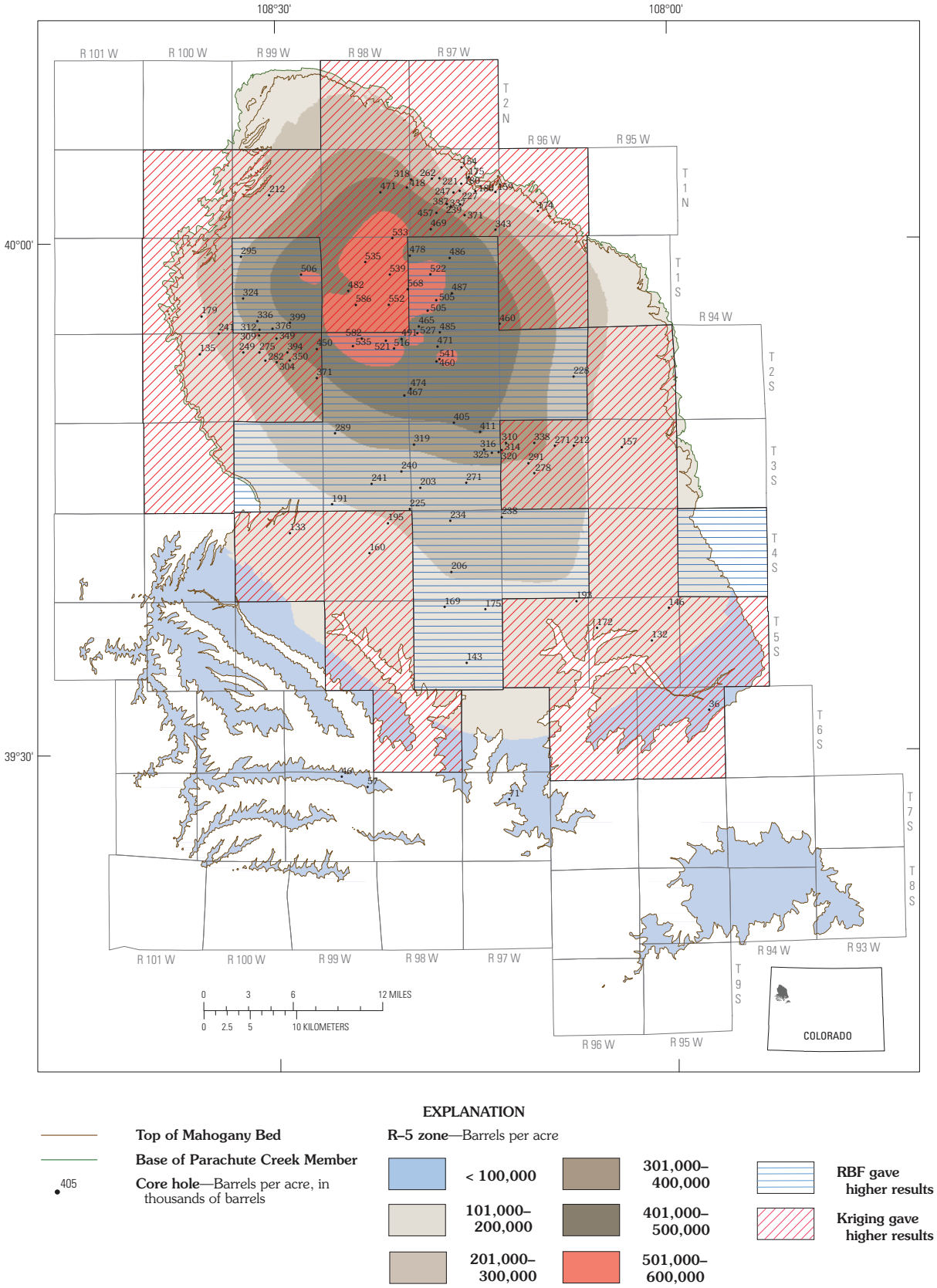


Figure 39. Barrels per acre map for the R-5 zone plotted using the Radial Basis Function Method (RBF) using the same core holes and the same barrels per acre values (in black) used by Pitman and others (1989).

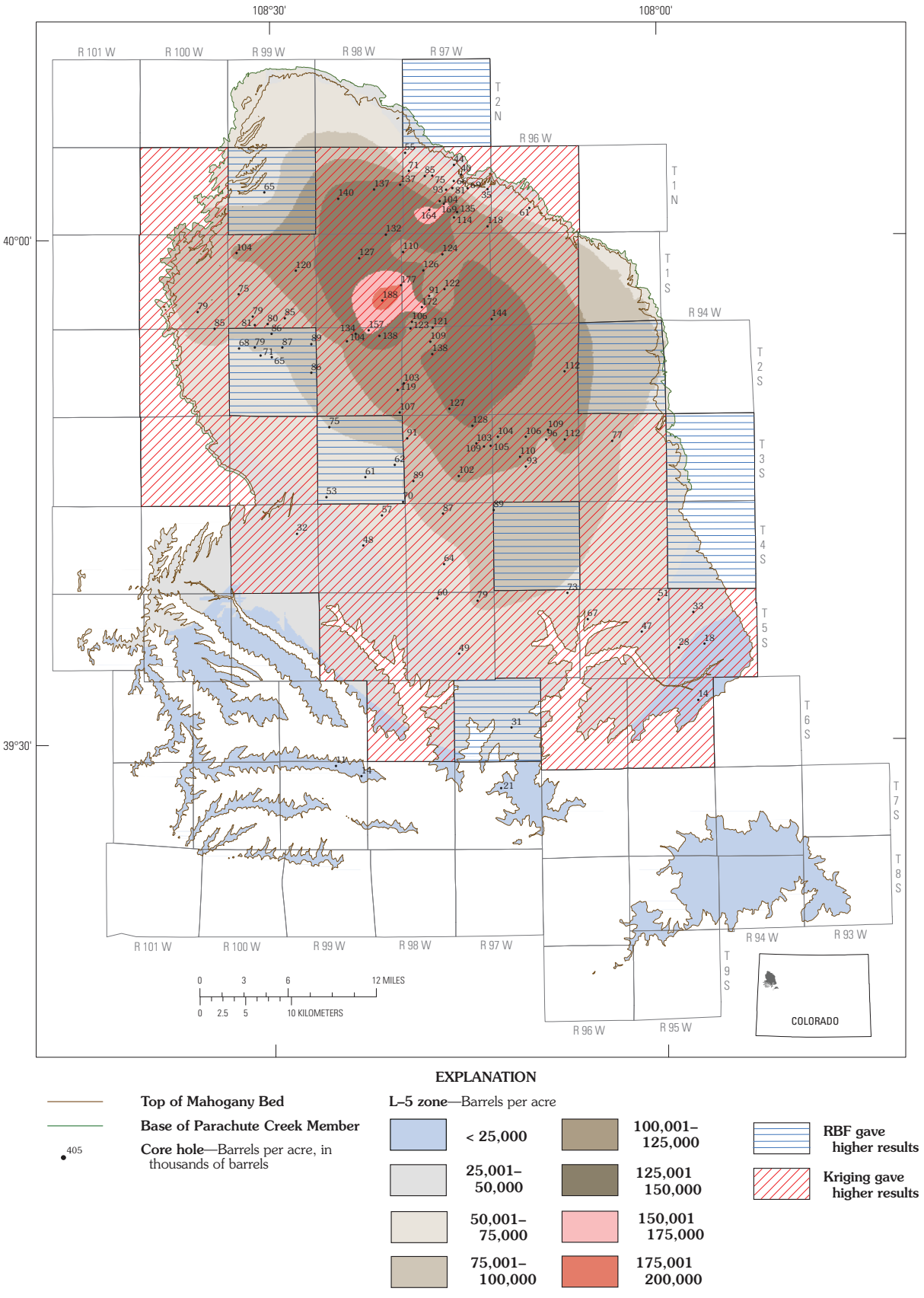


Figure 40. Barrels per acre map for the L-5 zone plotted using the Radial Basis Function Method (RBF) using the same core holes and the same barrels per acre values (in black) used by Pitman and others (1989).

Table 7. Comparing total barrels per township for the R-5 zone using the Radial Basis Function Method (RBF) here with the results using kriging by Pitman and others (1989). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.

Township, Range	Kriging (Pitman and others, 1989) R-5	95 percent confidence	RBF using Pitman's data	Percent diff. RBF vs kriging
1N 96W	1,419,119,000	±22	1,794,120,000	26.42
1N 97W	5,921,871,000	±5	6,109,330,000	3.17
1N 98W	8,882,764,000	±14	9,292,230,000	4.61
1N 99W	5,785,083,000	±23	5,966,310,000	3.13
1N 100W	220,454,000	±82	965,061,000	337.76
2N 97W	187,961,000	±85	432,532,000	130.12
2N 98W	218,723,000	±1298	3,576,110,000	1534.99
2N 99W		–-		
2N 100W				
1S 95W		–-		
1S 96W	6,708,348,000	±31	7,329,560,000	9.26
1S 97W	11,746,252,000	±5	11,674,400,000	-0.61
1S 98W	12,581,545,000	±4	12,612,100,000	0.24
1S 99W	9,627,029,000	±7	9,560,800,000	-0.69
1S 100W	2,743,627,000	±33	3,481,780,000	26.90
2S 94W				
2S 95W	3,875,865,000	±88	3,922,430,000	1.20
2S 96W	7,483,801,000	±17	7,332,360,000	-2.02
2S 97W	10,877,714,000	±9	10,807,300,000	-0.65
2S 98W	10,094,247,000	±8	10,058,000,000	-0.36
2S 99W	6,651,097,000	±15	6,695,290,000	0.66
2S 100W	1,676,860,000	±57	2,031,350,000	21.14
3S 94W		–-		
3S 95W	3,085,710,000	±79	3,643,140,000	18.06
3S 96W	5,834,195,000	±13	5,907,430,000	1.26
3S 97W	7,077,905,000	±8	6,944,300,000	-1.89
3S 98W	5,882,000,000	±12	5,855,370,000	-0.45
3S 99W	4,045,525,000	±49	4,003,880,000	-1.03
3S 100W	150,523,000	±216	472,698,000	214.04
4S 94W	1,406,316,000	±153	1,090,650,000	-22.45
4S 95W	3,709,025,000	±60	3,831,660,000	3.31
4S 96W	4,733,460,000	±35	4,686,960,000	-0.98
4S 97W	4,840,702,000	±16	4,831,700,000	-0.19
4S 98W	3,626,276,000	±31	3,760,870,000	3.71
4S 99W	2,211,771,000	±119	2,666,560,000	20.56
4S 100W		–-		
4S 101W		–-		
5S 94W	1,659,768,000	±175	1,679,310,000	1.18
5S 95W	2,635,176,000	±33	2,714,700,000	3.02
5S 96W	3,099,056,000	±53	3,114,720,000	0.51
5S 97W	3,375,428,000	±35	3,360,190,000	-0.45

Table 7. Comparing total barrels per township for the R-5 zone using the Radial Basis Function Method (RBF) here with the results using kriging by Pitman and others (1989). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.—Continued

Township, Range	Kriging (Pitman and others, 1989) R-5	95 percent confidence	RBF using Pitman's data	Percent diff. RBF vs kriging
5S 98W	1,760,651,000	±198	2,143,860,000	21.77
5S 99W		—-		
5S 100W		—-		
5S 101W		—-		
6S 94W		—-		
6S 95W	561,821,000	±199	633,172,000	12.70
6S 96W	838,119,000	±142	845,871,000	0.92
6S 97W		—-		
6S 98W	856,785,000	±114	913,930,000	6.67
Total:	168,092,572,000		176,742,034,000	
	Percent difference using RBF.	5.15		
	Sum best townships kriged:	100,850,025,000		
	Sum best townships RBF:	100,985,320,000		
	Percent difference using RBF:	0.13		

Table 8. Comparing total barrels per township for the L-5 zone using the Radial Basis Function Method (RBF) here with the results using kriging by Pitman and others (1989). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.

Township, Range	Kriging, Pitman and others (1989) L-5	95 percent confidence	RBF using Pitman's data	Percent diff RBF vs Kriging
1N 96W	481,007,000	±36	597,498,000	24.22
1N 97W	1,742,788,000	±10	1,947,430,000	11.74
1N 98W	2,191,041,000	±16	2,721,310,000	24.20
1N 99W	2,074,246,000	±33	1,879,500,000	-9.39
1N 100W	120,010,000	±54	377,498,000	214.56
2N 97W	59,849,000	±54	91,961,300	53.66
2N 98W		—-		
2N 99W		—-		
2N 100W				
1S 95W		—-		
1S 96W	2,120,861,000	±29	2,601,150,000	22.65
1S 97W	2,949,845,000	±10	3,145,710,000	6.64
1S 98W	2,866,351,000	±8	3,371,510,000	17.62
1S 99W	2,293,272,000	±13	2,397,060,000	4.53
1S 100W	1,143,711,000	±38	1,399,940,000	22.40
2S 94W				
2S 95W	2,533,654,000	±53	2,038,080,000	-19.56
2S 96W	2,605,432,000	±18	2,785,940,000	6.93
2S 97W	2,850,288,000	±9	2,983,640,000	4.68
2S 98W	2,218,631,000	±10	2,336,020,000	5.29
2S 99W	1,663,017,000	±24	1,654,860,000	-0.49
2S 100W	745,547,000	±71	862,447,000	15.68
3S 94W	57,906,000	±384	248,785,000	329.64
3S 95W	1,771,464,000	±66	1,750,070,000	-1.21
3S 96W	2,157,516,000	±17	2,227,300,000	3.23
3S 97W	2,181,891,000	±10	2,353,650,000	7.87
3S 98W	1,630,335,000	±17	1,544,520,000	-5.26
3S 99W	1,072,910,000	±50	1,105,750,000	3.06
3S 100W	81,431,000	±115	167,073,000	105.17
4S 94W	604,929,000	±115	415,039,000	-31.39
4S 95W	1,504,636,000	±25	1,525,650,000	1.40
4S 96W	1,863,716,000	±18	1,818,460,000	-2.43
4S 97W	1,693,348,000	±20	1,712,340,000	1.12
4S 98W	1,064,422,000	±47	1,095,160,000	2.89
4S 99W	565,643,000	±235	712,652,000	25.99
4S 100W		—-		
4S 101W		—-		
5S 94W	462,398,000	±131	475,563,000	2.85

Table 8. Table comparing total barrels per township for the L-5 zone using the Radial Basis Function Method (RBF) here with the results using kriging by Pitman and others (1989). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.—Continued

Township, Range	Kriging, Pitman and others (1989) L-5	95 percent confidence	RBF using Pitman's data	Percent diff RBF vs Kriging
5S 95W	979,482,000	±40	988,904,000	0.96
5S 96W	1,133,047,000	±30	1,220,350,000	7.71
5S 97W	1,134,248,000	±46	1,225,900,000	8.08
5S 98W	478,075,000	±206	635,610,000	32.95
5S 99W		—-		
5S 100W		—-		
5S 101W		—-		
6S 94W		—-		
6S 95W	185,888,000	±259	223,354,000	20.16
6S 96W	270,021,000	±74	302,842,000	12.15
6S 97W	709,285,000	±74	617,220,000	-12.98
6S 98W	270,399,000	±70	272,452,000	0.76
Total:	52,532,540,000		55,830,198,300	
Percent difference using RBF:		6.28		
Sum best townships Kriged:		27,086,938,000		
Sum best townships RBF:		29,117,590,000		
Percent difference using RBF:		7.50		

Table 9. Estimating thicknesses, gallons per ton (GPT), and barrels per acre (BPA) for surface sections. Data was used to control isopach maps and GPT maps in basin margin areas.

Name	Reference	Notes	Location	Latitude	Longitude	B thickness
Philadelphia Creek	Johnson and others (1988)		32-1S-100W	39°55'18"	108°38'03"	18
Little Burma Road	Johnson and others (1988)		18-4S-100W	39°42'04"	108°39'27"	10
Spring Creek	Unpublished sur. Sec.		11-2N-99W	40°09'48"	108°27'48"	81
Yellow Creek	Unpublished sur. Sec.		15-2N-98W	40°08'57"	108°22'39"	98
Deep Channel Creek	Unpublished sur. Sec.	Assumes top Ss is top R-0	36-4N-96W	40°16'37"	108°07'04"	
Anvil Points	Unpublished sur. Sec.	Assumes top red is top R-0	18-6S-94W	39°31'4"	107°55'29"	
Rio Blanco	Unpublished sur. Sec.		5-4S-94W	39°44'15"	107°57'24"	
Horsethief Mtn.	Johnson and May (1978)	Assumes top Ss is top R-0	18-9S-96W	39°16'37"	108°08'34"	
Kissinger Gulch	Pipiringos and Johnson (1976)	Assumes "C" bed is top R-0	14-1N-96W	40°03'31"	108°08'14"	
Sec. D Wagon Track Ridge	Johnson and May (1978)	Top R-0 is top big Ss below Km tuff	21-8S-98W	39°20'29"	108°19'54"	
Sec. C Wagon Track Ridge	Johnson and May (1978)	Top R-0 is top big Ss below Km tuff	32-8S-99W	39°19'	108°26'52"	
Sec B Left Hand Draw	Johnson and May (1978)	Top R-0 tied to Km, base 1st algal below Km	23-8S-100W	39°20'27"	108°31'13"	
Sec A Middle Dry Fork	Johnson and May (1978)	Top R-0 tied to Km, base 1st algal below Km	7-8S-100W	39°22'52"	108°35'37"	
Munger Creek	Johnson and others (1988)		12-7S-102W	39°27'46"	108°43'10"	
Baxter Pass	Johnson and others (1988)	Base L-1 is base 1st good oil shale	24-5S-103W	39°36'20"	108°53'59"	
Evacuation Creek	Johnson and others (1988)	Base L-1 is base 1st good oil shale	1-12S-25 E	39°47'59"	109°04'28"	
Hell's Hole	Johnson and others (1988)	Base L-1 is base 1st good oil shale	31-1S-103	39°54'52"	108°59'35"	
Powell Park	Pipiringos and Johnson (1975)	R-0, L-0 all Ss with some red beds	28-1N-95W	40°01'50"	108°03'52"	
Lower Piceance Creek	Pipiringos and Johnson (1976)	Top "C" is top L-0	11-1N-97W	40°04'10"	108°14'33"	
Douglas Pass	Johnson and others (1988)		25-5S-102	39°35'36"	108°47'05"	

Table 9. Estimating thicknesses, gallons per ton (GPT), and barrels per acre (BPA) for surface sections. Data was used to control isopach maps and GPT maps in basin margin areas.—Continued

Name	R6 thickness	L5 thickness	R-5 thickness	L-4 thickness	R-4 thickness	L-3 thickness	R-3 thickness	L-2 thickness	R-2 thickness
Philadelphia Creek	98	100	100	50	50	27	54	27	54
Little Burma Road	113	59	60	30	30	13	25	13	25
Spring Creek	292	192	145						
Yellow Creek	537	256							
Deep Channel Creek									
Anvil Points									
Rio Blanco									
Horsethief Mtn.									
Kissinger Gulch									
Sec. D Wagon Track Ridge									
Sec. C Wagon Track Ridge									
Sec B Left Hand Draw									
Sec A Middle Dry Fork									
Munger Creek									
Baxter Pass									
Evacuation Creek									
Hell's Hole									
Powell Park									
Lower Piceance Creek									
Douglas Pass									

Table 9. Estimating thicknesses, gallons per ton (GPT), and barrels per acre (BPA) for surface sections. Data was used to control isopach maps and GPT maps in basin margin areas.—Continued

Name	L-1 thickness	R-1 thickness	L-0 thickness	R-0 thickness	L-5 GPT	L-5 BPA	R-5 GPT	R-5 BPA	L-4 GPT	L-4 BPA	R-4 GPT	R-4 BPA
Philadelphia Creek	75	288	25	195								
Little Burma Road	150	392	15	75								
Spring Creek												
Yellow Creek												
Deep Channel Creek				463								
Anvil Points				585								
Rio Blanco				390								
Horsethief Mtn.			20	260	0.1	500	0.1	500	0.1	500	0.1	500
Kissinger Gulch			20	500								
Sec. D Wagon Track Ridge			20	245								
Sec. C Wagon Track Ridge			20	232								
Sec B Left Hand Draw			20	162								
Sec A Middle Dry Fork	135	255	20	166					0.1	500	0.1	500
Munger Creek		248	30	142								
Baxter Pass	120	314	20	98								
Evacuation Creek	175	403	20	72								
Hell's Hole	177	324	20	60								
Powell Park												
Lower Piceance Creek												
Douglas Pass												

Table 9. Estimating thicknesses, gallons per ton (GPT), and barrels per acre (BPA) for surface sections. Data was used to control isopach maps and GPT maps in basin margin areas.—Continued

Name	L-3 GPT	L-3 BPA	R-3 GPT	R-3 BPA	L-2 GPT	L-2 BPA	R-2 GPT	R-2 BPA	L-1 GPT	L-1 BPA	R-1 GPT	R-1 BPA	L-0 GPT	L-0 BPA	R-0 GPT	R-0 BPA
Philadelphia Creek																
Little Burma Road	0.1	500	0.1	500	0.1	500	0.1	500								
Spring Creek																
Yellow Creek																
Deep Channel Creek	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500
Anvil Points	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500
Rio Blanco									0.1	500	0.1	500	0.1	500	0.1	500
Horsethief Mtn.	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500
Kissinger Gulch																
Sec. D Wagon Track Ridge									0.1	500	0.1					
Sec. C Wagon Track Ridge									0.1	500	0.1					
Sec B Left Hand Draw									0.1	500	0.1					
Sec A Middle Dry Fork	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1					
Munger Creek																
Baxter Pass	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1					
Evacuation Creek	0.1	500	0.1	500	0.1	500	0.1	500								
Hell's Hole	0.1	500	0.1	500	0.1	500	0.1	500								
Powell Park									0.1	500	0.1	500	0.1	500	0.1	500
Lower Piceance Creek													0.1	500	0.1	500
Douglas Pass	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500	0.1	500				

for these calculations because of the many issues raised here with missing core intervals. As previously discussed, missing intervals had to be assigned values in order to make the FORTRAN program function. The program uses a special algorithm to identify the longest sequence in an assayed core or section that maintained a specified average yield of oil in GPT and also has restraints that exclude intervals of low-grade shale that were too thick. Unless the individual is extremely skillful at assigning values to missing core, it would seem that the algorithm would not calculate very meaningful results.

R-0 Zone

The R-0 and L-0 zones comprise the first stage of Lake Uinta as defined by Johnson (1985) and have not been assessed prior to this assessment. The R-0 oil shale zone is the first oil shale zone deposited after the Long Point transgression when two much smaller freshwater lakes in the Piceance and Uinta Basins expanded and connected across the Douglas Creek arch to form one large lake, Lake Uinta (figs. 3 and 4) (Johnson, 1985). The base of the R-0 zone is the base of the Long Point bed, the basal transgressive bed of the Long Point transgression, which is marked in outcrop around much of the basin margins by a mollusk-rich bed overlying the variegated mudstones of the fluvial Wasatch Formation (Johnson, 1989). The base of the R-0 zone can be identified throughout much of the deeper parts of the basin as a distinctive resistivity "kick" on electric logs (see for example, Johnson, 1989). Along the northwest margin of the basin, the R-0 zone overlies freshwater lacustrine rocks of the Cow Ridge Member of the Green River Formation, and in this area, the base of the R-0 zone is marked by a change from mollusk-bearing freshwater lacustrine rocks below to low-grade oil shale above (Johnson, 1985; Johnson and others, 1988). The R-0 zone grades into sandstones towards the eastern margin of the basin.

The upper part of the R-0 zone is marked in the central part of the basin by a distinctive increase in resistivity on electric logs known informally as the orange marker, named for the color of pen used to mark it on geophysical logs (Chancellor and others, 1974; Ziemba, 1974). The orange marker, which comprises about the upper 30 ft of the R-0 zone (fig. 7), is caused by a slight increase in carbonate in the illitic sediments. The orange marker is equivalent to the carbonate marker in the Uinta Basin part of Lake Uinta, which also represents a temporary increase in carbonate precipitation (Johnson, 1989).

This slight increase in carbonate content is not conspicuous in outcrop, and the top of the R-0 zone is difficult to identify in marginal lacustrine rocks exposed around the margins of the basin. However, the top of the overlying L-0 zone or base of the R-1 zone is thought to occur at the base of the first illitic moderate to rich oil shale bed of the R-1 oil shale zone. Table 4 lists approximate thicknesses for the R-0 and overlying L-0 zones from detailed measured sections and surface locations published by Johnson and May (1978), Johnson and others (1988), and Johnson (unpub. surface sections). In addition one thickness for the R-0 zone, the Powell Park locality (table 4) was estimated from surface mapping by Pipiringos and Johnson (1976). The contact between the R-0 and L-0 zones cannot be distinguished in most of these surface locations, and the thickness of the R-0 zone is obtained by assuming that the L-0 zone is 20 ft thick, the approximate thickness in nearby drill holes.

The R-0 zone is thinnest in the westernmost part of the basin, along the Douglas Creek arch (fig. 2) where it is about 75 ft thick (fig. 41). It thickens and becomes sandy to the southeast, east, and northeast, reaching a maximum thickness of about 585 ft thick at Anvil Points, just west of Rifle, Colo. (fig. 2) in the southeast part of the basin where it is predominantly fluvial and consists of variegated mudstone and lenticular sandstone. The R-0 zone is typically included in the Wasatch Formation in areas along the eastern margins of the basin where it is predominantly fluvial (see for example, O'Sullivan, 1986), but its equivalent can generally still be recognized because it includes some lacustrine lithologies including ostracodal and oolitic limestones (Johnson, unpub. measured section at Anvil Points). The R-0 zone is included in the Anvil Points Member of the Green River Formation in the eastern part of the basin where it is very sandy but not predominantly fluvial.

The R-0 zone was assayed in just 34 core holes in the Piceance Basin. Using only these core holes, oil-yield values are remarkably uniform, from 10 to 20 GPT, throughout a broad area of the central part of the basin with yields decreasing in a regular fashion towards the basin margins (fig. 42). Oil yields are very low along the east margins of the basin where the zone is predominantly sandstone, and oil-yield estimates in surface sections there were set at the minimum value (table 8). There is no oil-yield data for the R-0 zone for much of the south and southwestern parts of the basin, but in these areas, the zone is predominantly shale that probably contains some kerogen. No attempt to estimate kerogen content in the surface sections was made here (table 4). Barrels per acre in the central part of the basin varies from 150,000 to 250,000 and decreased in a regular fashion outward (fig. 43). Maximum in-place oil is in T. 1 S., R. 98 W. with over 4.8 billion barrels (fig. 44). Estimated total in-place oil in the R-0 zone is just over 83.4 billion barrels (table 10).

L-0 Zone

The L-0 zone is a thin lean zone, with a thickness of from 13 to 35 ft throughout most of the basin, but it attains a thickness of 77 ft in one anomalous well in sec. 26, T. 3 S., R. 99 W. (fig. 45). The L-0 zone thickens in an irregular fashion towards the east margin of the basin, where it grades into sandstone. Maximum recorded thickness in the eastern part of the basin is 90 ft in sec. 28, T. 3 S., R. 95 W. In outcrop, along the eastern margin of the basin, the L-0 zone occurs within an overall sandy interval and cannot be recognized.

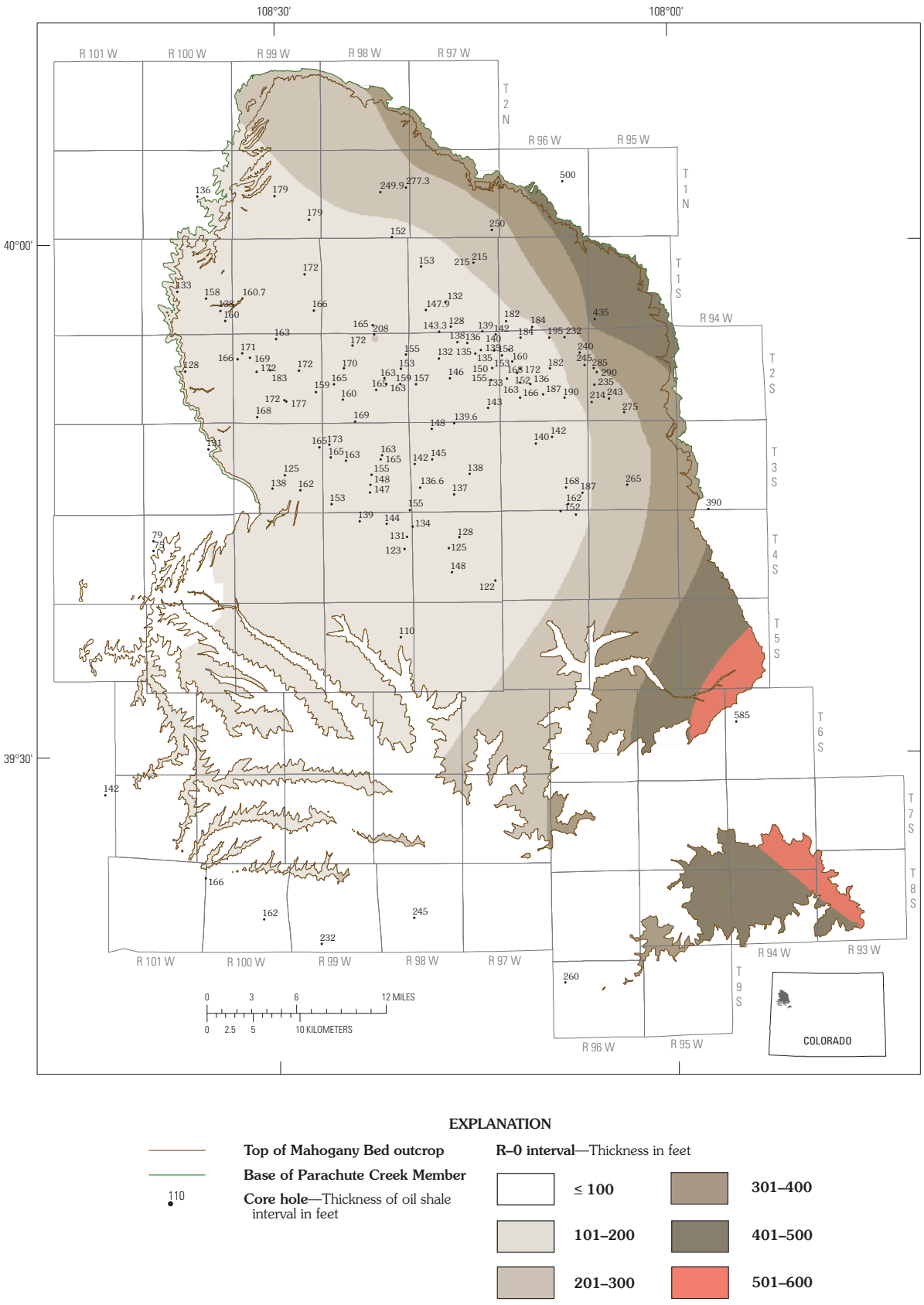


Figure 41. Isopach map of the R-0 zone using both core hole and rotary hole data. Radial Basis Function Method (RBF) method was used for contouring. Contour interval in feet is variable.

The L-0 zone was assessed in 74 core holes. Oil yields vary from 5.0 to 14.3 GPT in the central part of the basin, in approximately the same area of high oil yields for the underlying zone, and decrease in a regular fashion towards the basin margins (fig. 46). Trends towards the east margin of the basin are controlled by surface sections in which oil yields were set at the minimum value of 0.1 GPT—the extrapolation program required some value above zero (table 8). Maximum in-place resources in the L-0 zone varies from 7,500 to 32,000 BPA in the central part of the basin and decrease outwards (fig. 47). Maximum in-place oil in a township is just over one-half billion barrels in T. 2 S., R. 97 W. (fig. 48). Total in-place oil in the R-0 zone is estimated to be 8.3 billion barrels (table 11).

R-1 Zone

The R-1 zone consists of illite-rich oil shale similar to the underlying R-0 zone but much richer. It varies in thickness from about 100 to 125 ft in the central part of the basin to over 350 ft along much of the eastern, southeastern, and southwestern margins (fig. 49). Unlike the underlying R-0 and L-0 zones, which thicken mainly towards the east, the R-1 zone thickens in all directions away from the central part of the basin (fig. 49). Of note, the interval thickens markedly towards the southwest, with much of the thickening due to the insertion of discrete, southwestward thickening, kerogen-poor, mudstone and sandstone wedges into the oil shale interval (Johnson, 1985; 1989; Johnson and others, 1988; Pitman and others, 1989). The wedges appear to be predominantly lacustrine, consisting of non-laminated to laminated carbonate-rich mudstone in the center of the basin, grading to the southwest first into sandstone and mudstone that is, in part, highly contorted, and then into carbonate-rich mudstone and ripple laminated sandstone with stromatolitic, ostracodal, and oolitic limestone (Johnson, 1985; Johnson and others, 1988). One wedge thickens from about 8 ft in the center of the basin to about 230 ft along the southwest margin (Johnson, 1985, p. 264), suggesting that it was deposited comparatively rapidly.

The R-1 zone was assessed in 91 core holes in the basin. Oil-yield trends towards the east and south were established by assuming oil-yield values of 0.1 GPT in surface sections there (table 8), as the R-1 zone has graded into marginal lacustrine, kerogen-poor rocks in these areas. Estimated oil yield varies from about 20–29 GPT in the central part of the basin with oil yields decreasing markedly towards the basin margins (fig. 50).

Estimated in-place oil varies from 300,000 to 435,000 BPA through a broad crescent-shaped depocenter (fig. 51) that is somewhat south of the depocenter for the underlying L-0 zones. Oil yields are lower in this depocenter then farther to the north, but this is due largely to the insertion of clastic wedges into the R-1 interval discussed earlier. Maximum in-place oil occurs in T. 4 S., R. 97 W. in the middle of the depocenter, with an estimated 9.4 billion barrels of oil (fig. 52). Total in-place oil in the R-1 zone is estimated at 195.4 billion barrels (table 12).

Pitman and others (1989) estimated 115.4 billion barrels of oil in place in the R-1 zone using a manual "extrapolated" method and 137.0 billion barrels using kriging (table 12), but they assess fewer townships than were assessed here. Their kriged number is larger than their extrapolated number because they assessed two more townships using kriging than they did manually (table 12). If only the townships that were assessed by Pitman and others (1989) are compared to our results in those townships using only core holes, our results are 4.52 percent higher than their "extrapolated" results and 7.65 percent lower than their kriged results.

Considerably more control was available for this assessment than for Pitman and others (1989), and comparison was only made of townships where sufficient control was available at the time they made their assessment. When only townships where the kriged results from Pitman and others (1989) estimated an error of 20 percent or less at the 95 percent confidence level are compared, our results are 15.7 percent higher than their extrapolated results and 8.89 percent higher than their kriged results. The results of Pitman and others (1989) for the R-1 zone are in question, however. Their results list unreasonably high assessment numbers for T. 1 N., R. 100 W., and T. 2 N., R. 97 and 98 W. (table 12, shown in red). Their assessment numbers for these townships are far higher than geologically reasonable for these areas, and their small estimated errors for their kriged results are inconsistent with the very limited control available at the time of their assessment in these townships. These three townships were not included in the comparison of best townships presented above.

L-1 Zone

The L-1 zone is also illite-rich, similar to the underlying R-1 zone and is, in essence, the highest of the southwest-thickening clastic wedges that entered Lake Uinta during the illitic phase of the lake. The L-1 zone is similar in lithology to the clastic wedges in the underlying R-1 zone. One hundred twenty two holes were used to assess the L-1 zone as compared to 63 in the previous assessment (Pitman and others, 1989). The zone varies from about 10 to 45 ft thick throughout the north-central part of the basin. It thickens to the east to a maximum of about 100 ft and to the southwest to a maximum recorded thickness of 168 ft in sec. 13, T. 6 S., R. 98 W. (fig. 53).

Maximum oil yields are from about 5 to 25 GPT in the north-central part of the basin (fig. 54). The BPA map (fig. 55) shows a depocenter with from 20,000 to 80,000 barrels per acre in the south-central part of the basin, the same area as the depocenter during the previous R-1 zone, but several much smaller areas with high in-place oil occur scattered throughout the northern part of the basin. Maximum in-place oil in a township is 876 million barrels in T. 3 S., R. 97 W. (fig. 56).

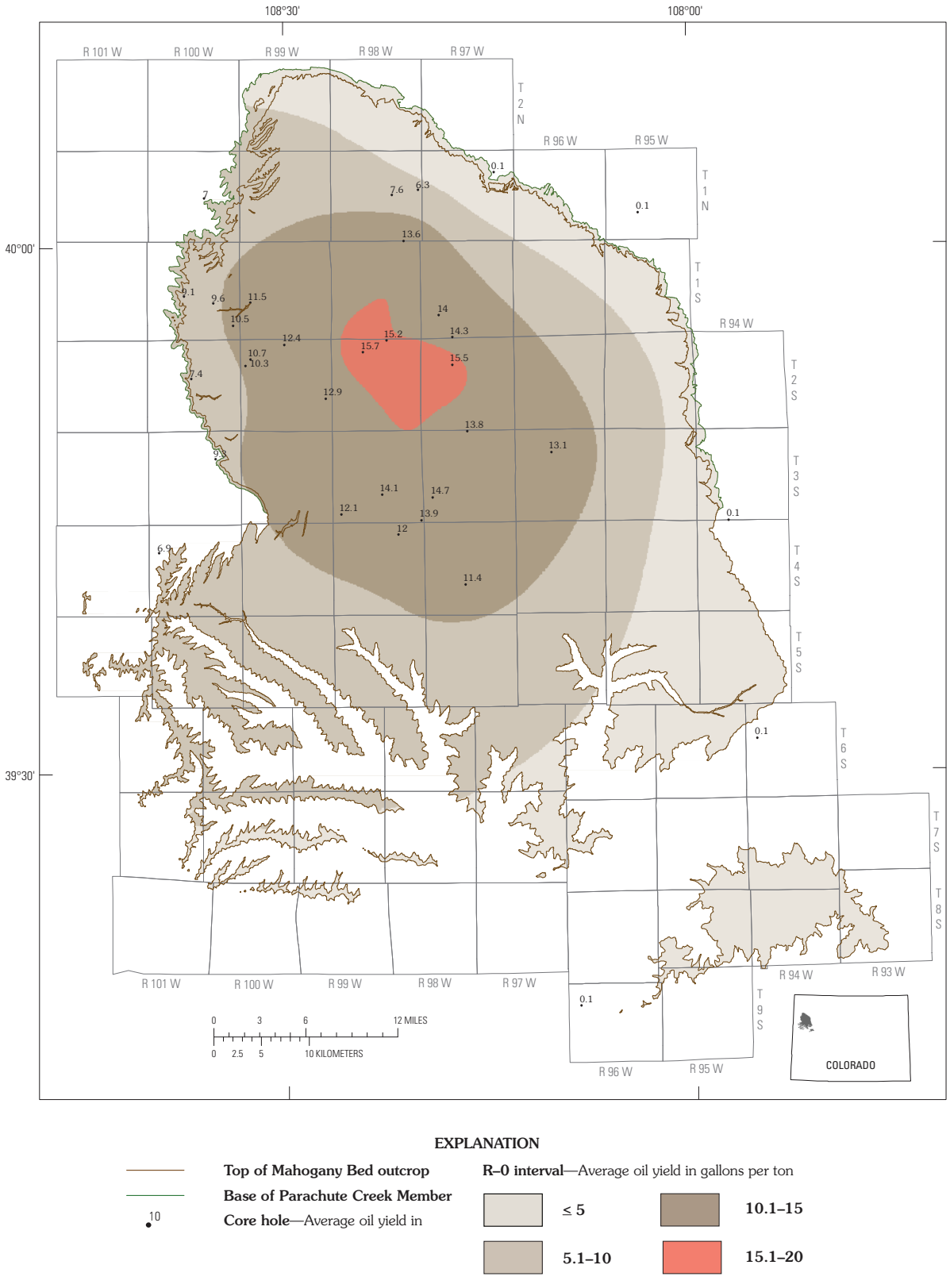


Figure 42. Isoresource map of the R-0 zone showing the oil yield in gallons per ton (GPT). The Radial Basis Function Method (RBF) was used for contouring.

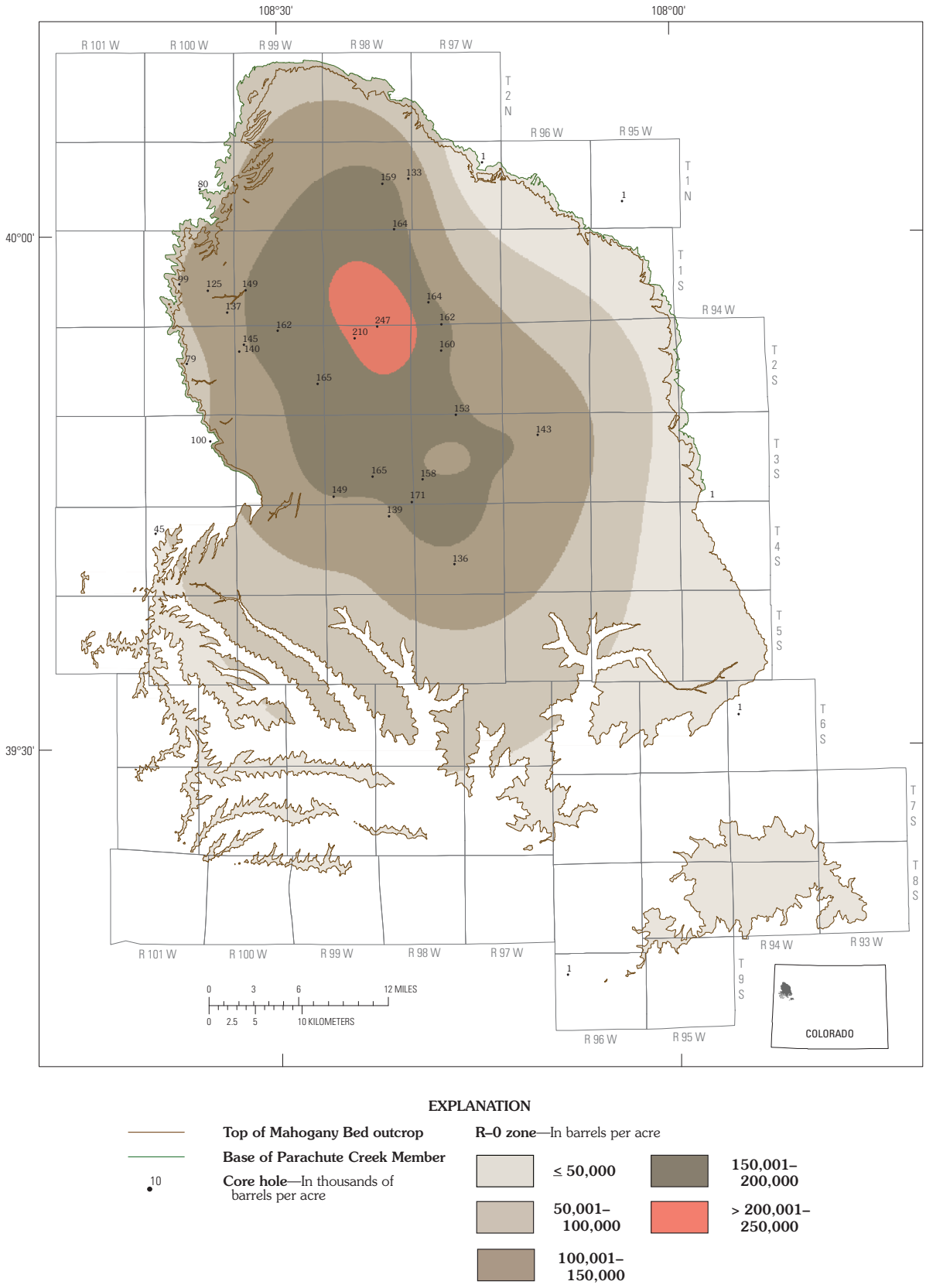


Figure 43. Isoresource map of the R-0 zone showing oil yields in barrels per acre (BPA). The Radial Basis Function Method (RBF) was used for contouring.

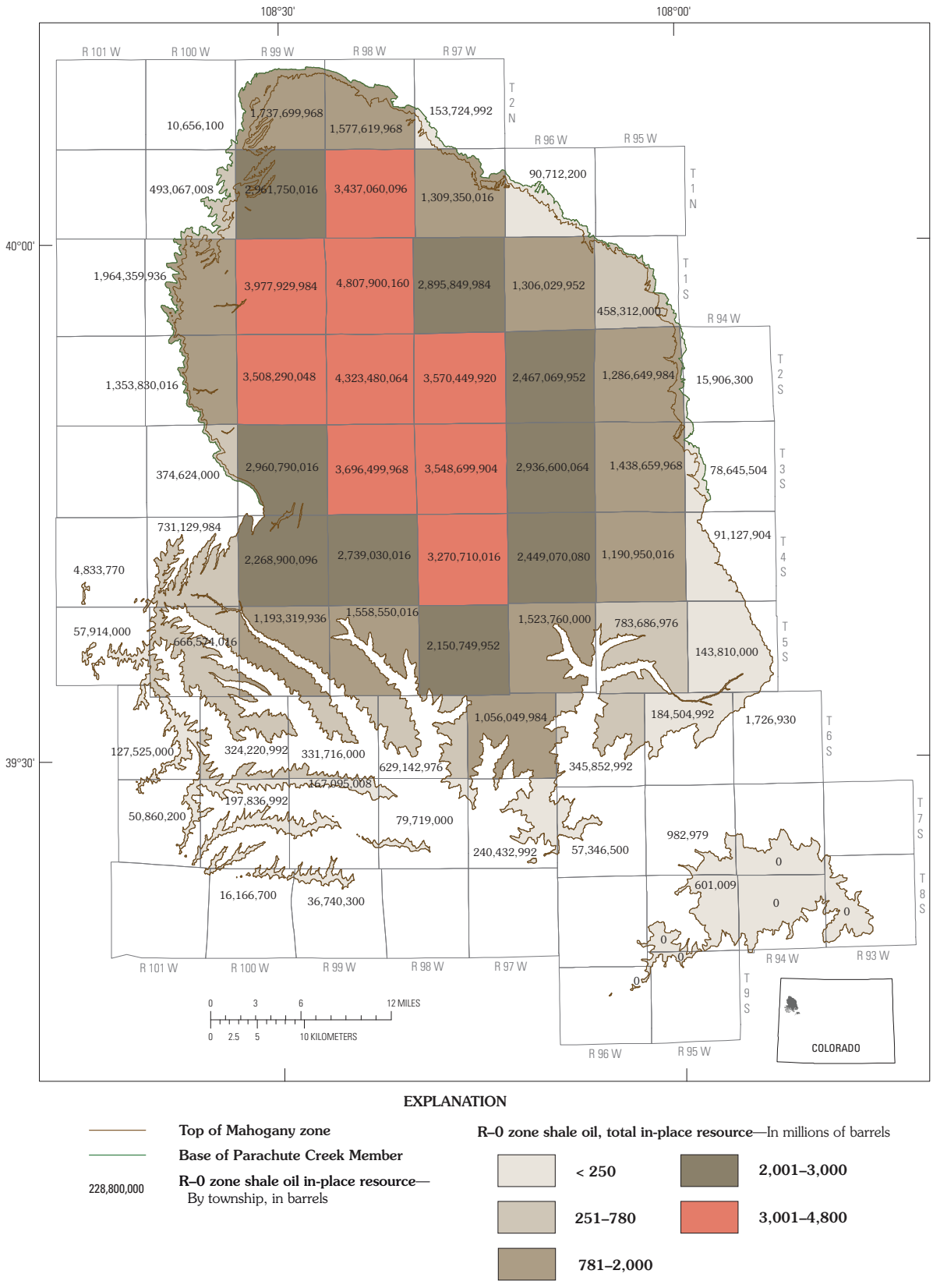


Figure 44. Isoresource map of the R-0 zone showing total number of barrels of oil in each township.

Table 10. Total number of in-place barrels of oil per acre (BPA) in each township for the R-0 zone calculated here using the Radial Basis Function Method (RBF).

Township and Range	SUM R-0 zone (BPA)
1N 96W	90,712,200
1N 97W	1,309,350,000
1N 98W	3,437,060,000
1N 99W	2,961,750,000
1N 100W	493,067,000
2N 97W	153,725,000
2N 98W	1,577,620,000
2N 99W	1,737,700,000
2N 100W	10,656,100
1S 95W	458,312,000
1S 96W	1,306,030,000
1S 97W	2,895,850,000
1S 98W	4,807,900,000
1S 99W	3,977,930,000
1S 100W	1,964,360,000
2S 94W	15,906,300
2S 95W	1,286,650,000
2S 96W	2,467,070,000
2S 97W	3,570,450,000
2S 98W	4,323,480,000
2S 99W	3,508,290,000
2S 100W	1,353,830,000
3S 94W	78,645,500
3S 95W	1,438,660,000
3S 96W	2,936,600,000
3S 97W	3,548,700,000
3S 98W	3,696,500,000
3S 99W	2,960,790,000
3S 100W	374,624,000
4S 94W	91,127,900
4S 95W	1,190,950,000
4S 96W	2,449,070,000
4S 97W	3,270,710,000
4S 98W	2,739,030,000
4S 99W	2,268,900,000
4S 100W	731,130,000
4S 101W	4,833,770
5S 94W	143,810,000
5S 95W	783,687,000
5S 96W	1,523,760,000
5S 97W	2,150,750,000
5S 98W	1,558,550,000
5S 99W	1,193,320,000
5S 100W	666,574,000
5S 101W	57,914,000
6S 94W	1,726,930
6S 95W	184,505,000
6S 96W	345,853,000
6S 97W	1,056,050,000
6S 98W	629,143,000
6S 99W	331,716,000
6S 100W	324,221,000
6S 101W	127,525,000
7S 93W	0
7S 94W	0
7S 95W	982,979
7S 96W	57,346,500
7S 97W	240,433,000
7S 98W	79,719,000
7S 99W	167,095,000
7S 100W	197,837,000
7S 101W	50,860,200
8S 93W	0
8S 94W	0
8S 95W	601,009
8S 96W	23,395
8S 99W	36,740,300
8S 100W	16,166,700
8S 101W	1,762,280
9S 94W	0
9S 95W	0
9S 96W	0
Total:	83,416,642,063

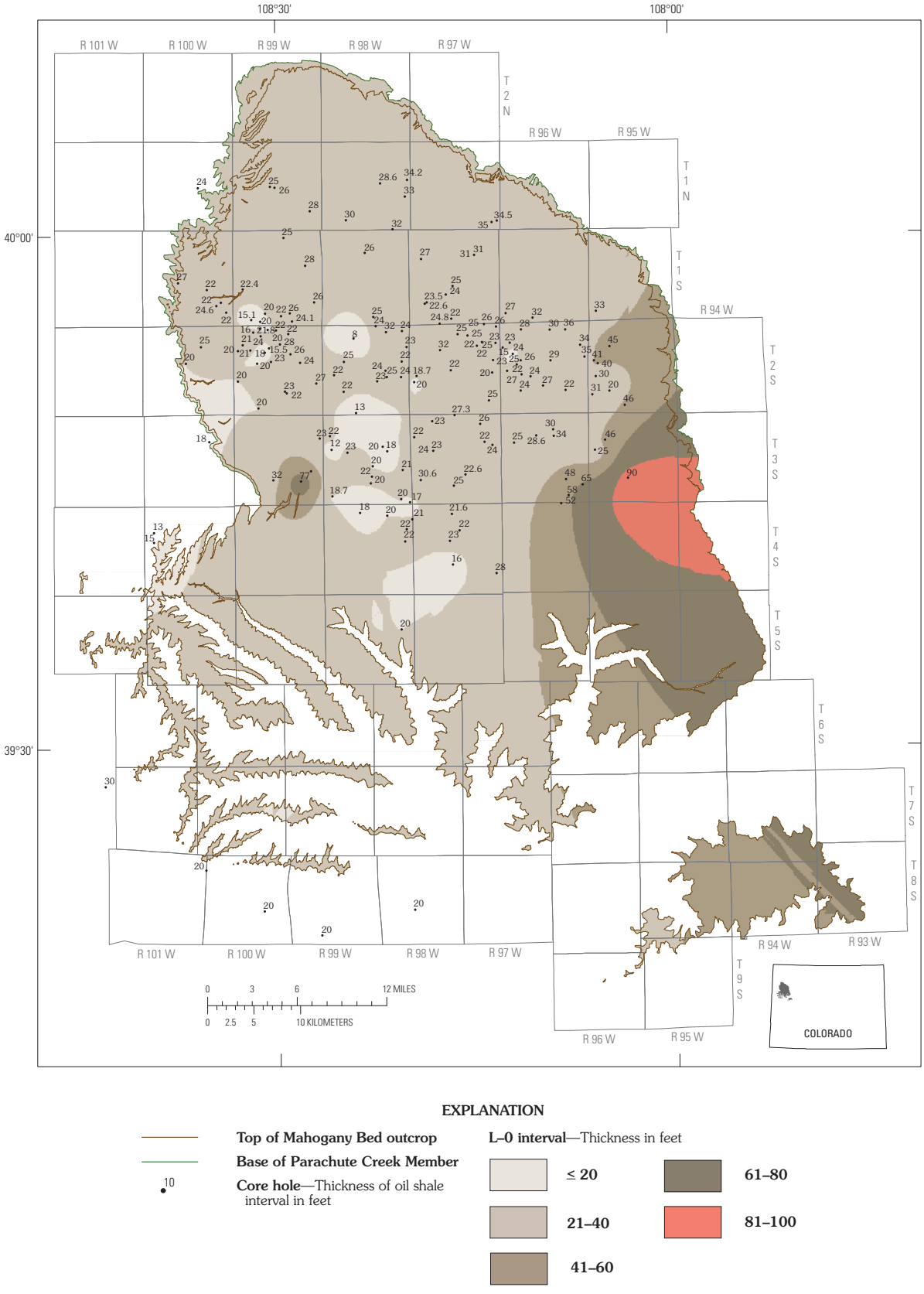


Figure 45. Isopach map of the L-0 zone using both core hole and rotary hole data. Radial Basis Function Method (RBF) was used for contouring. Contour interval in feet is variable.

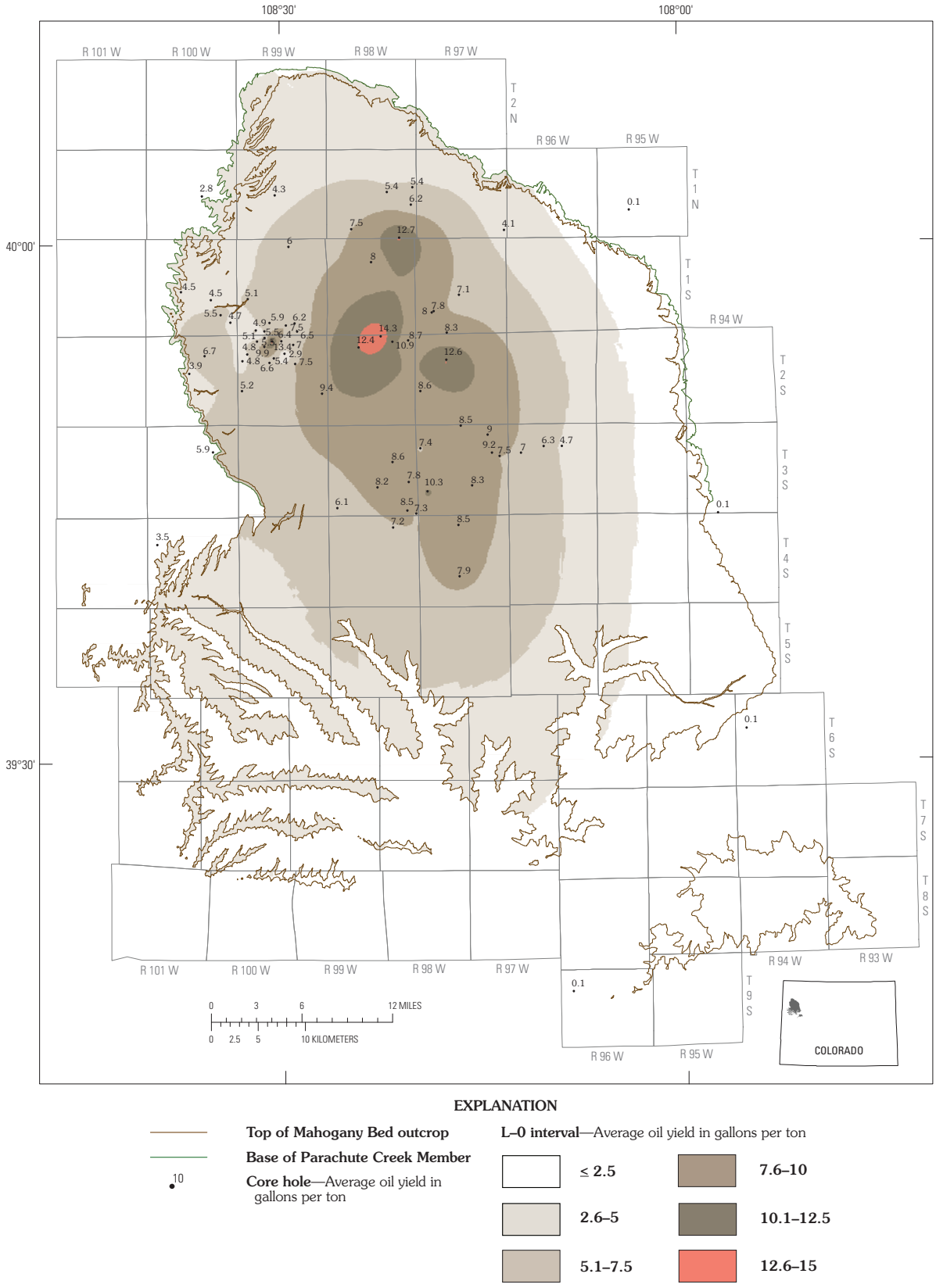


Figure 46. Isoresource map of the L-0 zone showing the oil yield in gallons per ton (GPT). The Radial Basis Function Method (RBF) was used for contouring.

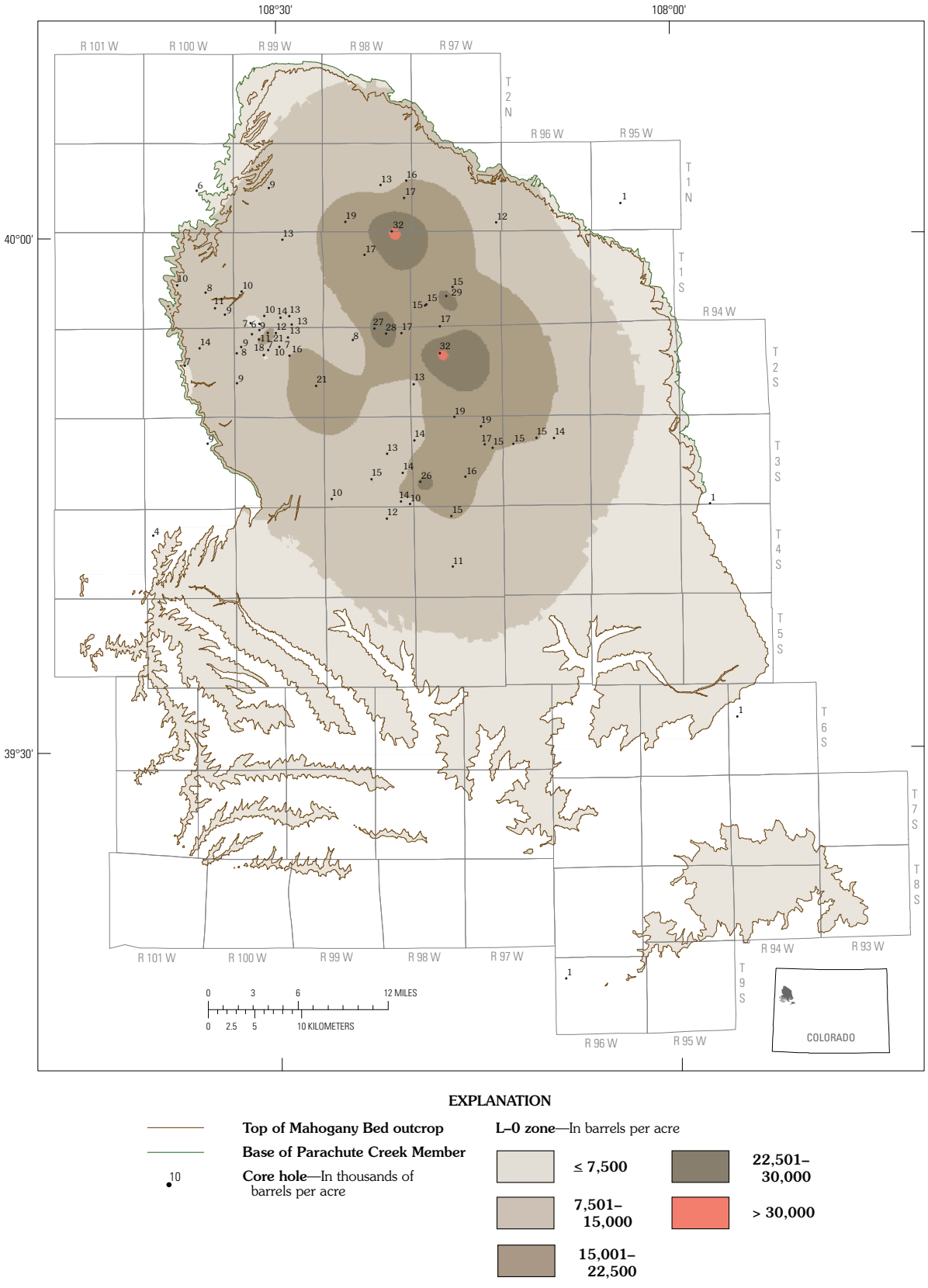


Figure 47. Isoresource map of the L-0 zone showing oil yields in barrels per acre (BPA). The Radial Basis Function Method (RBF) was used for contouring.

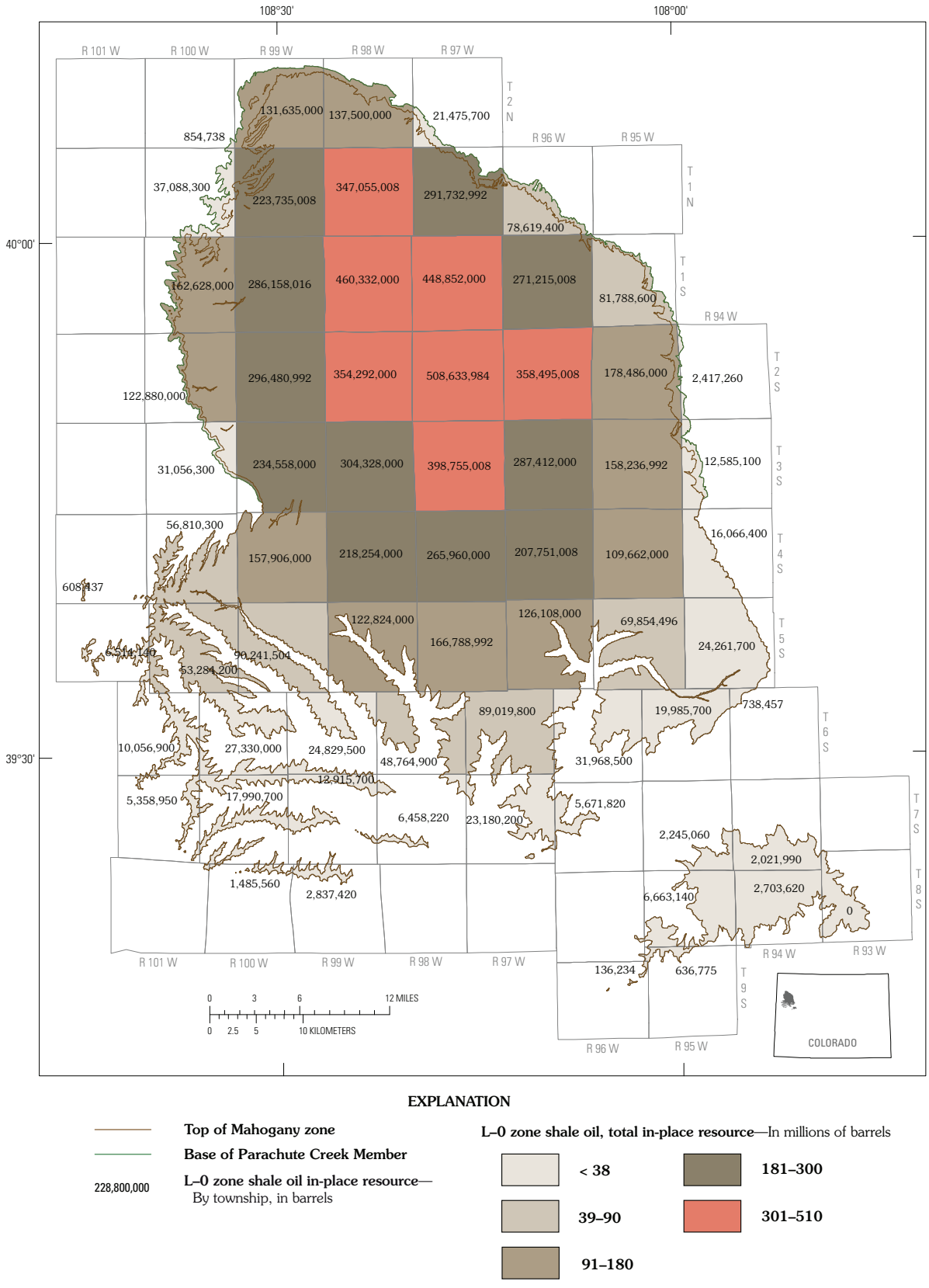


Figure 48. Isoresource map of the L-0 zone showing total number of barrels of oil in each township.

Table 11. Total number of in-place barrels of oil per acre (BPA) in each township for the L-0 zone calculated here using the Radial Basis Function Method (RBF).

Township, Range	SUM L-0 zone (BPA)
1N 96W	78,619,400
1N 97W	291,733,000
1N 98W	347,055,000
1N 99W	223,735,000
1N 100W	37,088,300
2N 97W	21,475,700
2N 98W	137,500,000
2N 99W	131,635,000
2N 100W	854,738
1S 95W	81,788,600
1S 96W	271,215,000
1S 97W	448,852,000
1S 98W	460,332,000
1S 99W	286,158,000
1S 100W	162,628,000
2S 94W	2,417,260
2S 95W	178,486,000
2S 96W	358,495,000
2S 97W	508,634,000
2S 98W	354,292,000
2S 99W	296,481,000
2S 100W	122,880,000
3S 94W	12,585,100
3S 95W	158,237,000
3S 96W	287,412,000
3S 97W	398,755,000
3S 98W	304,328,000
3S 99W	234,558,000
3S 100W	31,056,300
4S 94W	16,066,400
4S 95W	109,662,000
4S 96W	207,751,000
4S 97W	265,960,000
4S 98W	218,254,000
4S 99W	157,906,000
4S 100W	56,810,300
4S 101W	608,437
5S 94W	24,261,700
5S 95W	69,854,500
5S 96W	126,108,000
5S 97W	166,789,000
5S 98W	122,824,000
5S 99W	90,241,500
5S 100W	53,284,200
5S 101W	6,514,140
6S 94W	738,457
6S 95W	19,985,700
6S 96W	31,968,500
6S 97W	89,019,800
6S 98W	48,764,900
6S 99W	24,829,500
6S 100W	27,330,000
6S 101W	10,056,900
7S 93W	0
7S 94W	2,021,990
7S 95W	2,245,060
7S 96W	5,671,820
7S 97W	23,180,200
7S 98W	6,458,220
7S 99W	12,915,700
7S 100W	17,990,700
7S 101W	5,358,950
8S 93W	0
8S 94W	2,703,620
8S 95W	6,663,140
8S 96W	89,019
8S 99W	2,837,420
8S 100W	1,485,560
8S 101W	197,084
9S 94W	5,379
9S 95W	636,775
9S 96W	136,234
Total:	8,265,472,203

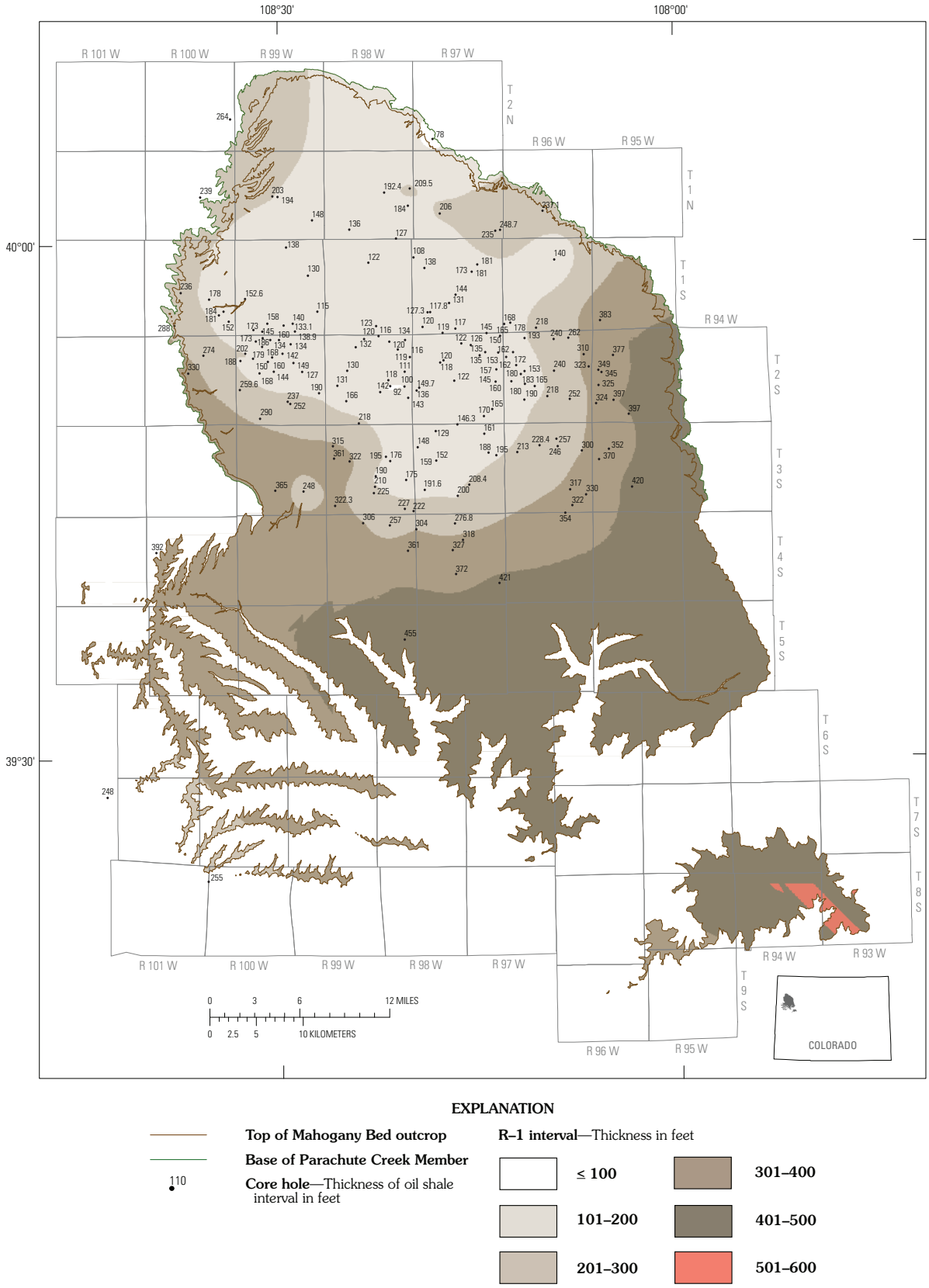


Figure 49. Isopach map of the R-1 zone using both core hole and rotary hole data. Radial Basis Function Method (RBF) was used for contouring. Contour interval in feet is variable.

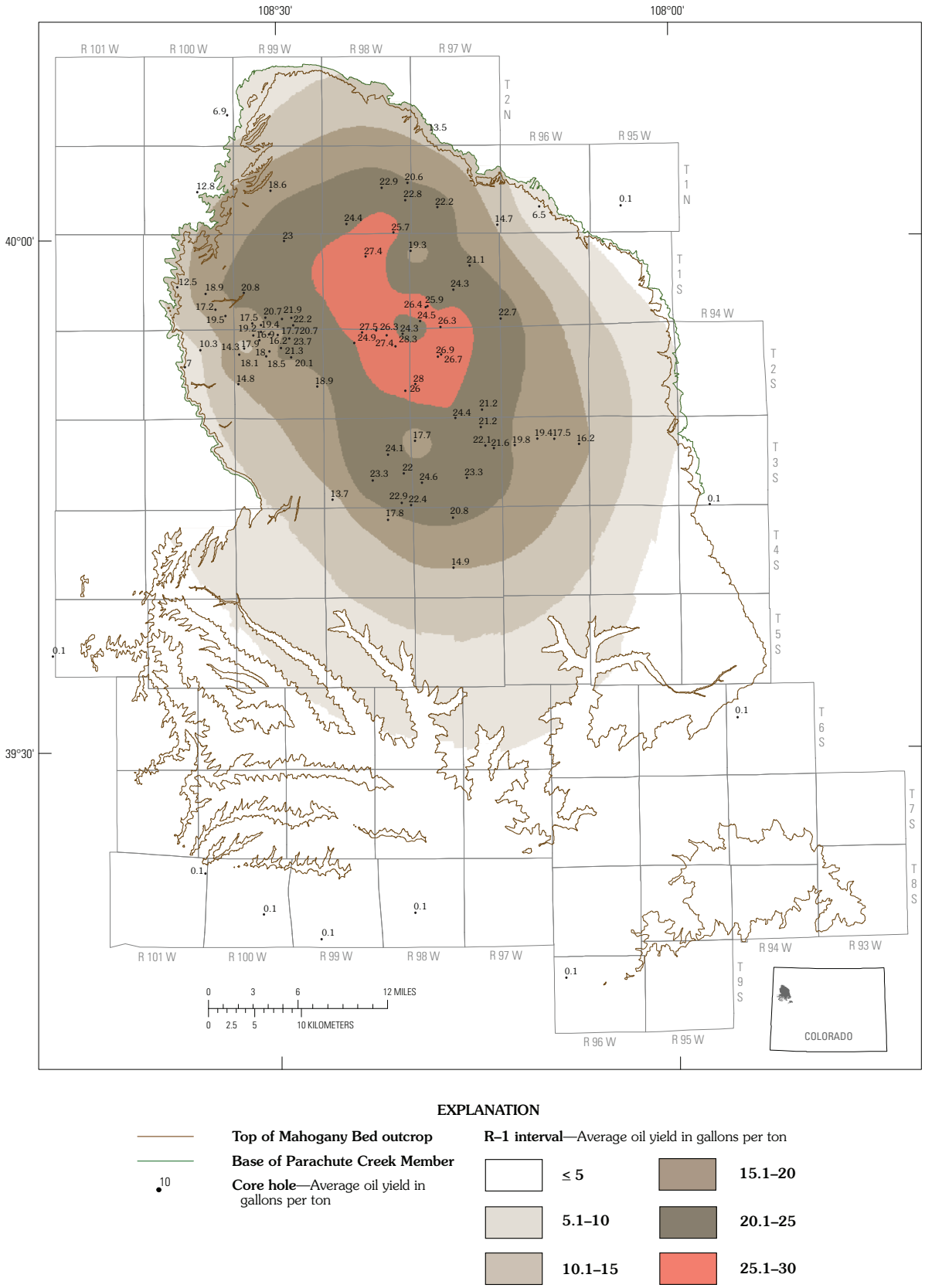


Figure 50. Isoresource map of the R-1 zone showing the oil yield in gallons per ton (GPT). The Radial Basis Function Method (RBF) was used for contouring.

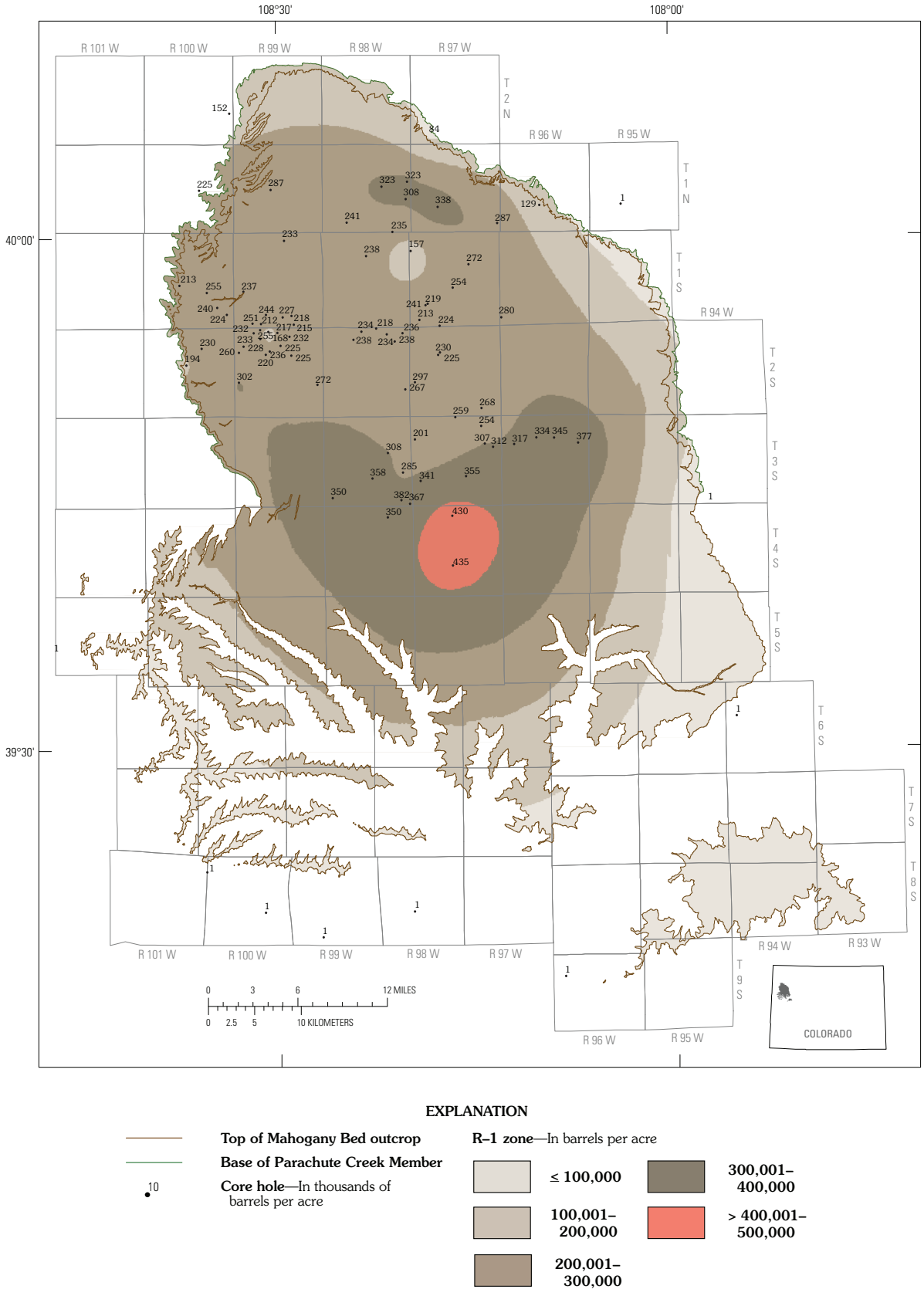


Figure 51. Isoresource map of the R-1 zone showing oil yields in barrels per acre (BPA). The Radial Basis Function Method (RBF) was used for contouring.

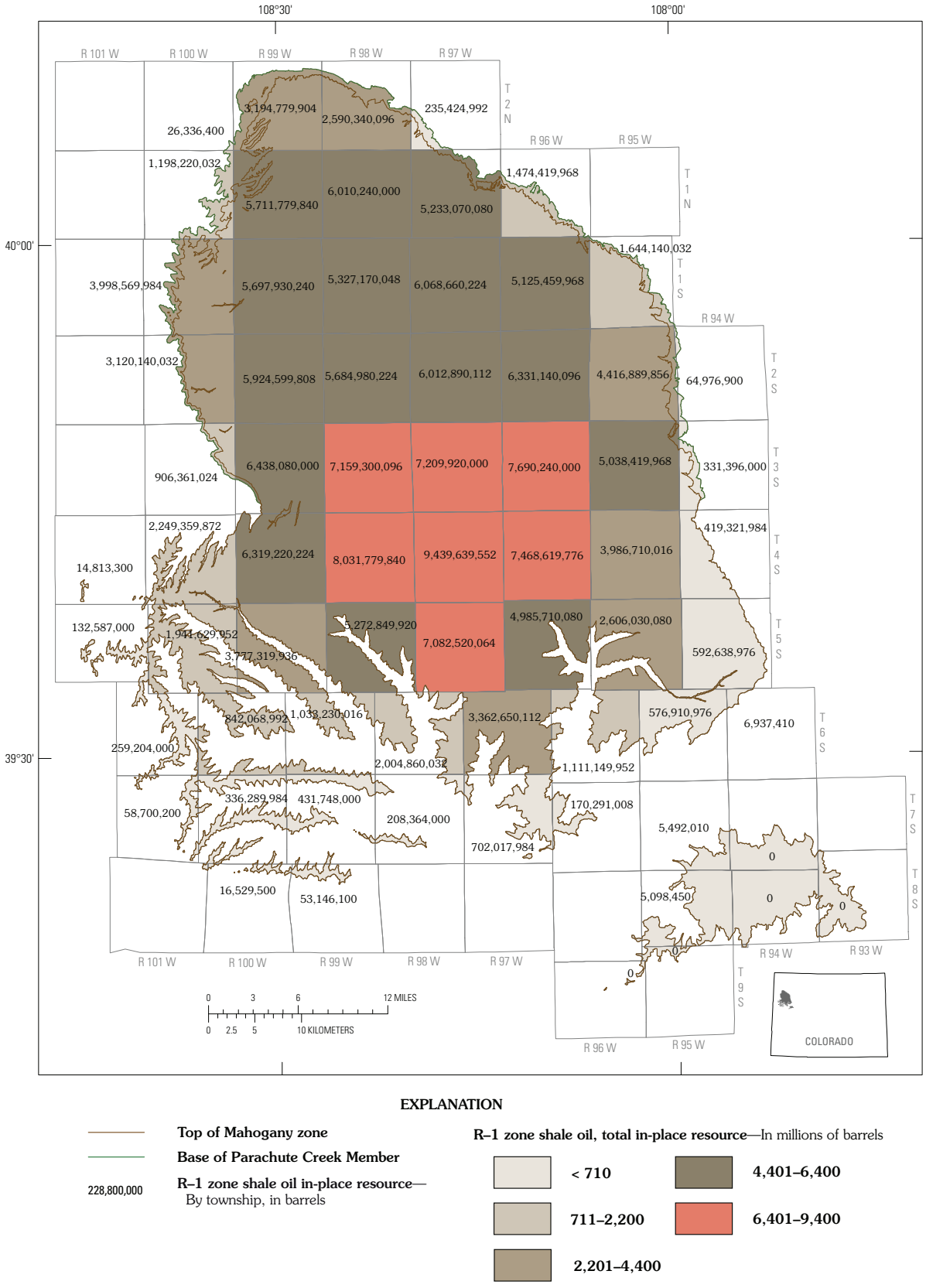


Figure 52. Isoresource map of the R-1 zone showing total number of barrels of oil in each township using only core hole data.

Table 12. Total number of in-place barrels of oil per acre (BPA) in each township for the R-1 zone calculated here using the Radial Basis Function Method (RBF). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Results for the R-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent differrence using the RBF method here. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).

Township, Range	SUM R-1 no rotary holes	Extrapolated (Pitman and others,1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	1,474,420,000				468,274,000	±27	1,006,146,000	215
1N 97W	5,233,070,000				5,921,654,000	±30	-688,584,000	-12
1N 98W	6,010,240,000							
1N 99W	5,711,780,000	1,052,800,000	4,658,980,000	443	1,593,772,000	±30	4,118,008,000	258
1N 100W	1,198,220,000	4,171,420,000	-2,973,200,000	-71	5,680,672,000	±9	-4,482,452,000	-79
2N 97W	235,425,000	6,183,100,000	-5,947,675,000	-96	6,762,724,000	±10	-6,527,299,000	-97
2N 98W	2,590,340,000	5,874,550,000	-3,284,210,000	-56	6,011,643,000	±12	-3,421,303,000	-57
2N 99W	3,194,780,000	316,470,000	2,878,310,000	910	405,566,000	±32	2,789,214,000	688
2N 100W	26,336,400							
1S 95W	1,644,140,000							
1S 96W	5,125,460,000	4,741,400,000	384,060,000	8	6,197,299,000	±27	-1,071,839,000	-17
1S 97W	6,068,660,000	6,149,250,000	-80,590,000	-1	6,011,335,000	±8	57,325,000	1
1S 98W	5,327,170,000	5,490,100,000	-162,930,000	-3	5,401,393,000	±9	-74,223,000	-1
1S 99W	5,697,930,000	5,510,250,000	187,680,000	3	5,729,628,000	±11	-31,698,000	-1
1S 100W	3,998,570,000	2,990,600,000	1,007,970,000	34	3,454,415,000	±22	544,155,000	16
2S 94W	64,976,900							
2S 95W	4,416,890,000							
2S 96W	6,331,140,000	5,819,750,000	511,390,000	9	7,110,359,000	±16	-779,219,000	-11
2S 97W	6,012,890,000	5,814,585,000	198,305,000	3	5,742,464,000	±7	270,426,000	5
2S 98W	5,684,980,000	5,478,935,000	206,045,000	4	5,508,761,000	t8	176,219,000	3
2S 99W	5,924,600,000	5,317,830,000	606,770,000	11	5,354,657,000	±11	569,943,000	11
2S 100W	3,120,140,000	2,537,392,000	582,748,000	23	2,559,034,000	±19	561,106,000	22
3S 94W	331,396,000							
3S 95W	5,038,420,000							
3S 96W	7,690,240,000	7,935,200,000	-244,960,000	-3	8,141,686,000	±8	-451,446,000	-6
3S 97W	7,209,920,000	6,738,825,000	471,095,000	7	6,789,007,000	±4	420,913,000	6
3S 98W	7,159,300,000	6,992,980,000	166,320,000	2	6,656,552,000	±7	502,748,000	8
3S 99W	6,438,080,000	5,266,500,000	1,171,580,000	22	6,461,536,000	±22	-23,456,000	0
3S 100W	906,361,000	370,695,000	535,666,000	145	457,762,000	±42	448,599,000	98
4S 94W	419,322,000							

Table 12. Total number of in-place barrels of oil per acre (BPA) in each township for the R-1 zone calculated here using the Radial Basis Function Method (RBF). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Results for the R-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent differrence using the RBF method here. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-1 no rotary holes	Extrapolated (Pitman and others,1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 95W	3,986,710,000							
4S 96W	7,468,620,000	5,430,480,000	2,038,140,000	38	9,876,394,000	±26	-2,407,774,000	-24
4S 97W	9,439,640,000	8,740,125,000	699,515,000	8	9,734,521,000	±7	-294,881,000	-3
4S 98W	8,031,780,000	6,428,240,000	1,603,540,000	25	8,984,729,000	±13	-952,949,000	-11
4S 99W	6,319,220,000							
4S 100W	2,249,360,000							
4S 101W	14,813,300							
5S 94W	592,639,000							
5S 95W	2,606,030,000							
5S 96W	4,985,710,000							
5S 97W	7,082,520,000							
5S 98W	5,272,850,000							
5S 99W	3,777,320,000							
5S 100W	1,941,630,000							
5S 101W	132,587,000							
6S 94W	6,937,410							
6S 95W	576,911,000							
6S 96W	1,111,150,000							
6S 97W	3,362,650,000							
6S 98W	2,004,860,000							
6S 99W	1,033,230,000							
6S 100W	842,069,000							
6S 101W	259,204,000							
7S 93W	0							
7S 94W	0							
7S 95W	5,492,010							
7S 96W	170,291,000							
7S 97W	702,018,000							
7S 98W	208,364,000							
7S 99W	431,748,000							

Table 12. Total number of in-place barrels of oil per acre (BPA) in each township for the R-1 zone calculated here using the Radial Basis Function Method (RBF). Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Results for the R-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent differrence using the RBF method here. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-1 no rotary holes	Extrapolated (Pitman and others,1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 100W	336,290,000							
7S 101W	58,700,200							
8S 93W	0							
8S 94W	0							
8S 95W	5,098,450							
8S 96W	199,313							
8S 99W	53,146,100							
8S 100W	16,529,500							
8S 101W	576,316							
9S 94W	0							
9S 95W	0							
9S 96W	0							
Totals:	195,372,090,899	115,351,477,000			137,015,837,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	120,566,026,000	Sum of townships used here and kriging:	127,273,516,000
Percent difference using RBF here and Pitman and others (1989) extrapolated:	4.52	Percent difference between RBF and kriging:	-7.65
Sum of best townships RBF (20 percent)	91,167,010,000	Sum of best townships extrapolated:	78,953,462,000
		Sum of best townships kriging:	83,724,126,000
Percent difference RBF vs extrapolation for best townships:	15.47		
Percent difference RBF vs kriging for best townships:	8.89		

Total in-place oil in the L-1 zone is estimated to be just over 15 billion barrels (table 13).

Pitman and others (1989) estimated 10.7 billion barrels using manual extrapolation and 11.2 billion barrels using kriging for the L-1 zone (table 12), but again, they assessed fewer townships than were assessed here. None of the results from Pitman and others (1989) for individual townships for the L-1 zone appears to be geologically unreasonable. When only those townships that were used in both assessments are compared, our assessment is 6.44 percent higher than their manually extrapolated results and 3.43 percent higher than their kriged results (table 13). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 4.02 percent less than their manually extrapolated results and 0.91 percent higher than their kriged results (table 13).

R-2 Zone

The R-2 zone marks the beginning of the third stage of Lake Uinta as defined by Johnson (1985) and represents the transition from illitic-rich oil shales to carbonate-rich oil shales. In electric logs this shift is represented by a distinctive increase in resistivity informally known as the blue marker (Ziemba, 1974) because a blue pencil was used to mark it on geophysical logs. The first occurrence of disseminated nahcolite, a sodium bicarbonate mineral ($NaHCO_3$), is in the upper part of the L-2 zone in the north-central part of the basin (Dyni, 1974; 1981). Dawsonite, a hydrated aluminum carbonate mineral ($NaAl(OH)_2CO_3$) appears for the first time in the lower part of the R-2 zone, about 65–75 ft below the first occurrence of nahcolite (Dyni, 1981), and increases in abundance upwards. Illite correspondingly decreases in abundance upwards though the R-2 zone (Dyni, 1974; 1981; Robb and Smith, 1974). Dyni (1981) suggested that the alkaline lake waters destroyed much of the fine-grained detritus in the sediments, including the clays. These fine-grained sediments were replaced by a suite of authigenic minerals including dawsonite, authigenic feldspars, and authigenic quartz. Authigenic quartz in the saline interval is so clean and well crystallized that it has been used as an internal standard for d-spacing measurements in x-ray diffraction (Smith and Robb, 1966; 1973).

One hundred forty eight core holes were used to assess the R-2 zone here as compared to 85 in the previous assessment (Pitman and others, 1989). The zone is thickest along an east-to-northeast trending belt across the south-central and northeastern parts of the basin where it ranges from about 90 to 155 ft thick (fig. 57). The interval thins generally towards the southwest in the direction that the previous R-1 and L-1 zones had thickened markedly. Along the south and west margins of the basin, the R-2 zone cannot be separated from the overlying L-2, R-3, and L-3 zones, and thus all four zones are generally lumped together (Johnson, and others, 1988). Here, the four zones have a combined thickness of about 75 to 155 ft and consist of marlstone oil shale beds and stromatolites. In outcrop the underlying L-1 zone is much sandier and the overlying R-4 zone includes more rich oil shale beds than this distinctive interval (Johnson and others, 1988). In surface sections used for isopaching, this interval is arbitrarily proportioned so that the two rich zones are twice as thick as the two lean zones (table 4, Philadelphia Creek and Little Burma Road sections).

The oil shale depocenter during deposition of the R-2 zone is in the north-central part of the basin and north of the area where the zone is thickest (figs. 58–60). Here, maximum oil yield reaches 45 GPT, and decreases in a radial pattern outward. Oil yields reach near zero around the southeastern and southwestern margins and about 10–15 GPT around the northern and northwestern margins (fig. 58). Estimated in-place oil in barrels per acre reaches a maximum of 240,000 in this depocenter and decreases outward (fig. 59). Maximum in-place oil in a township is in T. 1 S., R. 98 W. with over 4 billion barrels (fig. 60). Total in-place oil in the basin in the R-2 zone is estimated to be 66.8 billion barrels (table 14).

As in all of the oil shale zones assessed here, we were able to assess more townships than were assessed by Pitman and others (1989) due largely to more control. When only those townships that were assessed in both assessments are compared, our assessment of the R-2 zone is 10.25 percent higher than the manually extrapolated result and 3.01 percent higher than the kriged result of Pitman and others (1989) (table 14). Six townships listed in Pitman and others (1989) gave either unreasonably high or unreasonably low results, based on the control points they used and current geologic knowledge. These values are shown in red in table 14. When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 4.87 percent higher than the manually extrapolated results and 4.47 percent higher than the kriged results of Pitman and others (1989) (table 14). We did not include any of the six townships with questionable results, even though two of them had estimated errors using kriging of significantly less than 20 percent.

L-2 Zone

Thickness and oil shale richness patterns for the L-2 zone are similar to those for the R-2 zone with the area of maximum thickness rimming the south end of the oil shale depocenter (fig. 61). The L-2 zone reaches a maximum thickness of 115 ft in this area. Maximum oil yield for the L-2 zone is about 34 GPT in the oil shale depocenter, with oil yields decreasing in a radial pattern outwards (fig. 62). Maximum BPA in the L-2 zone is 112,000 barrels (fig. 63), and maximum in-place resources in a township is just over 1.5 billion barrels in T. 1 S., R. 97 W. (fig. 64). Total in-place oil in the L-2 zone is estimated to be 24.2 billion barrels (table 15).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and

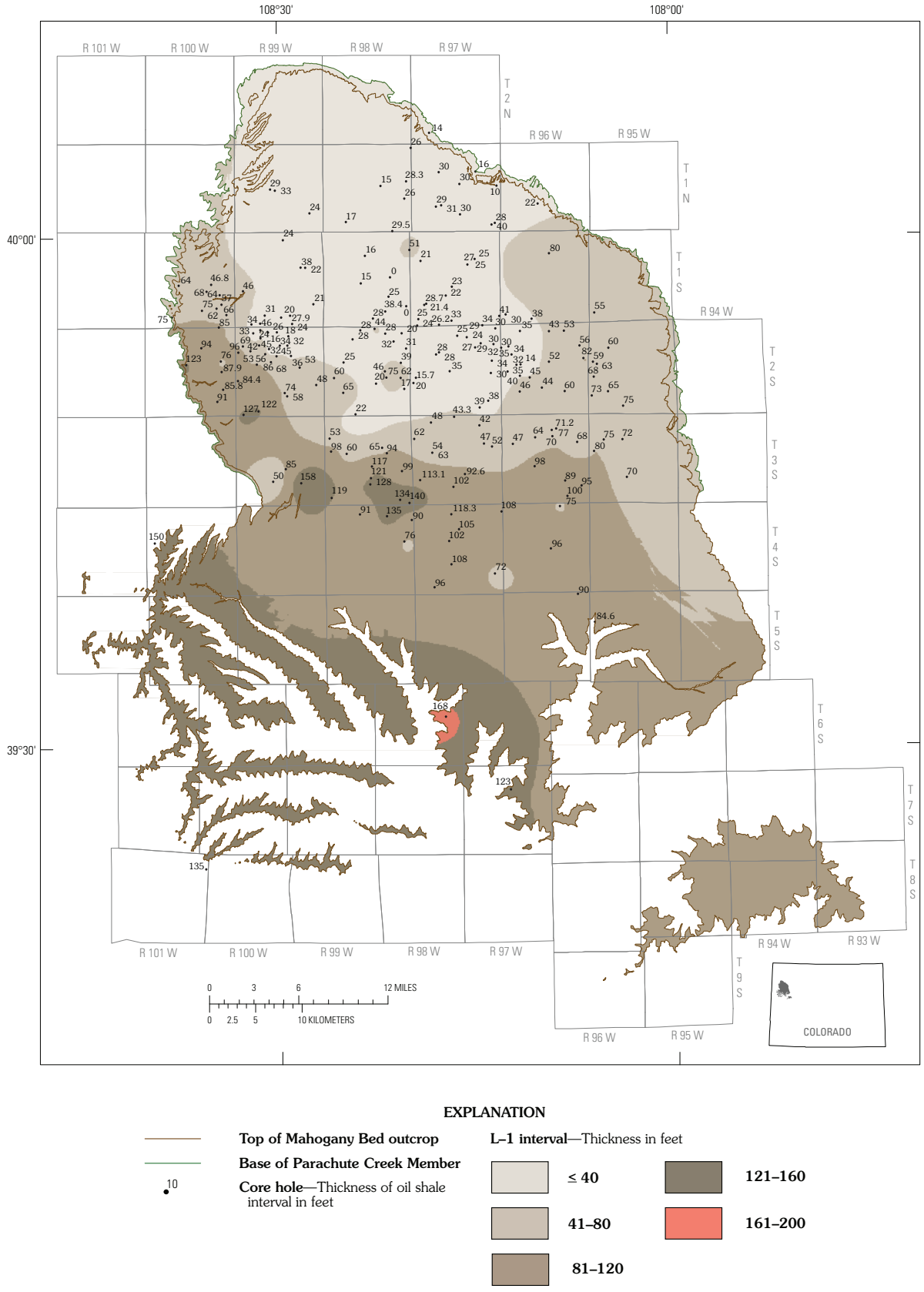


Figure 53. Isopach map of the L-1 zone using both core hole and rotary hole data. The Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

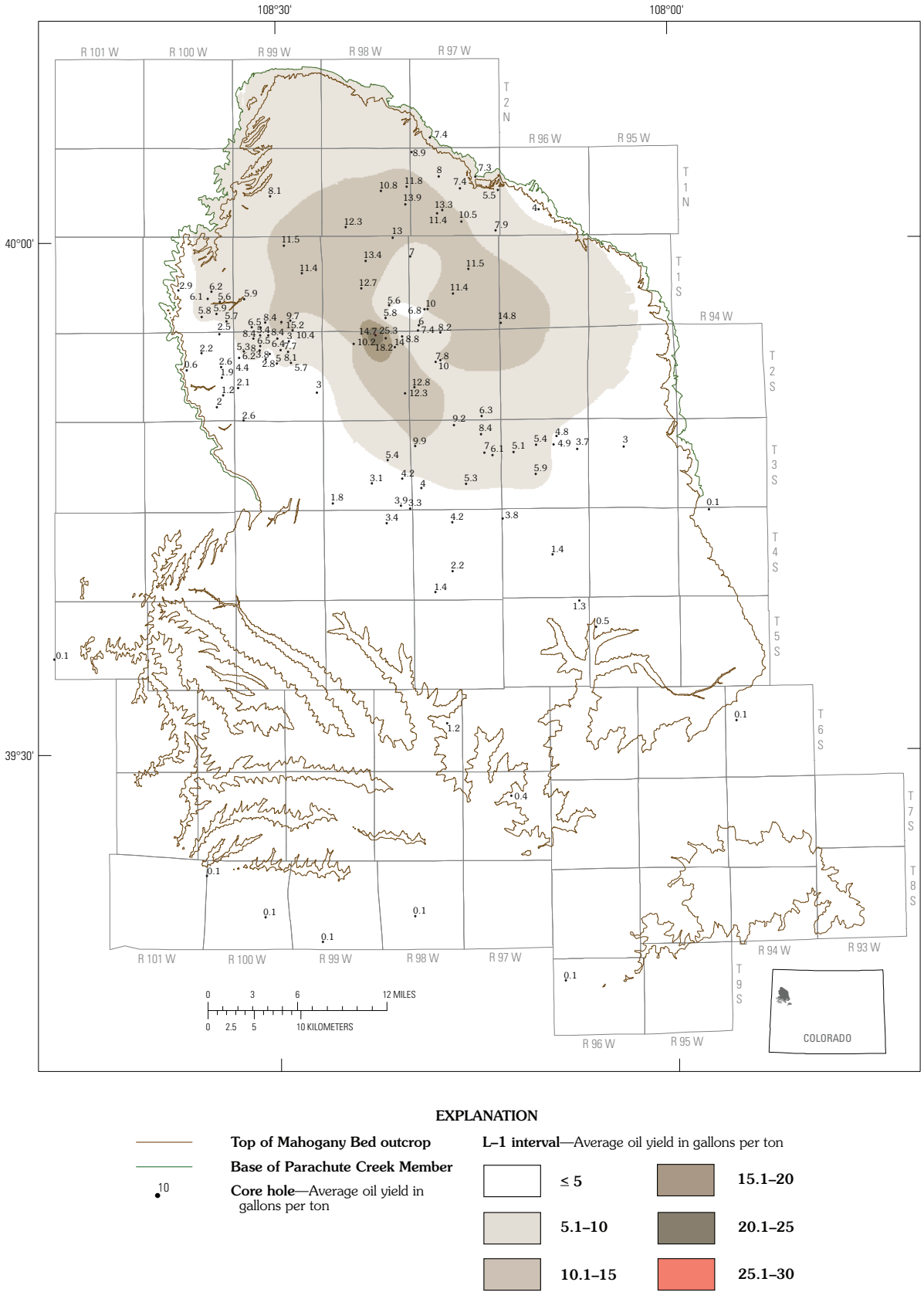


Figure 54. Isoresource map for the L-1 zone showing the oil yield in gallons per ton (GPT). The Radial Basis Function Method (RBF) was used for contouring.

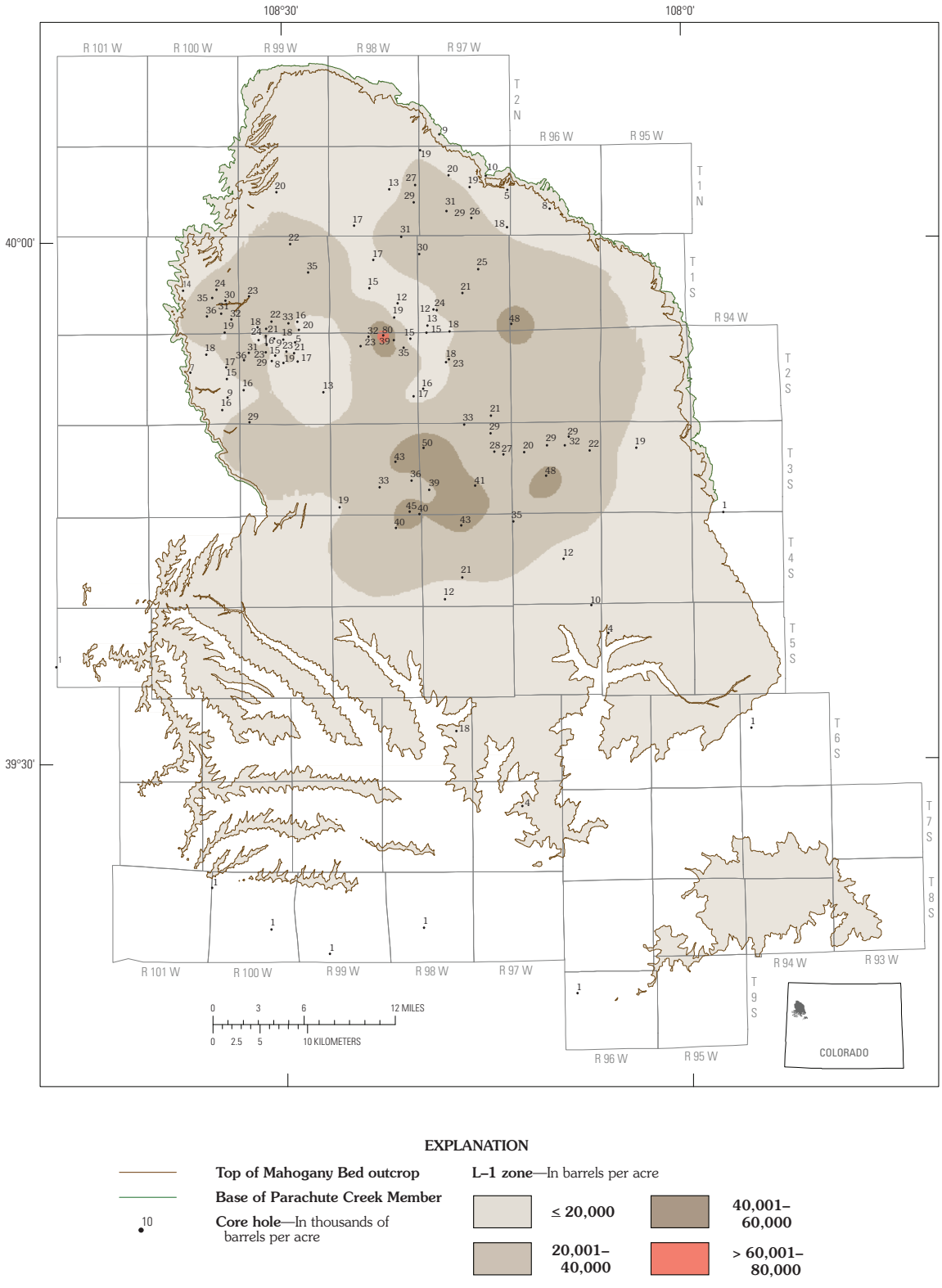
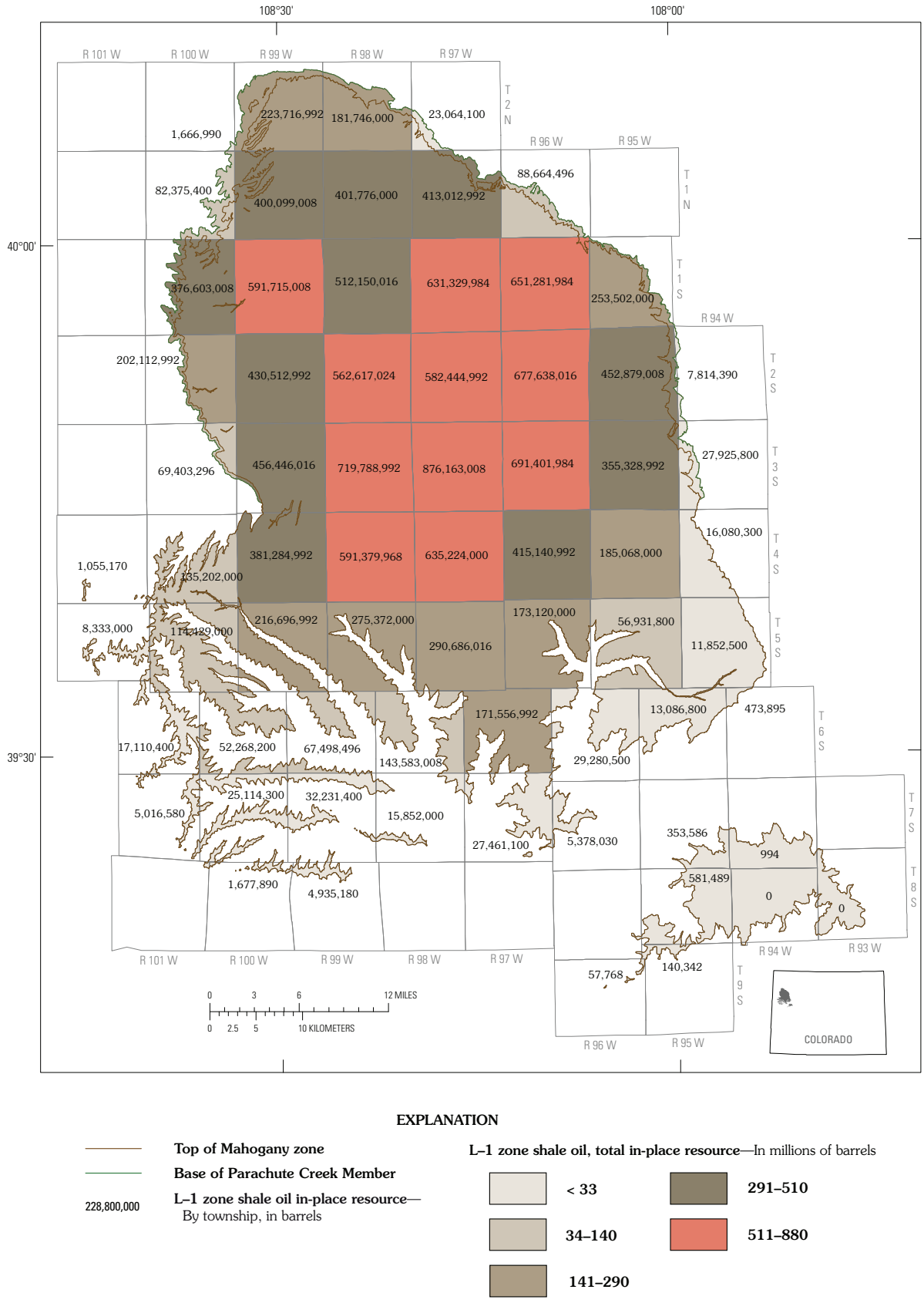


Figure 55. Isoresource map of the L-1 zone showing oil yields in barrels per acre (BPA). The Radial Basis Function Method (RBF) was used for contouring.



EXPLANATION

Top of Mahogany zone

Base of Parachute Creek Member

228,800,000 L–1 zone shale oil in-place resource—By township, in barrels

L–1 zone shale oil, total in-place resource—In millions of barrels

< 33

34–140

141–290

291–510

511–880

Figure 56. Isoresource map of the L-1 zone showing total number of barrels of oil in each township.

Table 13. Total number of in-place barrels of oil per acre (BPA) in each township for the L-1 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.

Township, Range	SUM L-1	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriged (Pitman and others 1989)	95 percent confidence
1N 96W	88,664,500	9,176,000	79,488,500	866	13,554,000	±138
1N 97W	413,013,000				102,512,000	±311
1N 98W	401,776,000					
1N 99W	400,099,000	105,280,000	294,819,000	280	85,744,000	±90
1N 100W	82,375,400	417,142,000	-334,766,600	-80	369,524,000	±29
2N 97W	23,064,100	337,260,000	-314,195,900	-93	465,107,000	±36
2N 98W	181,746,000	256,344,000	-74,598,000	-29	392,027,000	±75
2N 99W	223,717,000	7,535,000	216,182,000	2,869	35,684,000	±91
2N 100W	1,666,990					
1S 95W	253,502,000					
1S 96W	651,282,000	545,261,000	106,021,000	19	543,029,000	±72
1S 97W	631,330,000	688,716,000	-57,386,000	-8	540,687,000	±24
1S 98W	512,150,000	549,010,000	-36,860,000	-7	546,565,000	±22
1S 99W	591,715,000	587,760,000	3,955,000	1	527,804,000	±30
1S 100W	376,603,000	119,624,000	256,979,000	215	335,612,000	±57
2S 94W	7,814,390					
2S 95W	452,879,000					
2S 96W	677,638,000	698,370,000	-20,732,000	-3	686,079,000	±33
2S 97W	582,445,000	498,393,000	84,052,000	17	620,790,000	±18
2S 98W	562,617,000	424,897,000	137,720,000	32	536,230,000	±19
2S 99W	430,513,000	508,662,000	-78,149,000	-15	409,720,000	±45
2S 100W	202,113,000	170,786,000	31,327,000	18	288,845,000	±60
3S 94W	27,925,800					
3S 95W	355,329,000	333,645,000	21,684,000	6	545,476,000	±99
3S 96W	691,402,000	838,864,000	-147,462,000	-18	764,002,000	±19
3S 97W	876,163,000	1,064,025,000	-187,862,000	-18	767,124,000	±13
3S 98W	719,789,000	563,950,000	155,839,000	28	622,691,000	±24
3S 99W	456,446,000	337,056,000	119,390,000	35	512,766,000	±70
3S 100W	69,403,300	17,109,000	52,294,300	306	43,798,000	±95
4S 94W	16,080,300					—-
4S 95W	185,068,000	183,592,000	1,476,000	1		—-
4S 96W	415,141,000	429,913,000	-14,772,000	-3	478,261,000	±37
4S 97W	635,224,000	559,368,000	75,856,000	14	724,812,000	±34
4S 98W	591,380,000	367,328,000	224,052,000	61	282,314,000	±116

Table 13. Total number of in-place barrels of oil per acre (BPA) in each township for the L-1 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.—Continued

Township, Range	SUM L-1	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriged (Pitman and others 1989)	95 percent confidence
4S 99W	381,285,000					
4S 100W	135,202,000					
4S 101W	1,055,170					
5S 94W	11,852,500					
5S 95W	56,931,800					
5S 96W	173,120,000	78,452,000	94,668,000	121		
5S 97W	290,686,000					
5S 98W	275,372,000					
5S 99W	216,697,000					
5S 100W	114,429,000					
5S 101W	8,333,000					
6S 94W	473,895					
6S 95W	13,086,800					
6S 96W	29,280,500					
6S 97W	171,557,000					
6S 98W	143,583,000					
6S 99W	67,498,500					
6S 100W	52,268,200					
6S 101W	17,110,400					
7S 93W	0					
7S 94W	994					
7S 95W	353,586					
7S 96W	5,378,030					
7S 97W	27,461,100					
7S 98W	15,852,000					
7S 99W	32,231,400					
7S 100W	25,114,300					
7S 101W	5,016,580					

Table 13. Total number of in-place barrels of oil per acre (BPA) in each township for the L-1 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-1 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level.—Continued

Township, Range	SUM L-1	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriged (Pitman and others 1989)	95 percent confidence
8S 93W	0					
8S 94W	0					
8S 95W	581,489					
8S 96W	54,224					
8S 99W	4,935,180					
8S 100W	1,677,890					
8S 101W	100,561					
9S 94W	0					
9S 95W	140,342					
9S 96W	57,768					
	15,066,851,989	10,697,518,000			11,240,757,000	

Sum of townships used here and Pitman and others (1989) extrapolated:	11,386,537,300	Sum of townships used here and kriging	11,441,362,300
Percent difference using RBF here and Pitman and others (1989) extrapolated:	6.44	Percent difference betwee RBF and kriging:	1.78
Sum of best townships (RBF)	2,712,627,000		
Sum of best townships extrapolated:	2,826,179,000		
Sum of best townships kriged:	2,688,146,000		
Percent difference betwee RBF and extrapolation best townships:	4.19		
Percent difference between RBF and kriging best townships:	0.91		

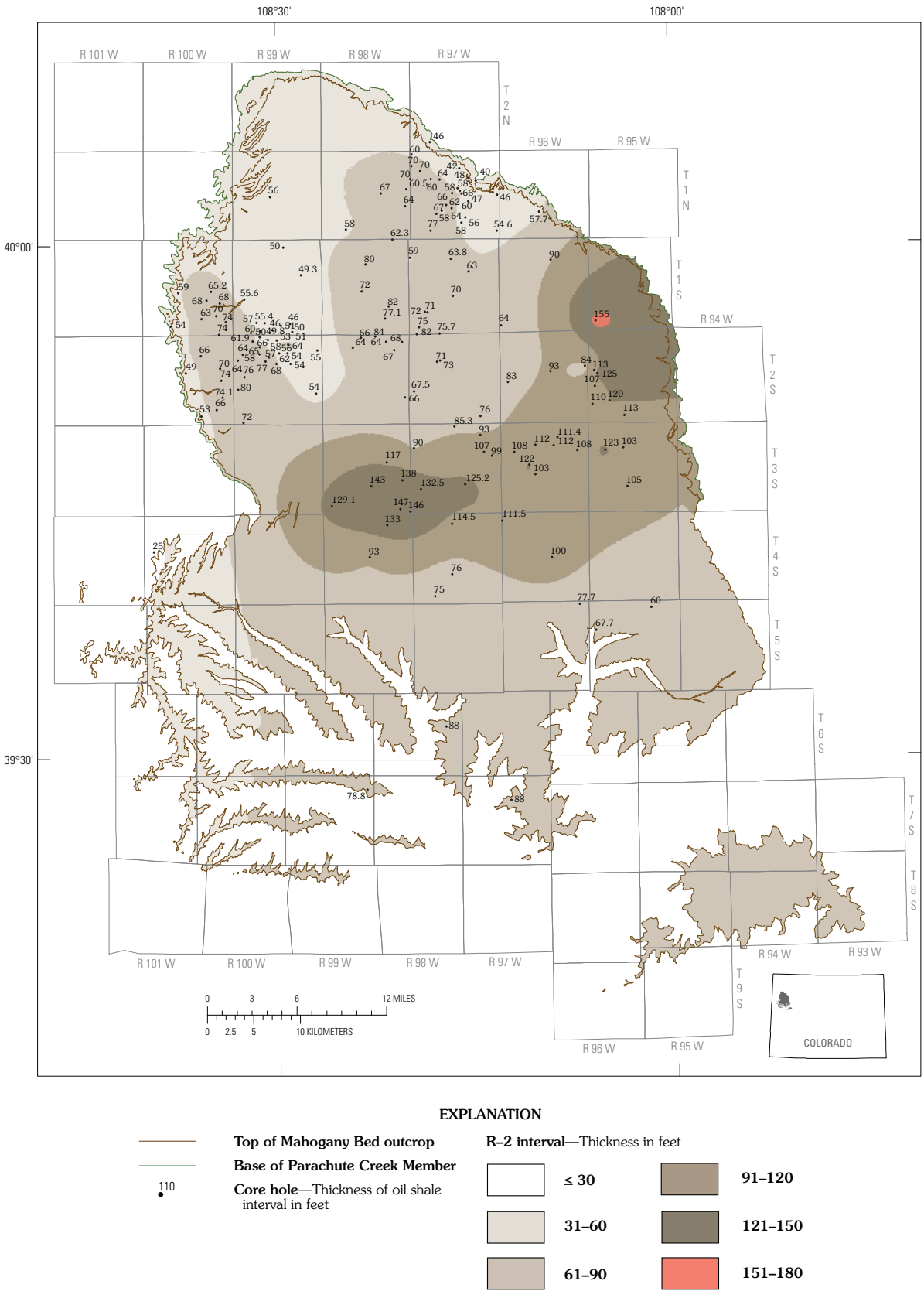


Figure 57. Isopach map of the R-2 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

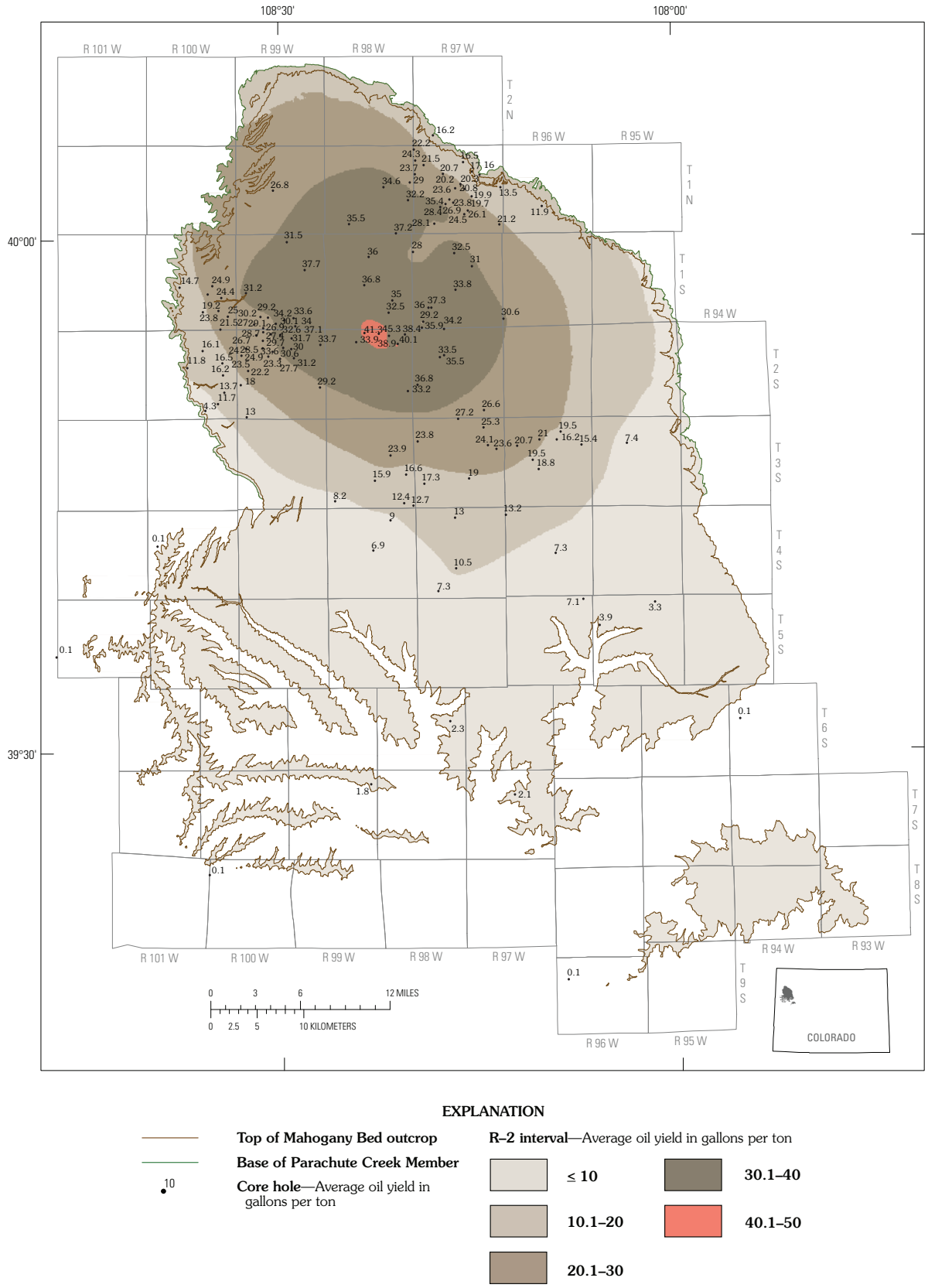


Figure 58. Isoresource map of the R-2 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

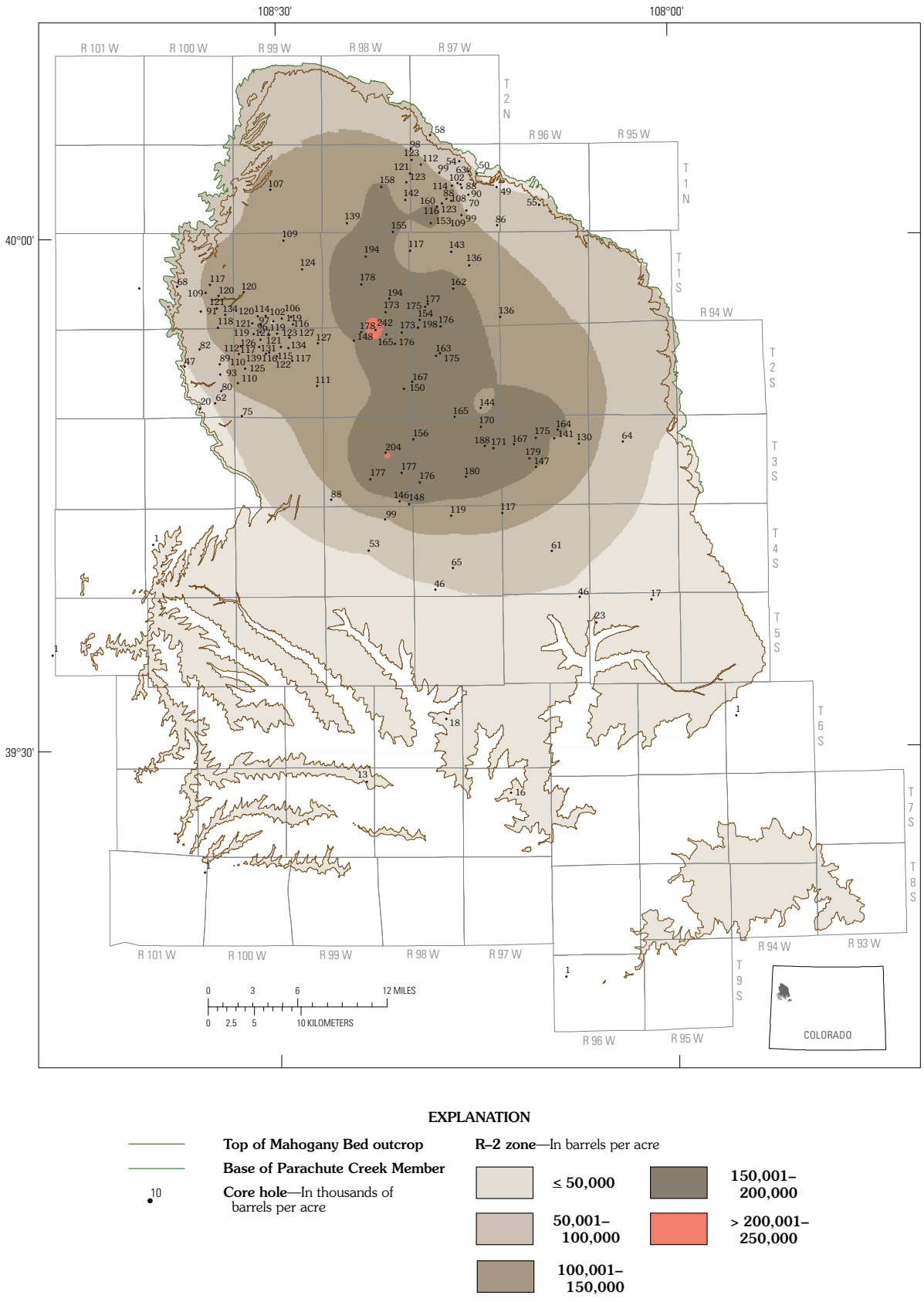
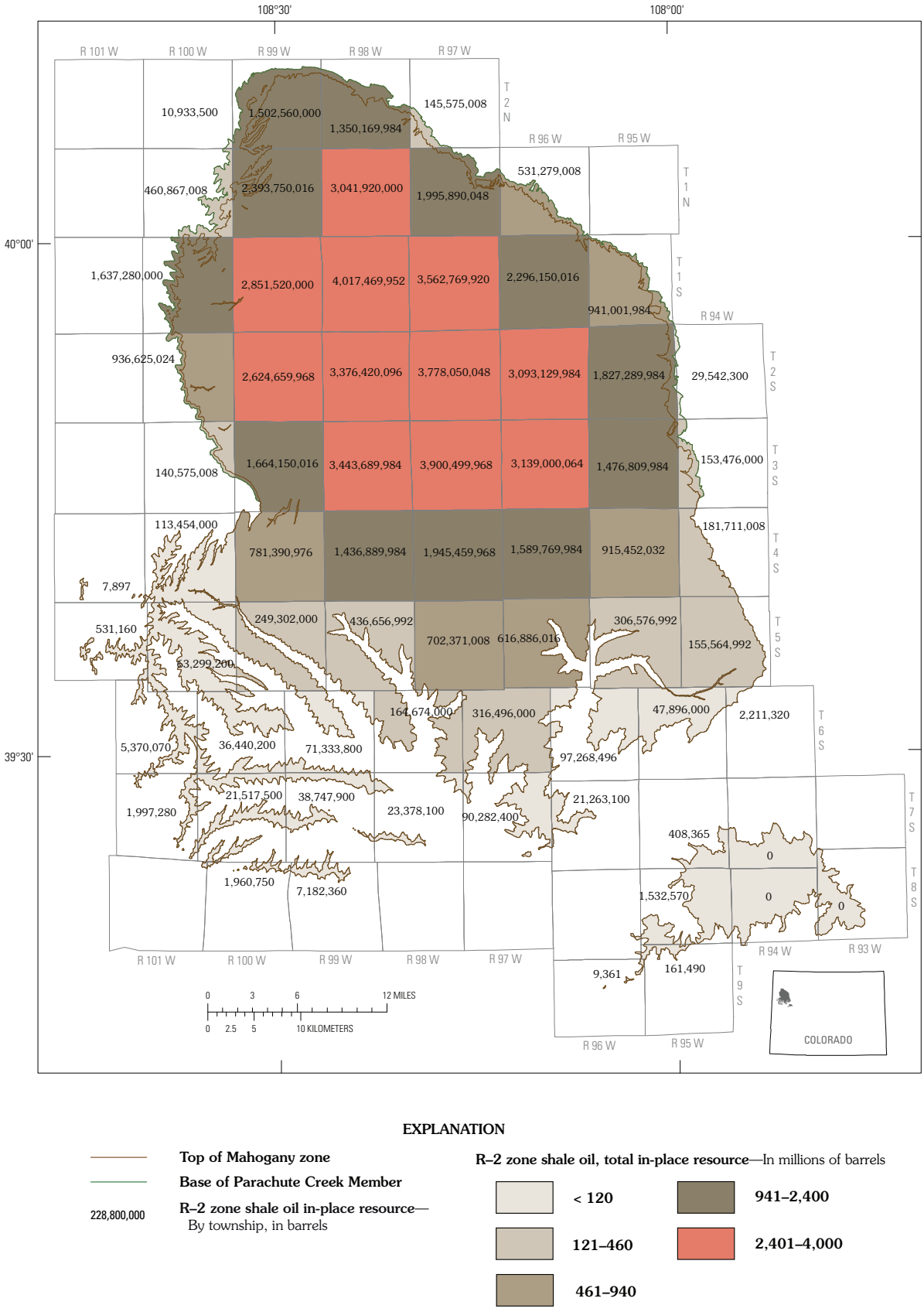


Figure 59. Isoresource map for the R-2 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.



EXPLANATION

Top of Mahogany zone

Base of Parachute Creek Member

228,800,000 R–2 zone shale oil in-place resource—By township, in barrels

R–2 zone shale oil, total in-place resource—In millions of barrels

- < 120
- 121–460
- 461–940
- 941–2,400
- 2,401–4,000

Figure 60. Isoresource map of the R-2 zone showing total number of barrels of oil in each township using only core hole data.

Table 14. Total number of in-place barrels of oil per acre (BPA) in each township for the R-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).

Township, Range	SUM R-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	531,279,000	34,410,000	496,869,000	1,444	85,904,000	±42	445,375,000	518
1N 97W	1,995,890,000	703,950,000	1,291,940,000	184	964,014,000	±84	1,031,876,000	107
1N 98W	3,041,920,000							
1N 99W	2,393,750,000	427,700,000	1,966,050,000	460	387,551,000	±27	2,006,199,000	518
1N 100W	460,867,000	1,896,100,000	-1,435,233,000	-76	1,874,660,000	±4	-1,413,793,000	-75
2N 97W	145,575,000	2,922,920,000	-2,777,345,000	-95	2,957,579,000	±14	-2,812,004,000	-95
2N 98W	1,350,170,000	2,221,648,000	-871,478,000	-39	2,405,777,000	±21	-1,055,607,000	-44
2N 99W	1,502,560,000	135,630,000	1,366,930,000	1,008	150,421,000	±50	1,352,139,000	899
2N 100W	10,933,500							
1S 95W	941,002,000							
1S 96W	2,296,150,000	1,825,439,000	470,711,000	26	1,985,566,000	±47	310,584,000	16
1S 97W	3,562,770,000	3,640,356,000	-77,586,000	-2	3,628,422,000	±7	-65,652,000	-2
1S 98W	4,017,470,000	3,771,460,000	246,010,000	7	3,814,808,000	±8	202,662,000	5
1S 99W	2,851,520,000	2,914,310,000	-62,790,000	-2	2,857,124,000	±16	-5,604,000	0
1S 100W	1,637,280,000	1,121,475,000	515,805,000	46	1,390,669,000	±28	246,611,000	18
2S 94W	29,542,300							
2S 95W	1,827,290,000	1,324,850,000	502,440,000	38	3,046,240,000	±76	-1,218,950,000	-40
2S 96W	3,093,130,000	2,560,690,000	532,440,000	21	2,932,199,000	±25	160,931,000	5
2S 97W	3,778,050,000	3,678,615,000	99,435,000	3	3,696,804,000	±8	81,246,000	2
2S 98W	3,376,420,000	3,086,094,000	290,326,000	9	3,171,693,000	±10	204,727,000	6
2S 99W	2,624,660,000	2,265,858,000	358,802,000	16	2,451,198,000	±14	173,462,000	7
2S 100W	936,625,000	878,328,000	58,297,000	7	1,059,230,000	±33	-122,605,000	-12
3S 94W	153,476,000							
3S 95W	1,476,810,000	1,156,636,000	320,174,000	28	802,979,000	±120	673,831,000	84
3S 96W	3,139,000,000	3,106,064,000	32,936,000	1	2,923,854,000	±9	215,146,000	7
3S 97W	3,900,500,000	3,783,200,000	117,300,000	3	3,737,419,000	±5	163,081,000	4
3S 98W	3,443,690,000	3,022,772,000	420,918,000	14	3,099,380,000	±11	344,310,000	11
3S 99W	1,664,150,000	863,706,000	800,444,000	93	1,533,706,000	±41	130,444,000	9
3S 100W	140,575,000				121,667,000	±100	18,908,000	16
4S 94W	181,711,000							

Table 14. Total number of in-place barrels of oil per acre (BPA) in each township for the R-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 95W	915,452,000	917,960,000	-2,508,000	0	782,210,000	±98	133,242,000	17
4S 96W	1,589,770,000	1,697,025,000	-107,255,000	-6	1,619,528,000	±36	-29,758,000	-2
4S 97W	1,945,460,000	1,631,490,000	313,970,000	19	1,763,993,000	±21	181,467,000	10
4S 98W	1,436,890,000	1,010,152,000	426,738,000	42	1,014,718,000	±49	422,172,000	42
4S 99W	781,391,000							
4S 100W	113,454,000							
4S 101W	7,897							
5S 94W	155,565,000							
5S 95W	306,577,000							
5S 96W	616,886,000	470,712,000	146,174,000	31	541,644,000	±262	75,242,000	14
5S 97W	702,371,000							
5S 98W	436,657,000							
5S 99W	249,302,000							
5S 100W	63,299,200							
5S 101W	531,160							
6S 94W	2,211,320							
6S 95W	47,896,000							
6S 96W	97,268,500							
6S 97W	316,496,000							
6S 98W	164,674,000							
6S 99W	71,333,800							
6S 100W	36,440,200							
6S 101W	5,370,070							
7S 93W	0							
7S 94W	0							
7S 95W	408,365							
7S 96W	21,263,100							
7S 97W	90,282,400							
7S 98W	23,378,100							
7S 99W	38,747,900							

Table 14. Total number of in-place barrels of oil per acre (BPA) in each township for the R-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 100W	21,517,500							
7S 101W	1,997,280							
8S 93W	0							
8S 94W	0							
8S 95W	1,532,570							
8S 96W	91,801							
8S 99W	7,182,360							
8S 100W	1,960,750							
8S 101W	87,132							
9S 94W	0							
9S 95W	161,490							
9S 96W	9,361							
	66,768,689,056	53,069,550,000			56,800,957,000			
Sum of townships used here and Pitman and others (1989) extrapolated:		58,510,064,000	Sum of townships used here and kriging:		58,510,064,000			
Percent difference using RBF here and Pitman and others (1989) extrapolated:		10.25	Percent difference between RBF and kriging:		3.01			
Sum of best townships RBF (20 percent):		30,694,080,000	Sum of best townships extrapolated:		29,268,729,000	Sum of best townships kriging:	29,380,702,000	
Percent difference RBF vs extrapolation for best TSPS:		4.87						
Percent difference RBF vs kriging for best TSPS:		4.47						

others (1989) our assessment of in-place oil for the L-2 zone is 8.28 percent higher than the manually extrapolated results and 4.83 percent higher than the kriged assessment of Pitman and others (1989) (table 15). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 0.47 percent lower than the manually extrapolated results and 6.21 percent higher than the kriged results of Pitman and others (1989) (table 15).

R-3 Zone

The saline depocenter in the north-central part of the basin became well established during deposition of the R-3 zone with several thick beds consisting of predominantly nahcolite scattered throughout the zone in this area (Dyni, 1974; 1981; Brownfield and others, chapter 2, this CD-ROM). Unlike the underlying R-2 and L-2 zone, in which maximum thicknesses were south and east of the oil shale and saline depocenter, the R-3 zone is thickest in the depocenter itself where it is over 150 ft thick. The R-3 zone thins in a radial pattern outward (fig. 65). The presence of several thick nahcolite beds in the R-3 zone is at least in part responsible for this thickening trend. The R-3 zone reaches a maximum of over 43 GPT and 381,000 BPA in this depocenter (figs. 66, 67). Maximum in-place oil in a township is nearly 6.5 billion barrels in T. 1 S., R. 98 W. in the heart of the oil shale and saline-mineral depocenter (fig. 68). Total in-place oil in the R-3 zone is estimated to be nearly 68.1 billion barrels (table 16).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989) our assessment of in-place oil for the R-3 zone is 5.17 percent higher than the manually extrapolated results and 6.22 percent higher than the kriged assessment of Pitman and others (1989) (table 16). Results from seven townships assessed by Pitman and others (1989) are questionable based on the control available at the time and our knowledge of the basin, and these are highlighted in red on table 16. When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 5.33 percent higher than the manually extrapolated results and 3.90 percent higher than the kriged results of Pitman and others (1989) (table 16). The questionable townships mentioned above were not included in this comparison of best townships.

L-3 Zone

One hundred fifty eight core holes were used to assess the L-3 zone in this assessment as compared to 93 in the previous assessment (Pitman and others, 1989). The L-3 zone is a comparatively thin oil shale zone that represents a near cessation of nahcolite deposition. Interestingly, the zone is thickest along the south margins of the oil shale depocenter similar to the R-2 and L-2 zones. Here the L-3 zone reaches a maximum thickness of 68 ft. (fig. 69). The oil shale depocenter during deposition of the L-3 zone occupies the same area in the north-central part of the basin as the previous R-3 zone (figs. 70–72). Maximum oil yields in this depocenter are about 35 GPT (fig. 70) and maximum in-place oil is about 94,000 BPA (fig. 71). Maximum in-place oil in a township is nearly 1.6 billion barrels in T. 2 S., R. 97 W. (fig. 72). Total in-place oil in the L-3 zone is estimated to be about 22.5 billion barrels (table 17).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989) our assessment of in-place oil for the L-3 zone is 7.45 percent higher than the manually extrapolated results and 2.18 percent higher than the kriged assessment of Pitman and others (1989) (table 17). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 6.39 percent higher than the manually extrapolated results and 0.48 percent higher than the kriged results of Pitman and others (1989) (table 17).

R-4 Zone

The base of the R-4 zone through the base of the Mahogany ledge comprises the fourth stage of Lake Uinta of Johnson (1985). A comparatively minor transgression marks the beginning of this stage, extending oil shale deposition into areas of the lake where marginal lacustrine facies previously predominated (Johnson, 1985; 1988). In some locations along the south and west margins of the basin, the transgression is marked by a shift from a marginal lacustrine sequence containing abundant thick stromatolite units to oil shale interbedded with marlstone and thin stromatolites (Johnson and others, 1988, sheet 1, measured section 4). In other locations the transgression is marked by a shift from interbedded oil shale and marlstone to predominantly oil shale (Johnson and others, 1988, sheet 1, measured section 2). The presence of stromatolites both above and below the base of the R-4 zone in some sections possibly suggests that the increase in average water depth after this transgression may not have been great. It should be remembered that water level probably fluctuated constantly throughout the history of this closed saline lake, but average water levels appear to have been somewhat higher beginning with the deposition of the R-4 zone than previously. Nahcolite is all but absent from the lower part of the R-4 zone in the saline depocenter, and only a few comparatively thin, persistent beds high in nahcolite occur in the R-4 zone overall (Dyni, 1974; 1981). This would suggest that lake water was less saline after the transgression than before.

One hundred seventy one core holes were used to assess the R-4 zone here as compared to 104 core holes in the previous assessment (Pitman and others, 1989). The R-4 zone is

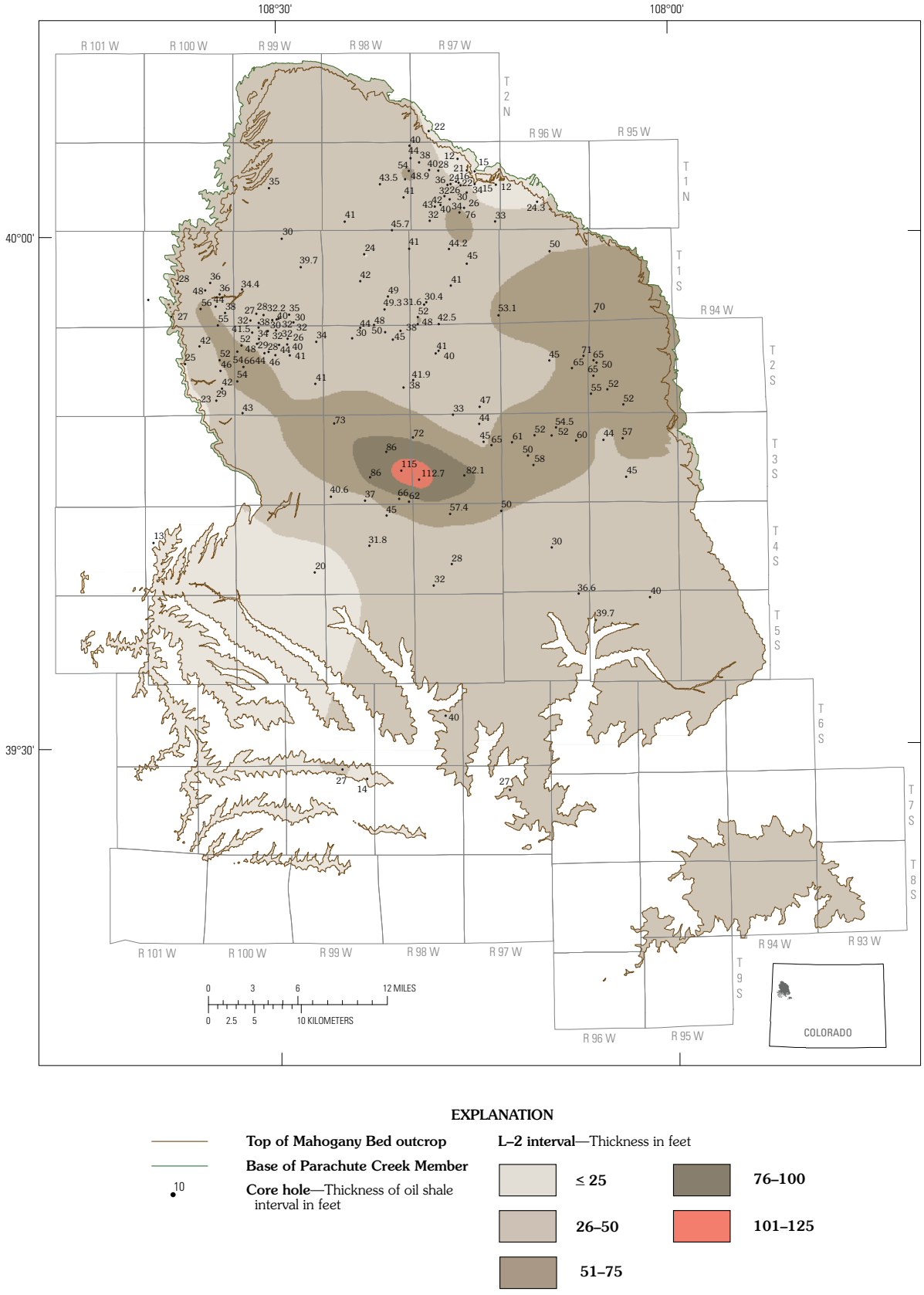


Figure 61. Isopach map of the L-2 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

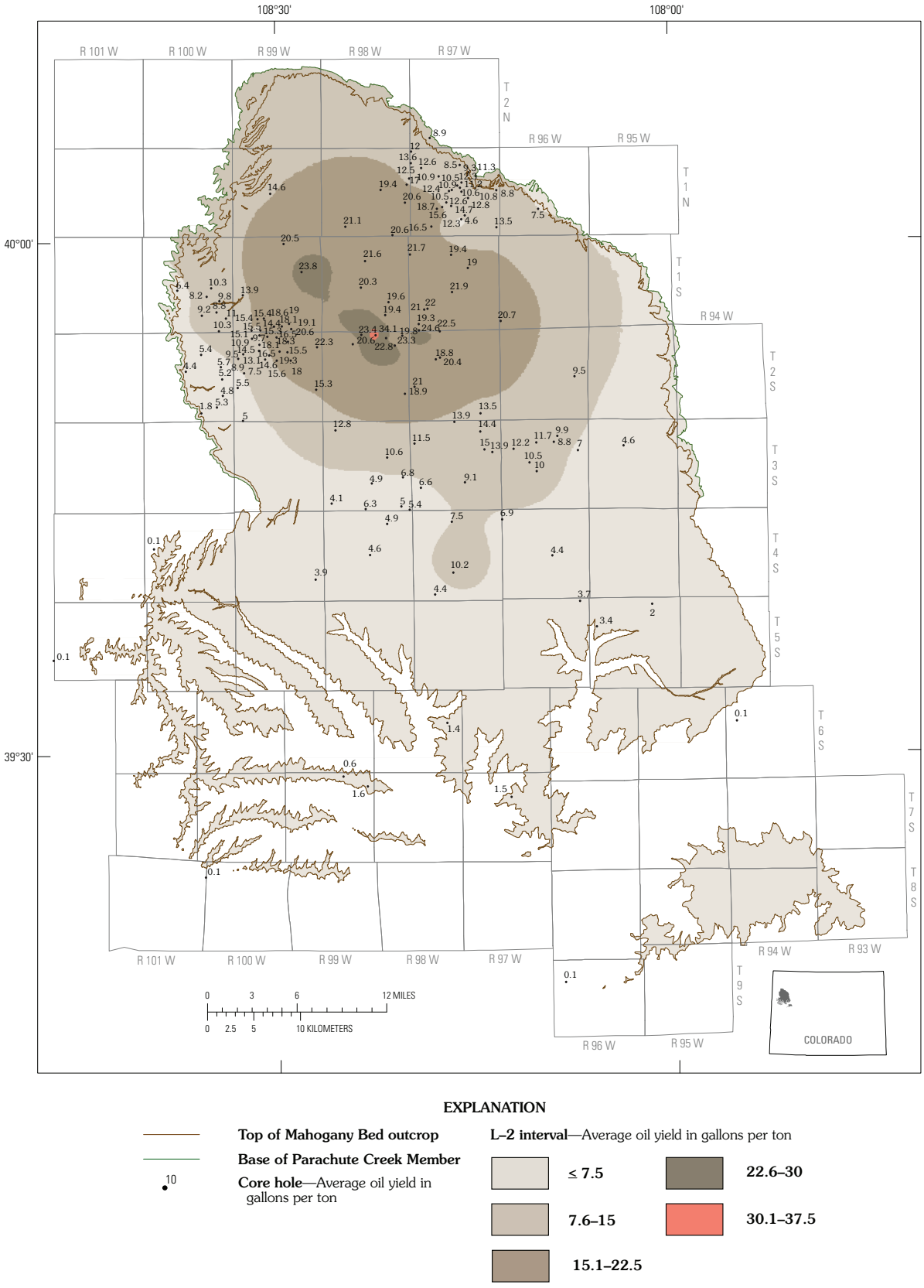


Figure 62. Isoresource map of the L-2 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

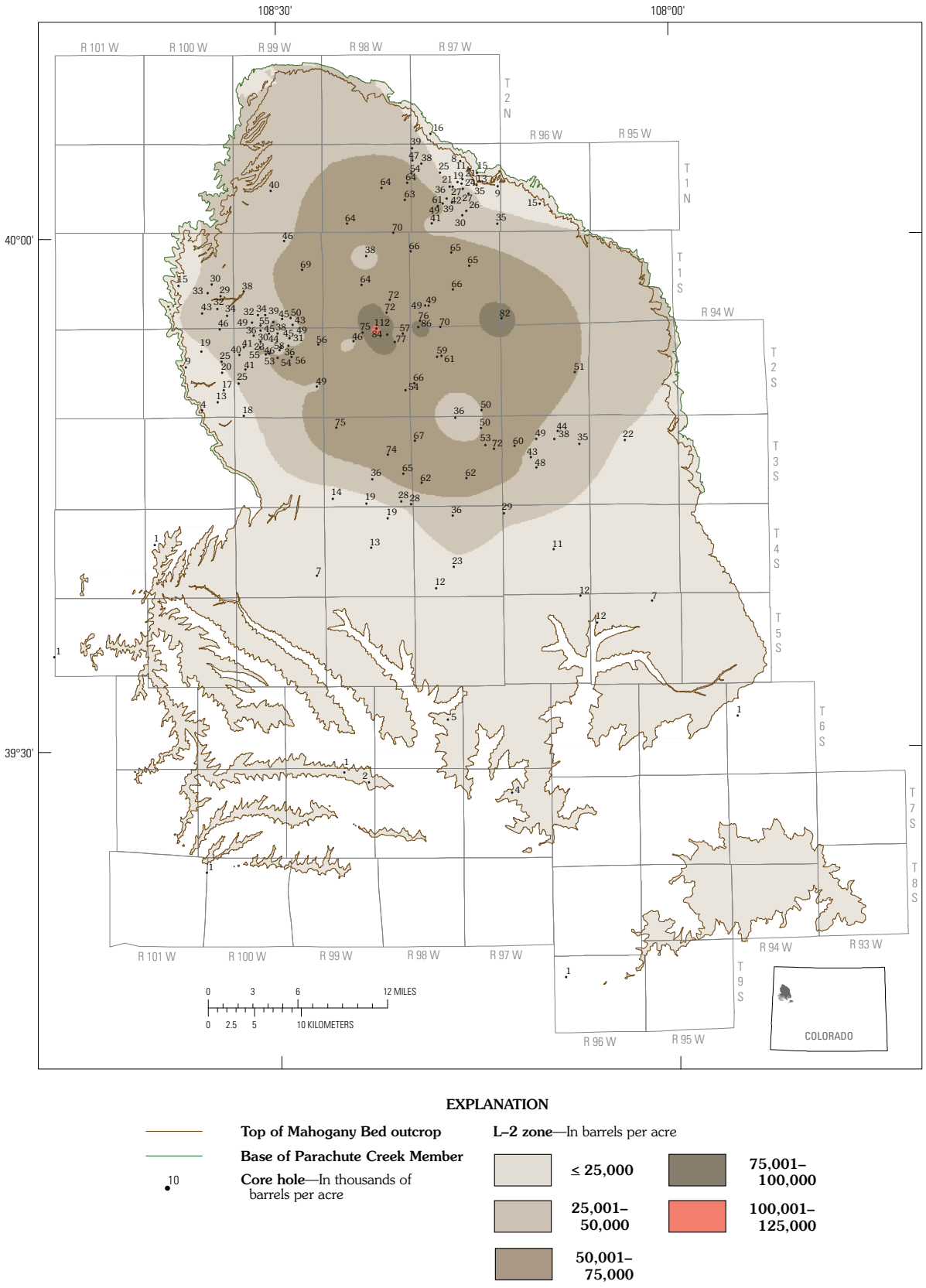


Figure 63. Isoresource map of the L-2 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

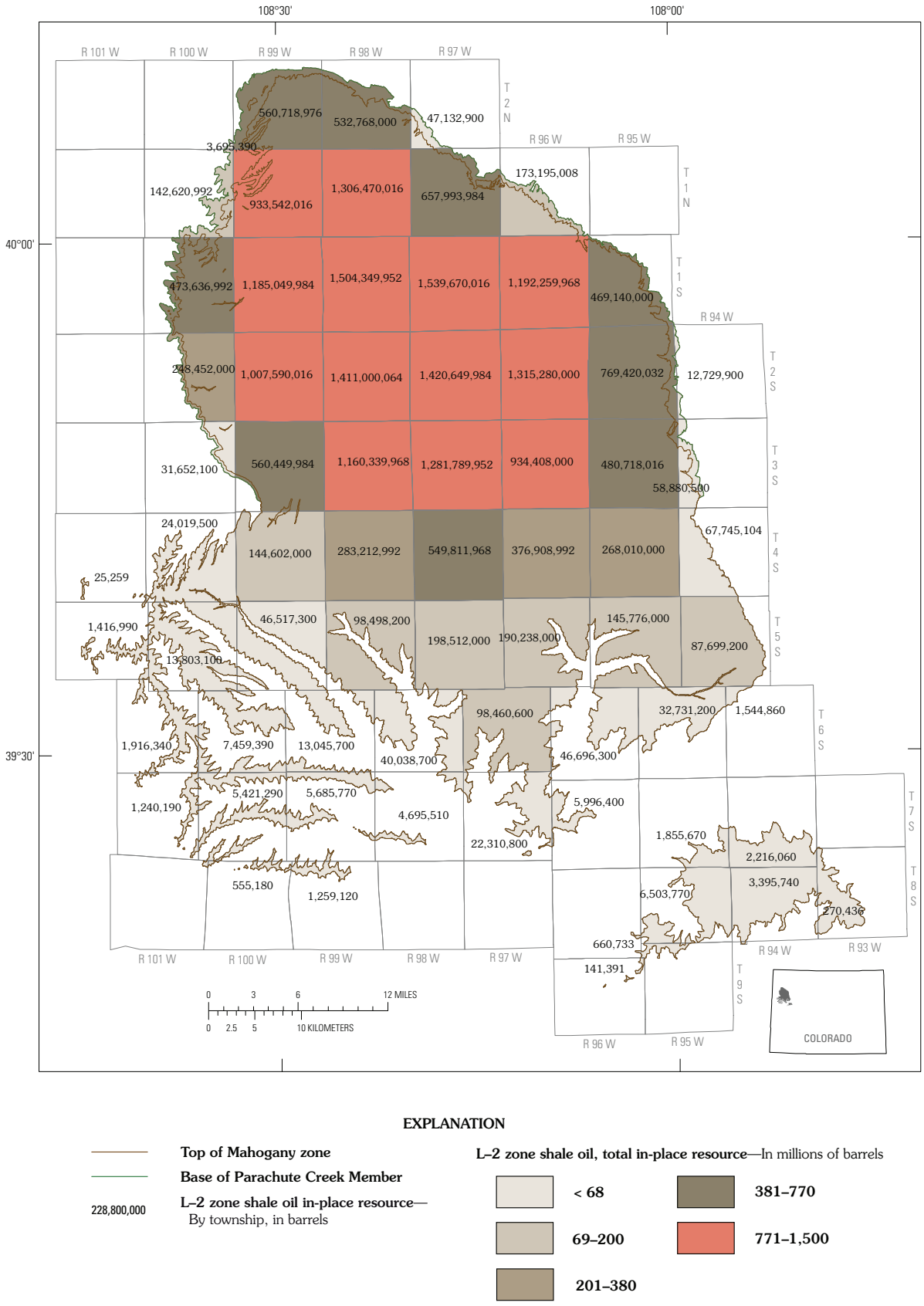


Figure 64. Isoresource map of the L-2 zone showing total number of barrels of oil in each township using only core hole data.

Table 15. Total number of in-place barrels of oil per acre (BPA) in each township for the L-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM L-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	173,195,000	22,940,000	150,255,000	655	25,132,000	±85	148,063,000	589
1N 97W	657,994,000	140,790,000	517,204,000	367	784,995,000	±73	-127,001,000	-16
1N 98W	1,306,470,000							
1N 99W	933,542,000	131,600,000	801,942,000	609	78,716,000	±144		
1N 100W	142,621,000	758,440,000	-615,819,000	-81	634,651,000	±20	-492,030,000	-78
2N 97W	47,132,900	1,124,200,000	-1,077,067,100	-96	1,242,144,000	±28	-1,195,011,100	-96
2N 98W	532,768,000	491,326,000	41,442,000	8	848,223,000	±122	-315,455,000	-37
2N 99W	560,719,000	13,563,000	547,156,000	4,034	101,135,000	±98	459,584,000	454
2N 100W	3,695,390							
1S 95W	469,140,000							
1S 96W	1,192,260,000	924,573,000	267,687,000	29	1,035,633,000	±60	156,627,000	15
1S 97W	1,539,670,000	1,598,805,000	-59,135,000	-4	1,187,460,000	±14	352,210,000	30
1S 98W	1,504,350,000	1,766,380,000	-262,030,000	-15	1,341,564,000	±11	162,786,000	12
1S 99W	1,185,050,000	1,175,520,000	9,530,000	1	1,229,485,000	±23	-44,435,000	-4
1S 100W	473,637,000	269,154,000	204,483,000	76	507,642,000	±63	-34,005,000	-7
2S 94W	12,729,900							
2S 95W	769,420,000	529,940,000	239,480,000	45	530,605,000	±307	238,815,000	45
2S 96W	1,315,280,000	1,163,950,000	151,330,000	13	1,173,075,000	±29	142,205,000	12
2S 97W	1,420,650,000	1,281,582,000	139,068,000	11	1,399,168,000	±10	21,482,000	2
2S 98W	1,411,000,000	1,341,780,000	69,220,000	5	1,231,889,000	±10	179,111,000	15
2S 99W	1,007,590,000	971,082,000	36,508,000	4	974,440,000	±19	33,150,000	3
2S 100W	248,452,000	207,383,000	41,069,000	20	480,258,000	±57	-231,806,000	-48
3S 94W	58,880,500							
3S 95W	480,718,000	400,374,000	80,344,000	20	275,185,000	±355	205,533,000	75
3S 96W	934,408,000	884,208,000	50,200,000	6	927,150,000	±24	7,258,000	1
3S 97W	1,281,790,000	1,418,700,000	-136,910,000	-10	1,092,010,000	±14	189,780,000	17
3S 98W	1,160,340,000	1,127,900,000	32,440,000	3	905,320,000	±22	255,020,000	28
3S 99W	560,450,000	273,858,000	286,592,000	105	361,049,000	±117	199,401,000	55
3S 100W	31,652,100				106,990,000	±501	-75,337,900	-70
4S 94W	67,745,100							
4S 95W	268,010,000	275,388,000	-7,378,000	-3	246,409,000	±175	21,601,000	9

Table 15. Total number of in-place barrels of oil per acre (BPA) in each township for the L-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 96W	376,909,000	362,032,000	14,877,000	4	565,147,000	±39	-188,238,000	-33
4S 97W	549,812,000	349,605,000	200,207,000	57	519,824,000	±67	29,988,000	6
4S 98W	283,213,000	344,370,000	-61,157,000	-18				
4S 99W	144,602,000							
4S 100W	24,019,500							
4S 101W	25,259							
5S 94W	87,699,200							
5S 95W	145,776,000							
5S 96W	190,238,000	196,130,000	-5,892,000	-3	179,051,000	±550	11,187,000	6
5S 97W	198,512,000	183,224,000	15,288,000	8				
5S 98W	98,498,200	201,972,000	-103,473,800	-51				
5S 99W	46,517,300							
5S 100W	13,803,100							
5S 101W	1,416,990							
6S 94W	1,544,860							
6S 95W	32,731,200							
6S 96W	46,696,300							
6S 97W	98,460,600	91,785,000	6,675,600	7				
6S 98W	40,038,700	53,220,000	-13,181,300	-25				
6S 99W	13,045,700							
6S 100W	7,459,390							
6S 101W	1,916,340							
7S 93W	87							
7S 94W	2,216,060							
7S 95W	1,855,670							
7S 96W	5,996,400							
7S 97W	22,310,800							
7S 98W	4,695,510							
7S 99W	5,685,770							
7S 100W	5,421,290							
7S 101W	1,240,190							

Table 15. Total number of in-place barrels of oil per acre (BPA) in each township for the L-2 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-2 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-2	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
8S 93W	270,436							
8S 94W	3,395,740							
8S 95W	6,503,770							
8S 96W	95,843							
8S 99W	1,259,120							
8S 100W	555,180							
8S 101W	70,614							
9S 94W	8,277							
9S 95W	660,733							
9S 96W	141,391							
Totals:	24,216,677,409	20,075,774,000			19,984,350,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	21,737,311,900	Sum of townships used here and kriging:	20,949,658,000			
Percent difference using RBF here and Pitman and others (1989)extrapolated:	8.28	Percent difference between RBF and kriging:	4.83			
Sum of best townships RBF (20 percent):	7,416,028,000	Sum of best townships extrapolated:	7,450,955,000	Sum of best townships kriging:	6,982,744,000	
Percent difference RBF vs extrapolation for best TSPS:	-0.47					
Percent difference RBF vs kriging for best TSPS:	6.21					

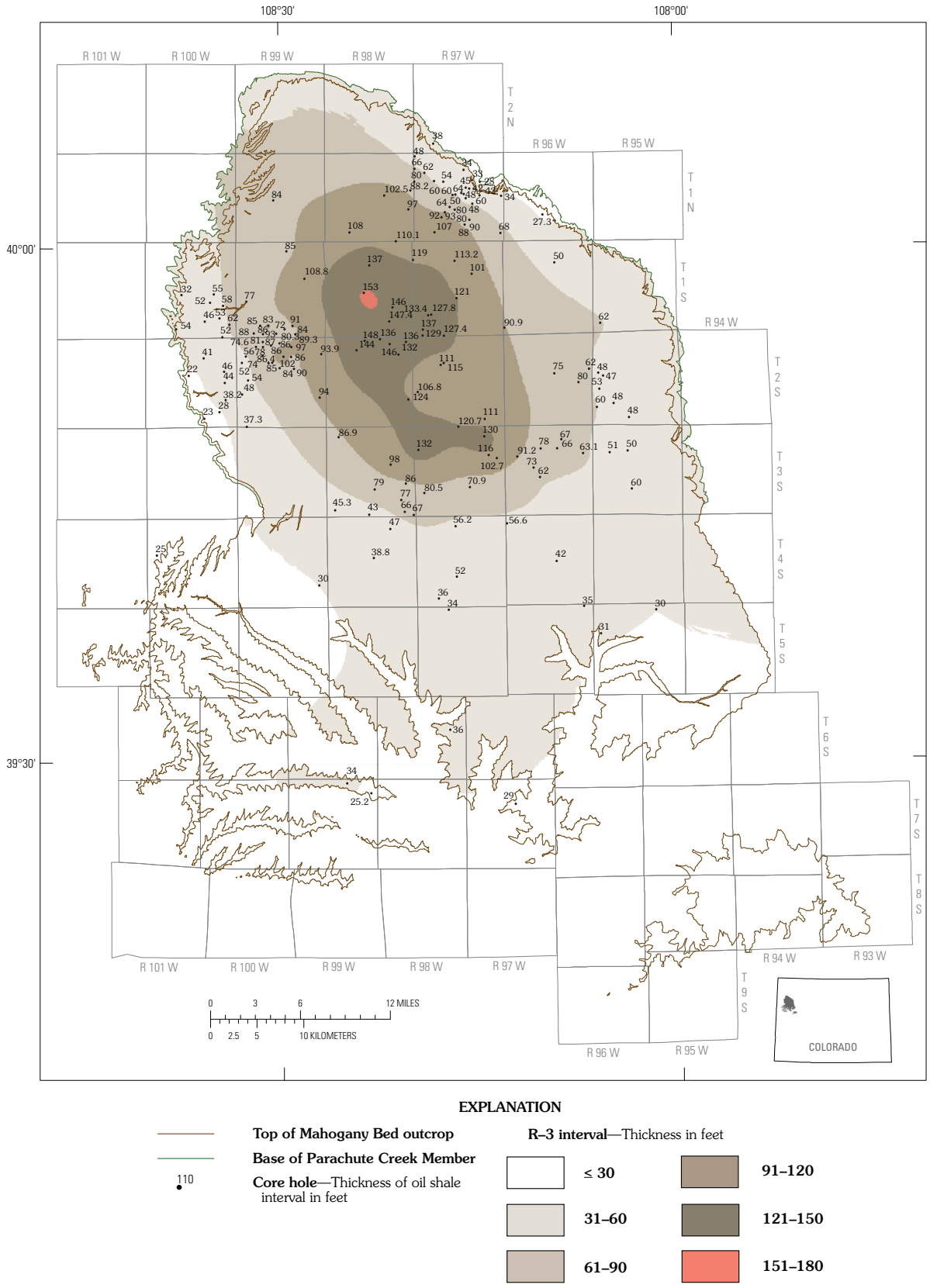


Figure 65. Isopach map of the R-3 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

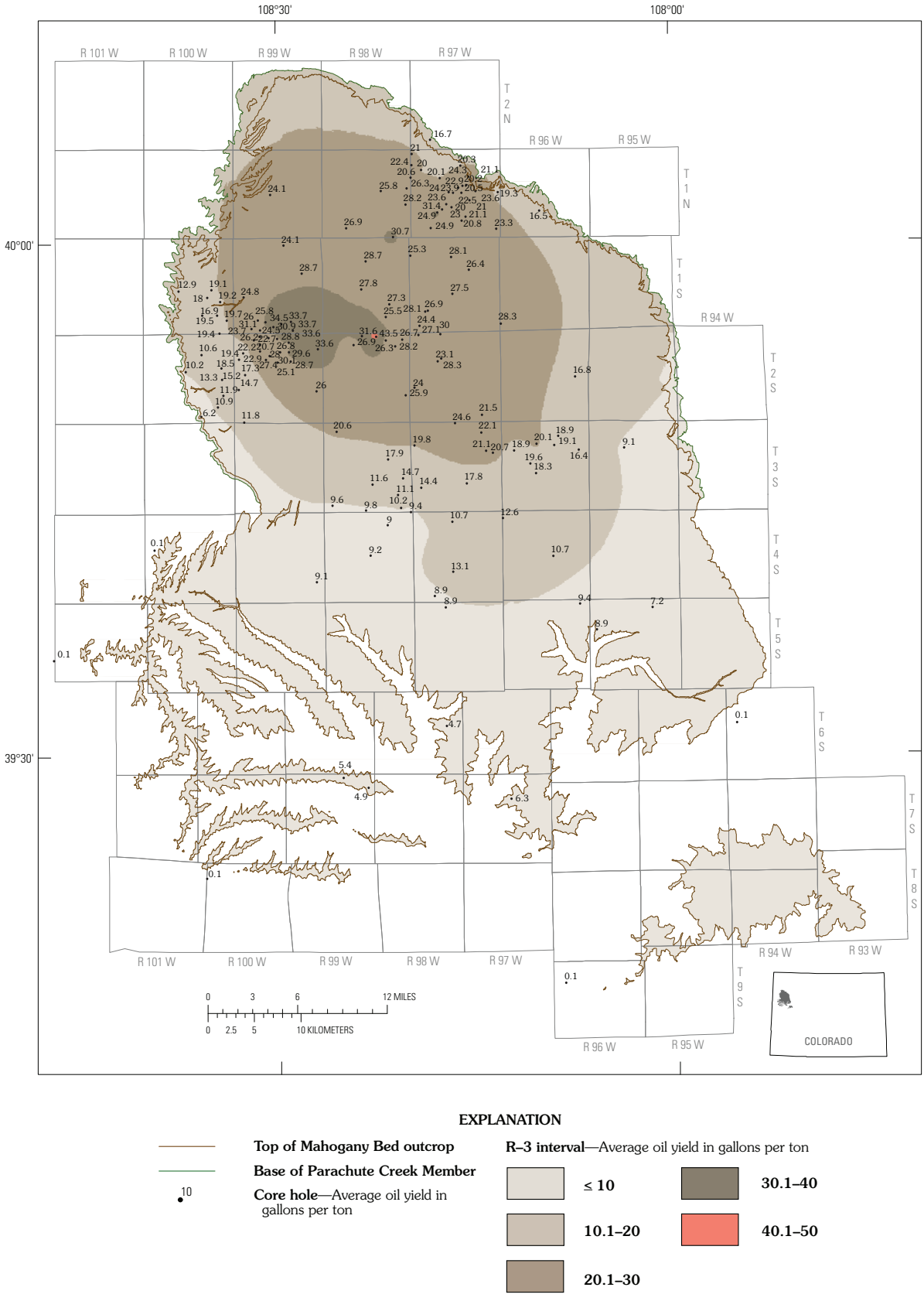


Figure 66. Isoresource map for the R-3 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

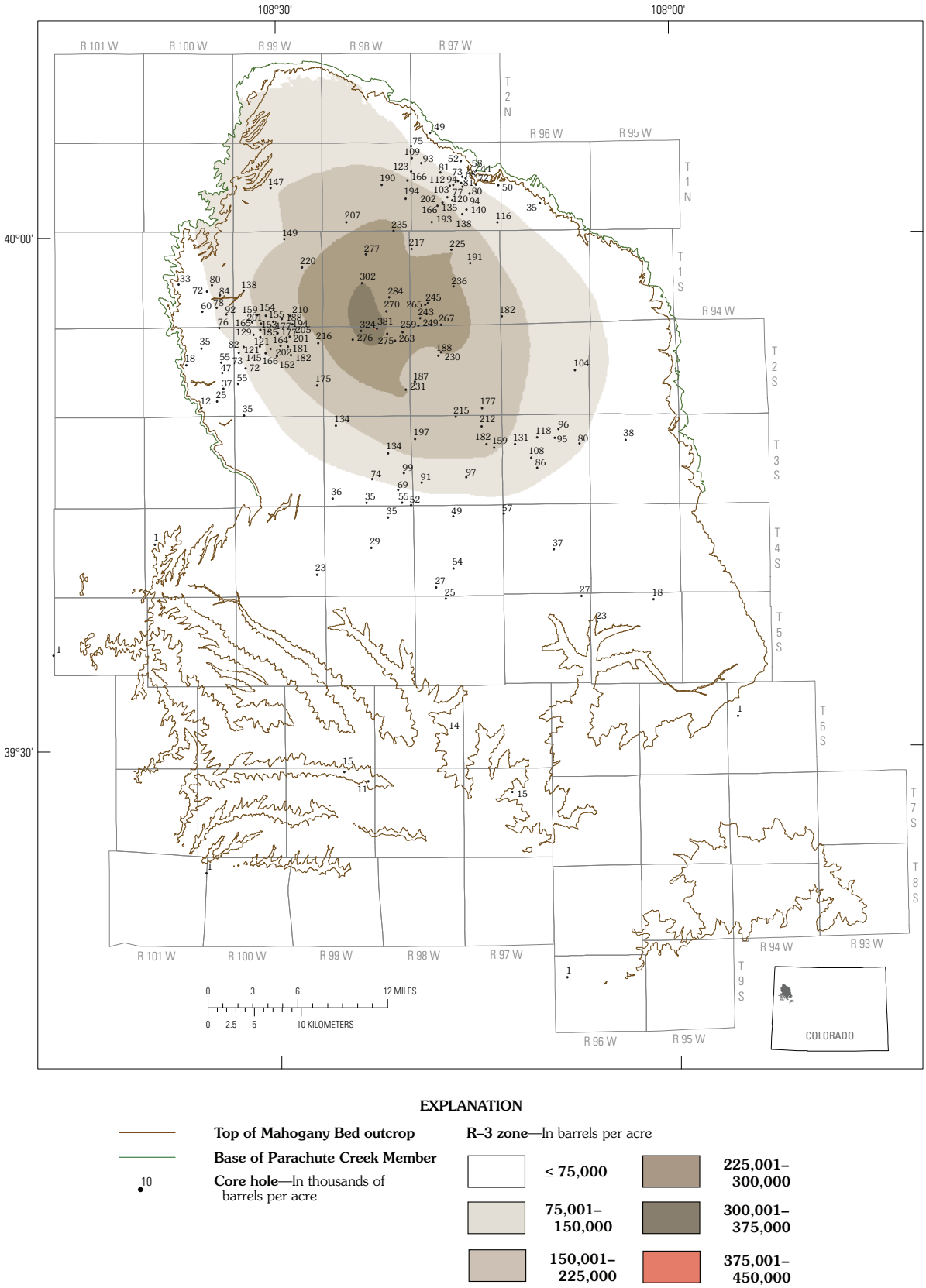


Figure 67. Isoresource map for the R-3 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

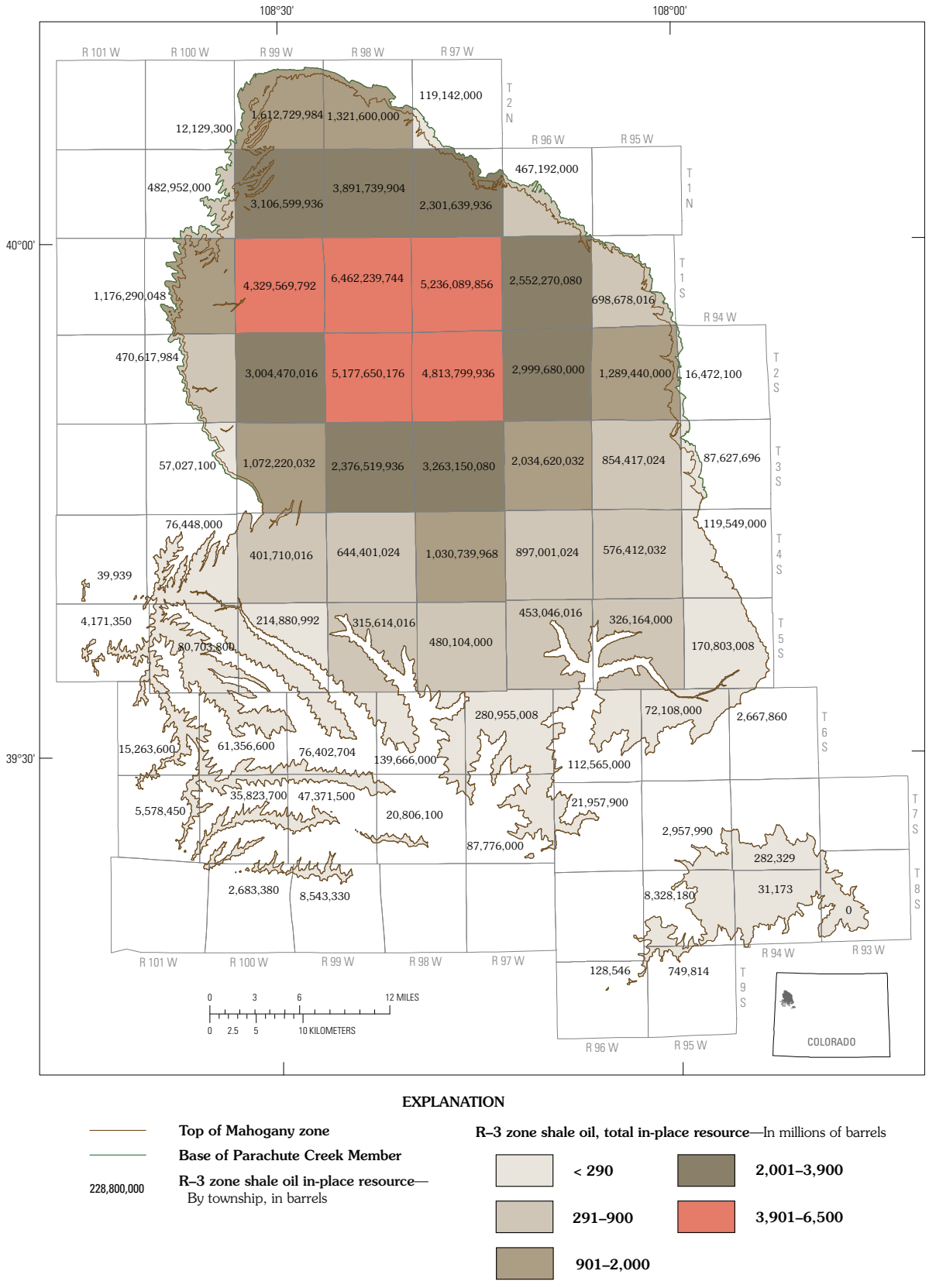


Figure 68. Isoresource map of the R-3 zone showing total number of barrels of oil in each township using only core hole data.

Table 16. Total number of in-place barrels of oil per acre (BPA) in each township for the R-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).

Township, Range	SUM R-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	467,192,000	57,350,000	409,842,000	715	46,180,000	±121	421,012,000	912
1N 97W	2,301,640,000	422,370,000	1,879,270,000	445	272,661,000	±461	2,028,979,000	744
1N 98W	3,891,740,000						3,891,740,000	
1N 99W	3,106,600,000	329,000,000	2,777,600,000	844	387,412,000	±44	2,719,188,000	702
1N 100W	482,952,000	1,896,100,000	-1,413,148,000	-75	2,176,476,000	±7	-1,693,524,000	-78
2N 97W	119,142,000	3,822,280,000	-3,123,602,000	-82	3,744,418,000	±17	-3,045,740,000	-81
2N 98W	1,321,600,000	2,969,318,000	-417,048,000	-14	3,083,941,000	±25	-531,671,000	-17
2N 99W	1,612,730,000	94,941,000	5,141,149,000	5,415	110,960,000	±103	5,125,130,000	4619
2N 100W	12,129,300						6,462,240,000	
1S 95W	698,678,000						4,329,570,000	
1S 96W	2,552,270,000	1,943,974,000	-767,684,000	-39	2,135,441,000	±60	-959,151,000	-45
1S 97W	5,236,090,000	5,411,340,000	-5,292,198,000	-98	5,037,376,000	±9	-4,918,234,000	-98
1S 98W	6,462,240,000	6,206,200,000	-4,884,600,000	-79	6,038,495,000	±8	-4,716,895,000	-78
1S 99W	4,329,570,000	4,408,200,000	-2,795,470,000	-63	4,291,099,000	±11	-2,678,369,000	-62
1S 100W	1,176,290,000	897,180,000	-885,050,700	-99	968,840,000	±60	-956,710,700	-99
2S 94W	16,472,100						16,472,100	
2S 95W	1,289,440,000	1,192,365,000	97,075,000	8	1,557,951,000	±117	-268,511,000	-17
2S 96W	2,999,680,000	3,259,060,000	-259,380,000	-8	2,996,821,000	±27	2,859,000	0
2S 97W	4,813,800,000	4,343,139,000	470,661,000	11	4,668,916,000	±11	144,884,000	3
2S 98W	5,177,650,000	5,143,490,000	34,160,000	1	4,906,089,000	±9	271,561,000	6
2S 99W	3,004,470,000	2,543,310,000	461,160,000	18	2,924,846,000	±18	79,624,000	3
2S 100W	470,618,000	414,766,000	55,852,000	13	325,491,000	±162	145,127,000	45
3S 94W	87,627,700						87,627,700	
3S 95W	854,417,000	444,860,000	409,557,000	92	426,256,000	±314	428,161,000	100
3S 96W	2,034,620,000	1,768,416,000	266,204,000	15	1,858,767,000	±22	175,853,000	9
3S 97W	3,263,150,000	3,050,205,000	212,945,000	7	3,208,191,000	±9	54,959,000	2
3S 98W	2,376,520,000	1,804,640,000	571,880,000	32	2,286,908,000	±16	89,612,000	4
3S 99W	1,072,220,000	842,640,000	229,580,000	27	844,997,000	±158	227,223,000	27
3S 100W	57,027,100	57,030,000	-2,900	0			57,027,100	

Table 16. Total number of in-place barrels of oil per acre (BPA) in each township for the R-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 94W	119,549,000						119,549,000	
4S 95W	576,412,000	688,470,000	-112,058,000	-16	560,013,000	±211	16,399,000	3
4S 96W	897,001,000	950,334,000	-53,333,000	-6	892,895,000	±97	4,106,000	0
4S 97W	1,030,740,000	1,002,201,000	28,539,000	3	920,011,000	±45	110,729,000	12
4S 98W	644,401,000	642,824,000	1,577,000	0	394,900,000	±178	249,501,000	63
4S 99W	401,710,000						401,710,000	
4S 100W	76,448,000						76,448,000	
4S 101W	39,939						39,939	
5S 94W	170,803,000						170,803,000	
5S 95W	326,164,000						326,164,000	
5S 96W	453,046,000	431,486,000	21,560,000	5	306,460,000	±403	146,586,000	48
5S 97W	480,104,000	503,866,000	-23,762,000	-5	275,889,000	±570	204,215,000	74
5S 98W	315,614,000	370,282,000	-54,668,000	-15	100,584,000	±2351	215,030,000	214
5S 99W	214,881,000							
5S 100W	80,703,800							
5S 101W	4,171,350							
6S 94W	2,667,860							
6S 95W	72,108,000							
6S 96W	112,565,000							
6S 97W	280,955,000	348,783,000	-67,828,000	-19				
6S 98W	139,666,000	122,080,000	17,586,000	14				
6S 99W	76,402,700							
6S 100W	61,356,600							
6S 101W	15,263,600							
7S 93W	0							
7S 94W	282,329							
7S 95W	2,957,990							
7S 96W	21,957,900							
7S 97W	87,776,000							

Table 16. Total number of in-place barrels of oil per acre (BPA) in each township for the R-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level. Numbers highlighted in red appear to be errors in the calculations made by Pitman and others (1989).—Continued

Township, Range	SUM R-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 98W	20,806,100							
7S 99W	47,371,500							
7S 100W	35,823,700							
7S 101W	5,578,450							
8S 93W	0							
8S 94W	31,173							
8S 95W	8,328,180							
8S 96W	171,246							
8S 99W	8,543,330							
8S 100W	2,683,380							
8S 101W	120,597							
9S 94W	0							
9S 95W	749,814							
9S 96W	128,546							
Totals:	68,084,658,284	58,382,500,000			57,749,284,000			

Sum of townships used here and Pitman and others, (1989) extrapolated:	61,399,867,100	Sum of townships used here and kriging	61,342,840,000				
Percent difference using RBF here and Pitman and others (1989) extrapolated:	5.17	Percent difference between RBF and kriging	6.22				
Sum of best townships RBF (20 percent):	34,663,490,000	Sum of best townships extrapolated:	32,910,524,000	Sum of best townships kriging:	33,361,920,000		
Percent difference RBF vs extrapolation for best TSPS:	5.33						
Percent difference RBF vs kriging for best TSPS:	3.90						

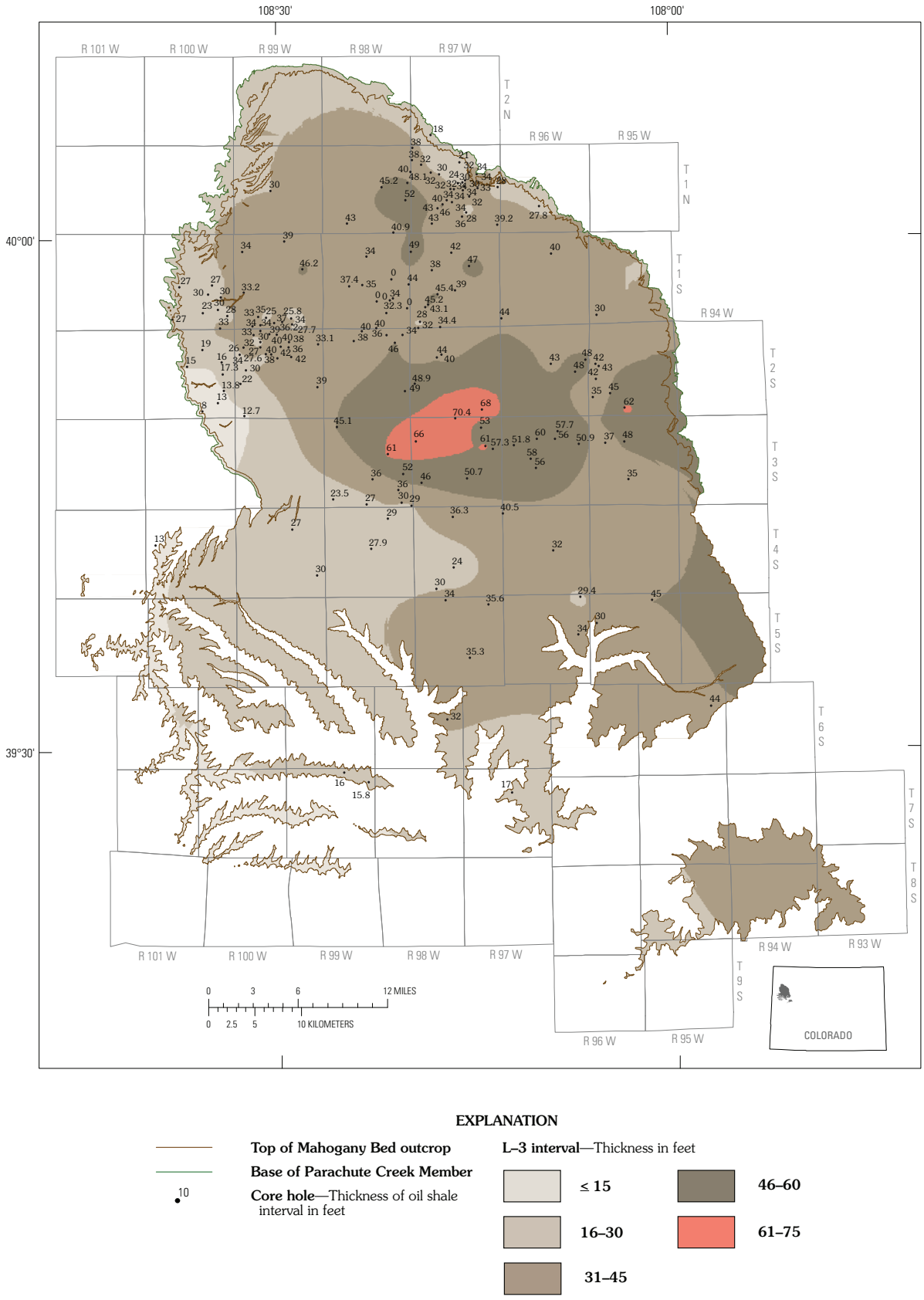


Figure 69. Isopach map of the L-3 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

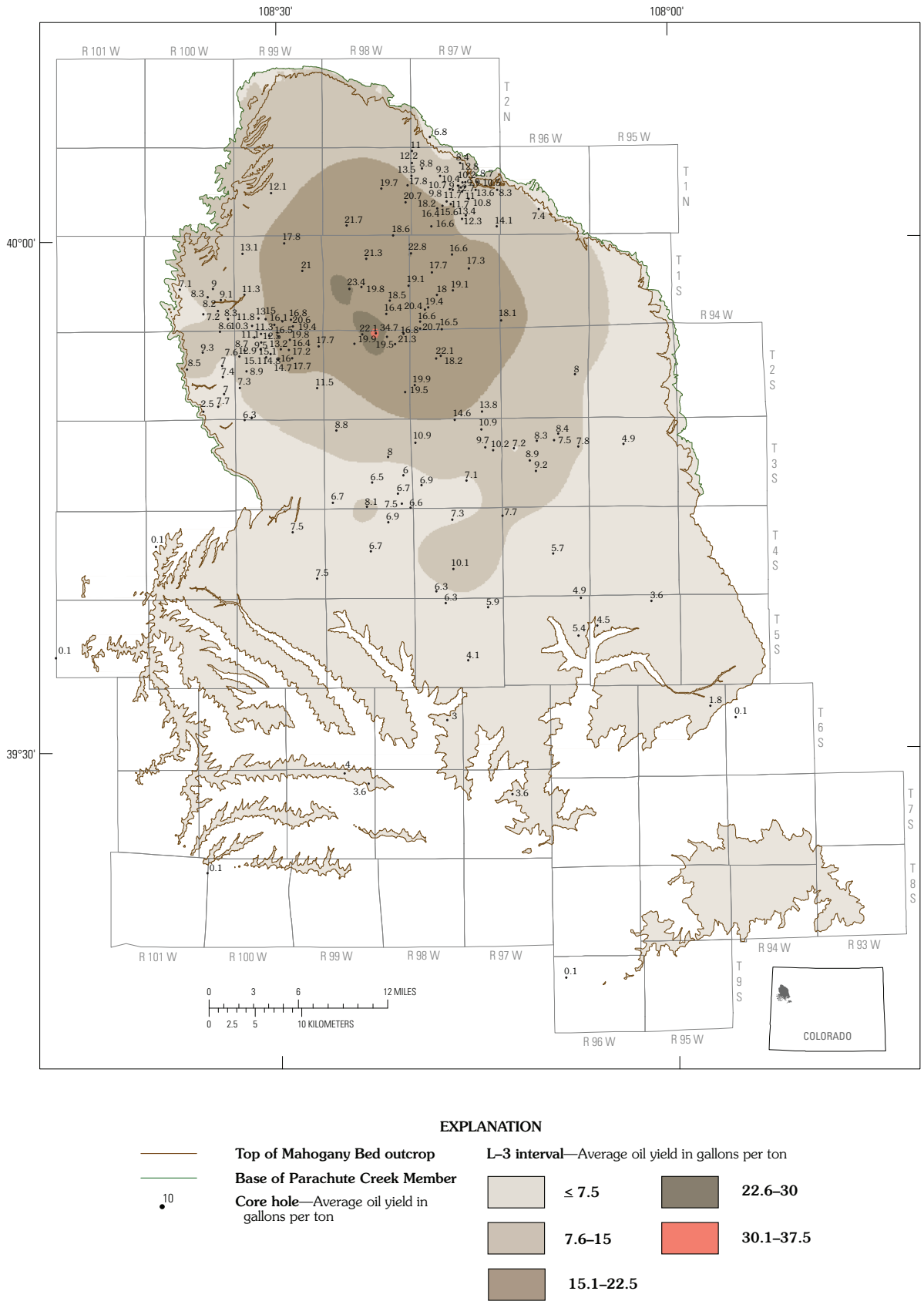


Figure 70. Isoresource map of the L-3 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

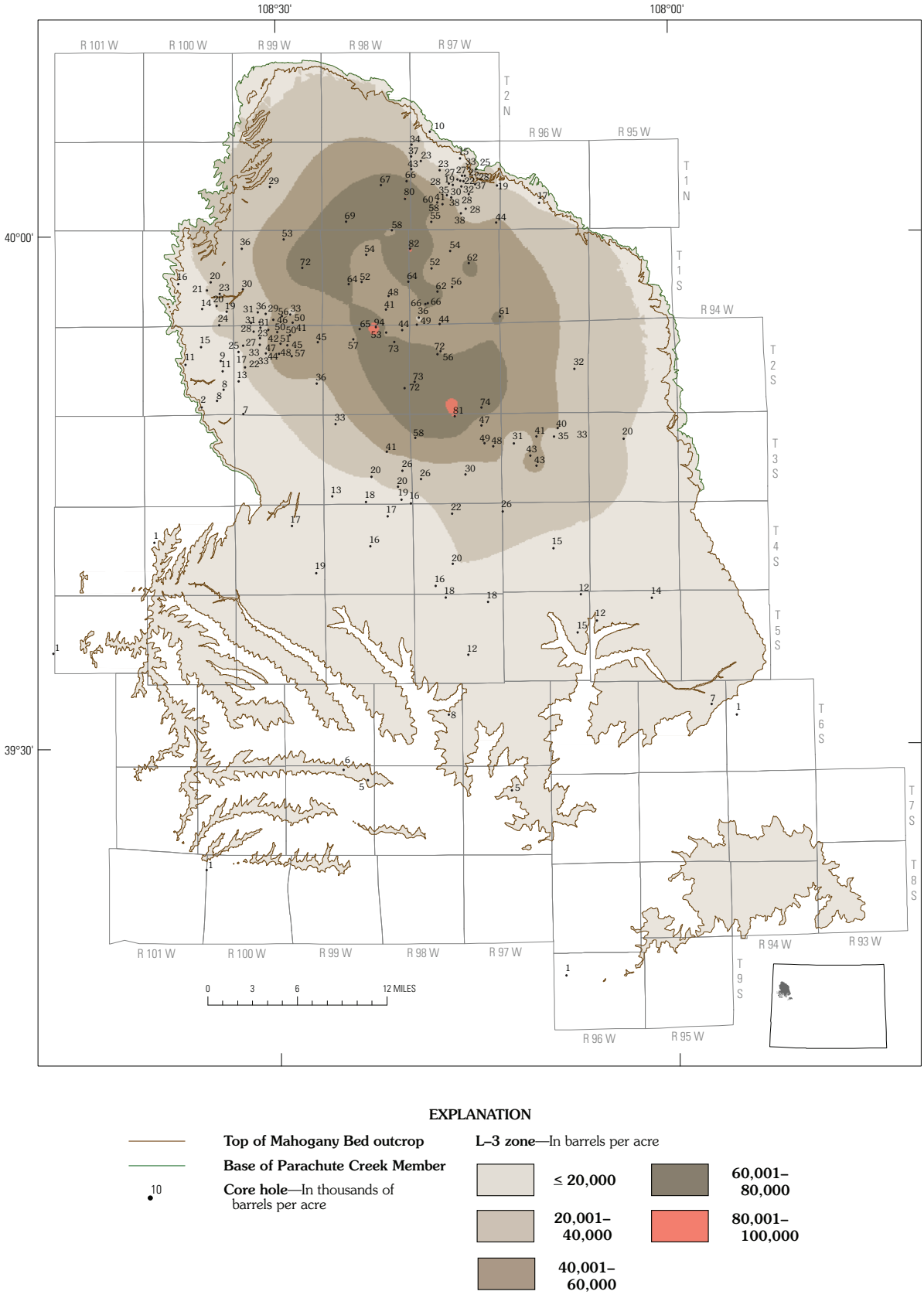
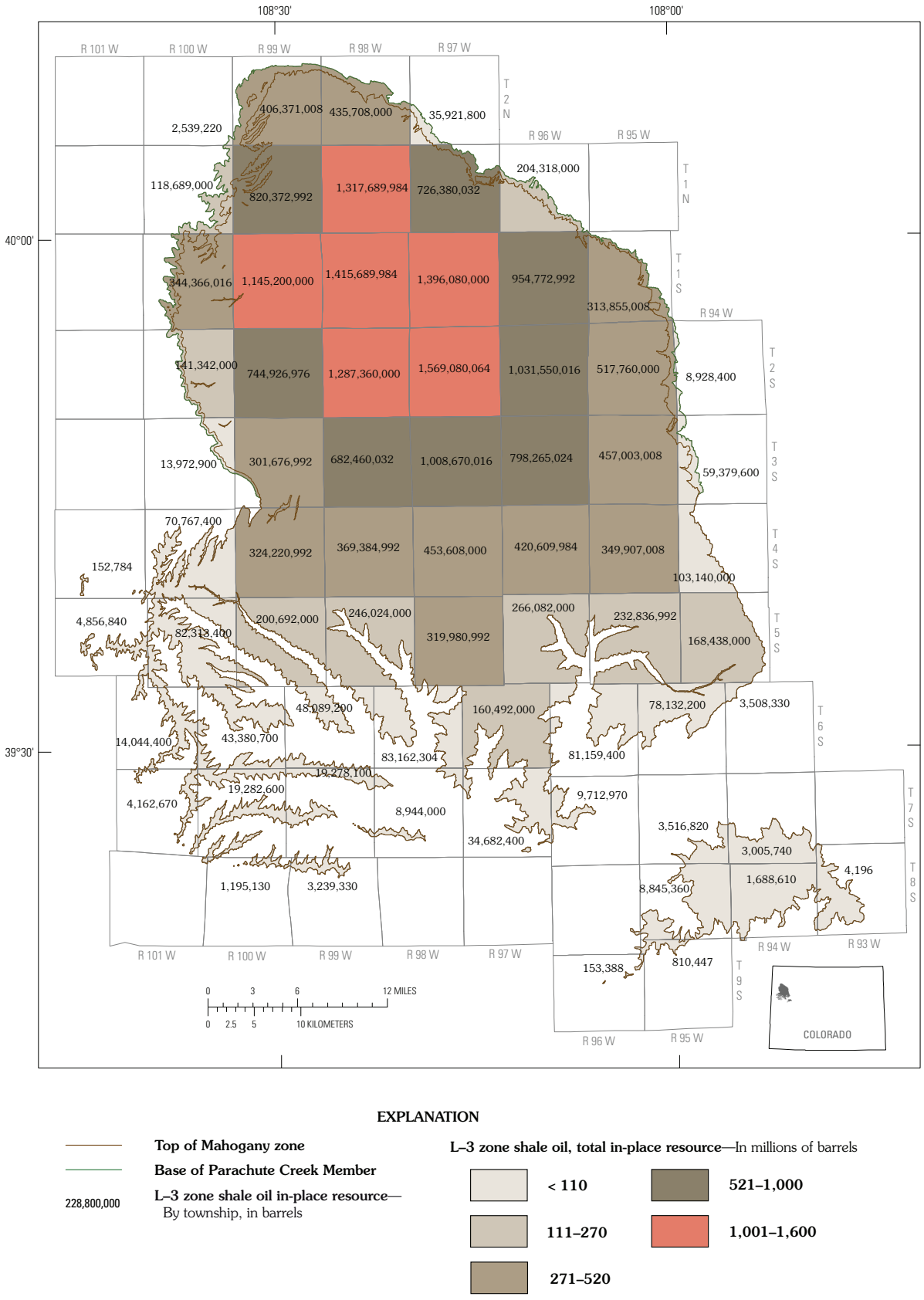


Figure 71. Isoresource map of the L-3 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.



EXPLANATION

Top of Mahogany zone

Base of Parachute Creek Member

228,800,000 — L–3 zone shale oil in-place resource— By township, in barrels

L–3 zone shale oil, total in-place resource—In millions of barrels

- < 110
- 111–270
- 271–520
- 521–1,000
- 1,001–1,600

Figure 72. Isoresource map of the L-3 zone showing total number of barrels of oil in each township using only core hole data.

Table 17. Total number of in-place barrels of oil per acre (BPA) in each township for the L-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM L-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	204,318,000	164,500,000	39,818,000	24	154,595,000	±45	49,723,000	24.34
1N 97W	726,380,000	625,713,000	100,667,000	16	711,063,000	±7	15,317,000	2.11
1N 98W	1,317,690,000	1,169,168,000	148,522,000	13	1,174,470,000	±23	143,220,000	10.87
1N 99W	820,373,000	598,136,000	222,237,000	37	810,883,000	±36	9,490,000	1.16
1N 100W	118,689,000	19,591,000	99,098,000	506	26,287,000	±155	92,402,000	77.85
2N 97W	35,921,800	17,205,000	18,716,800	109	24,426,000	±97	11,495,800	32.00
2N 98W	435,708,000	140,790,000	294,918,000	209	433,335,000	±102	2,373,000	0.54
2N 99W	406,371,000							
2N 100W	2,539,220							
1S 95W	313,855,000							
1S 96W	954,773,000	734,917,000	219,856,000	30	868,808,000	±54	85,965,000	9.00
1S 97W	1,396,080,000	1,451,223,000	-55,143,000	-4	1,411,881,000	±10	-15,801,000	-1.13
1S 98W	1,415,690,000	1,718,640,000	-302,950,000	-18	1,462,488,000	±10	-46,798,000	-3.31
1S 99W	1,145,200,000	1,028,580,000	116,620,000	11	1,099,224,000	±14	45,976,000	4.01
1S 100W	344,366,000	209,342,000	135,024,000	64	239,795,000	±86	104,571,000	30.37
2S 94W	8,928,400							
2S 95W	517,760,000	503,443,000	14,317,000	3	471,596,000	±163	46,164,000	8.92
2S 96W	1,031,550,000	1,000,997,000	30,553,000	3	1,021,110,000	±28	10,440,000	1.01
2S 97W	1,569,080,000	1,685,043,000	-115,963,000	-7	1,538,031,000	±12	31,049,000	1.98
2S 98W	1,287,360,000	1,207,602,000	79,758,000	7	1,265,613,000	±15	21,747,000	1.69
2S 99W	744,927,000	647,388,000	97,539,000	15	874,582,000	±27	-129,655,000	-17.41
2S 100W	141,342,000	170,786,000	-29,444,000	-17	232,584,000	±95	-91,242,000	-64.55
3S 94W	59,379,600							
3S 95W	457,003,000	400,374,000	56,629,000	14	352,433,000	±160	104,570,000	22.88
3S 96W	798,265,000	748,176,000	50,089,000	7	769,126,000	±22	29,139,000	3.65
3S 97W	1,008,670,000	945,800,000	62,870,000	7	1,044,790,000	±12	-36,120,000	-3.58
3S 98W	682,460,000	676,740,000	5,720,000	1	646,242,000	±23	36,218,000	5.31
3S 99W	301,677,000	337,056,000	-35,379,000	-10	475,943,000	±94	-174,266,000	-57.77
3S 100W	13,972,900	32,317,000	-18,344,100	-57	20,533,000	±361	-6,560,100	-46.95

Table 17. Total number of in-place barrels of oil per acre (BPA) in each township for the L-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 94W	103,140,000							
4S 95W	349,907,000				130,215,000	±614	219,692,000	62.79
4S 96W	420,610,000	407,286,000	13,324,000	3	429,568,000	±86	-8,958,000	-2.13
4S 97W	453,608,000	442,833,000	10,775,000	2	418,367,000	±61	35,241,000	7.77
4S 98W	369,385,000	344,370,000	25,015,000	7	298,384,000	±86	71,001,000	19.22
4S 99W	324,221,000	308,280,000	15,941,000	5	296,540,000	±201	27,681,000	8.54
4S 100W	70,767,400							
4S 101W	152,784							
5S 94W	168,438,000							
5S 95W	232,837,000							
5S 96W	266,082,000	215,743,000	50,339,000	23	222,338,000	±174	43,744,000	16.44
5S 97W	319,981,000	320,642,000	-661,000	0	306,488,000	±87	13,493,000	4.22
5S 98W	246,024,000	201,972,000	44,052,000	22	213,387,000	±382	32,637,000	13.27
5S 99W	200,692,000							
5S 100W	82,313,400							
5S 101W	4,856,840							
6S 94W	3,508,330							
6S 95W	78,132,200							
6S 96W	81,159,400							
6S 97W	160,492,000	165,213,000	-4,721,000	-3				
6S 98W	83,162,300	78,480,000	4,682,300	6				
6S 99W	48,089,200							
6S 100W	43,380,700							
6S 101W	14,044,400							
7S 93W	0							
7S 94W	3,005,740							
7S 95W	3,516,820							
7S 96W	9,712,970							
7S 97W	34,682,400							
7S 98W	8,944,000							

Table 17. Total number of in-place barrels of oil per acre (BPA) in each township for the L-3 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-3 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-3	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 99W	19,278,100							
7S 100W	19,282,600							
7S 101W	4,162,670							
8S 93W	4,196							
8S 94W	1,688,610							
8S 95W	8,845,360							
8S 96W	123,861							
8S 99W	3,239,330							
8S 100W	1,195,130							
8S 101W	95,016							
9S 94W	3,059							
9S 95W	810,447							
9S 96W	153,388		153,388					
Totals:	22,504,056,571	18,718,346,000			19,445,125,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	20,112,821,000	Sum of townships used here and kriging:	19,869,166,700		
Percent difference using RBF here and Pitman and others (1989) extrapolated:	7.45	Percent difference between RBF and kriging:	2.18		
Sum of best townships RBF (20 percent):	9,346,725,000	Sum of best townships extrapolated:	8,785,064,000	Sum of best townships kriging:	9,302,216,000
Percent difference RBF vs extrapolation for best TSPS:	6.39				
Percent difference RBF vs kriging for best TSPS:	0.48				

thickest along a southeast-trending belt extending from the oil shale depocenter in the north-central part of the basin to the east margin of the basin, reaching a maximum thickness of about 165 ft along this trend (fig. 73). Oil yield reaches a maximum of about 43 GPT in the saline depocenter (fig. 74). The area of at least 20 GPT extends farther towards the margins of the basin during R-4 deposition than any of the previous oil shale zones except the R-1 zone (figs. 46, 50, 54, 58, 62, 66, 70). Maximum BPA is about 424,000 in the middle part of the saline and oil shale depocenter in the north-central part of the basin (fig. 75). Maximum in-place oil in a township is over 8.9 billion barrels in T. 1 S., R. 98 W. (fig. 76). Total in-place oil in the R-4 zone is estimated to be over 127 billion barrels (table 18).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989), our assessment of in-place oil for the R-4 zone is 7.45 percent higher than the manually extrapolated results and 2.18 percent higher than the kriged assessment of Pitman and others (1989) (table 18). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 6.39 percent higher than the manually extrapolated results and 0.48 percent higher than the kriged results of Pitman and others (1989) (table 18).

L-4 Zone

One hundred seventy three core holes were used here to assess the L-4 zone as compared to 101 core holes in the previous assessment (Pitman and others, 1989). The L-4 zone is thickest in about the same southeast trending belt as the underlying R-4 zone reaching a maximum thickness of 184 ft in the saline depocenter (fig. 77). Oil yields gradually decline in the lower part of the L-4 zone (fig. 7). The L-4 zone contains large amounts of nahcolite in the saline depocenter, and several persistent nahcolite beds have been traced throughout the depocenter (Dyni, 1974; 1981). Oil yields are significantly lower overall in the L-4 zone than in the underlying R-4 zone, with a maximum of about 34 GPT in the saline depocenter and lower values throughout the marginal areas of the basin (fig. 78). Maximum BPA is about 426,000 in the saline depocenter (fig. 79). Maximum in-place oil in a township is over 6 billion barrels in T. 1 S., R. 98 W. (fig. 80). Total in-place oil in the L-4 zone is estimated to be over 69.1 billion barrels (table 19).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989) our assessment of in-place oil for the L-4 zone is 7.47 percent higher than the manually extrapolated results and 5.98 percent higher than the kriged assessment of Pitman and others (1989) (table 19). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 4.09 percent higher than the manually extrapolated results and 5.09 percent higher than the kriged results of Pitman and others (1989) (table 19).

R-5 Zone

A significant increase in oil yield marks the base of the R-5 zone (fig. 7). The basal bed of the R-5 zone contains abundant nahcolite in the oil shale depocenter, and thick beds of halite and nahcolite occur throughout the lower part of the R-5 zone starting about 15–20 ft above the base (fig. 7) (Dyni, 1974; 1981). Thinner beds of halite and nahcolite occur in the upper part of the R-5 zone, and nahcolite levels, in general, are comparatively high in the R-5 zone when compared to previous oil shale zones.

One hundred seventy six core holes were used to assess the R-5 zone here as compared to 107 in the previous assessment (Pitman and others, 1989). The R-5 zone is thickest through a broad band that extends from the oil shale depocenter southeastward to near the basin margin (fig. 81). Maximum thickness for the zone is in the oil shale and saline-mineral depocenter where thickness ranges from 225 to 380 ft. A silty and sandy zone about 60 ft thick occurs in the lower part of the R-5 zone along the east margin of the basin in about the same stratigraphic interval as the thick halite beds in the saline depocenter (Carter Oil Co. no. 2 upper Piceance Creek core hole in sec. 9, T. 3 S., R. 95 W., labeled 253 ft on fig. 81). This wedge appears to be eastern sourced as it wedges out to the west, and no similar wedge occurs along the southern, western, and northern margins of the basin.

The R-5 zone contains as much as 41.4 GPT in the oil shale and saline depocenter in the north-central part of the basin with oil yields generally decreasing in a radial pattern outward (fig. 82). Maximum BPA varies from about 400,000 to 870,000 in the oil shale and saline depocenter (fig. 83). Maximum in-place oil in the R-5 zone in a township is almost 13.4 billion barrels in T. 1 S., R. 98 W. (fig. 84). Total in-place oil in the R-5 zone is estimated to be over 198.2 billion barrels (table 20).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989) our assessment of in-place oil for the R-5 zone is 6.32 percent higher than the manually extrapolated results and 8.61 percent higher than the kriged assessment of Pitman and others (1989) (table 20). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 2.64 percent higher than the manually extrapolated results and 5.73 percent higher than the kriged results of Pitman and others (1989) (table 20).

L-5 Zone

The lower part of the L-5 zone contains huge deposits of halite and nahcolite in two beds about 20 ft a part with each bed reaching a maximum thickness of 60–65 ft (Dyni,

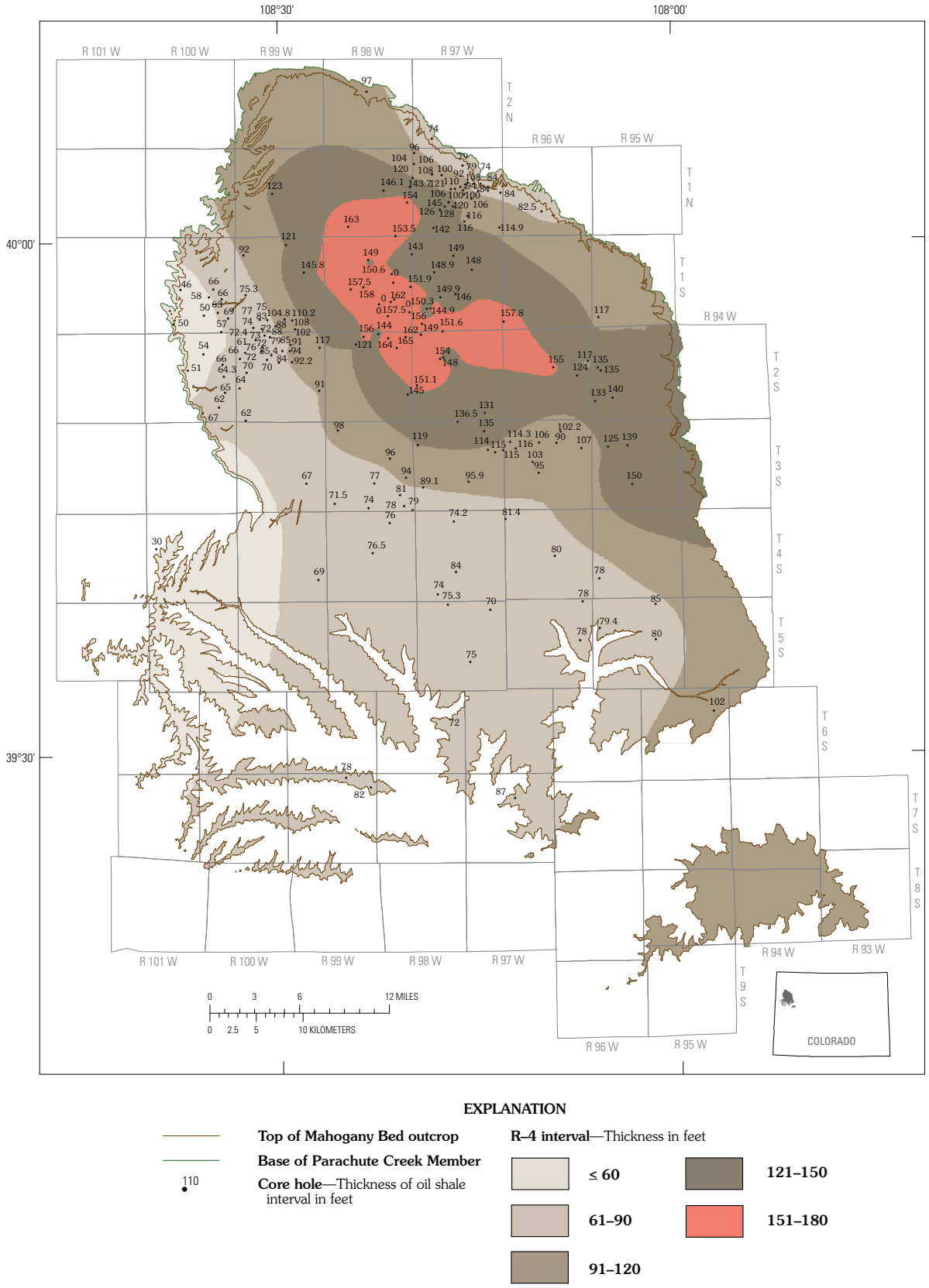


Figure 73. Isopach map of the R-4 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

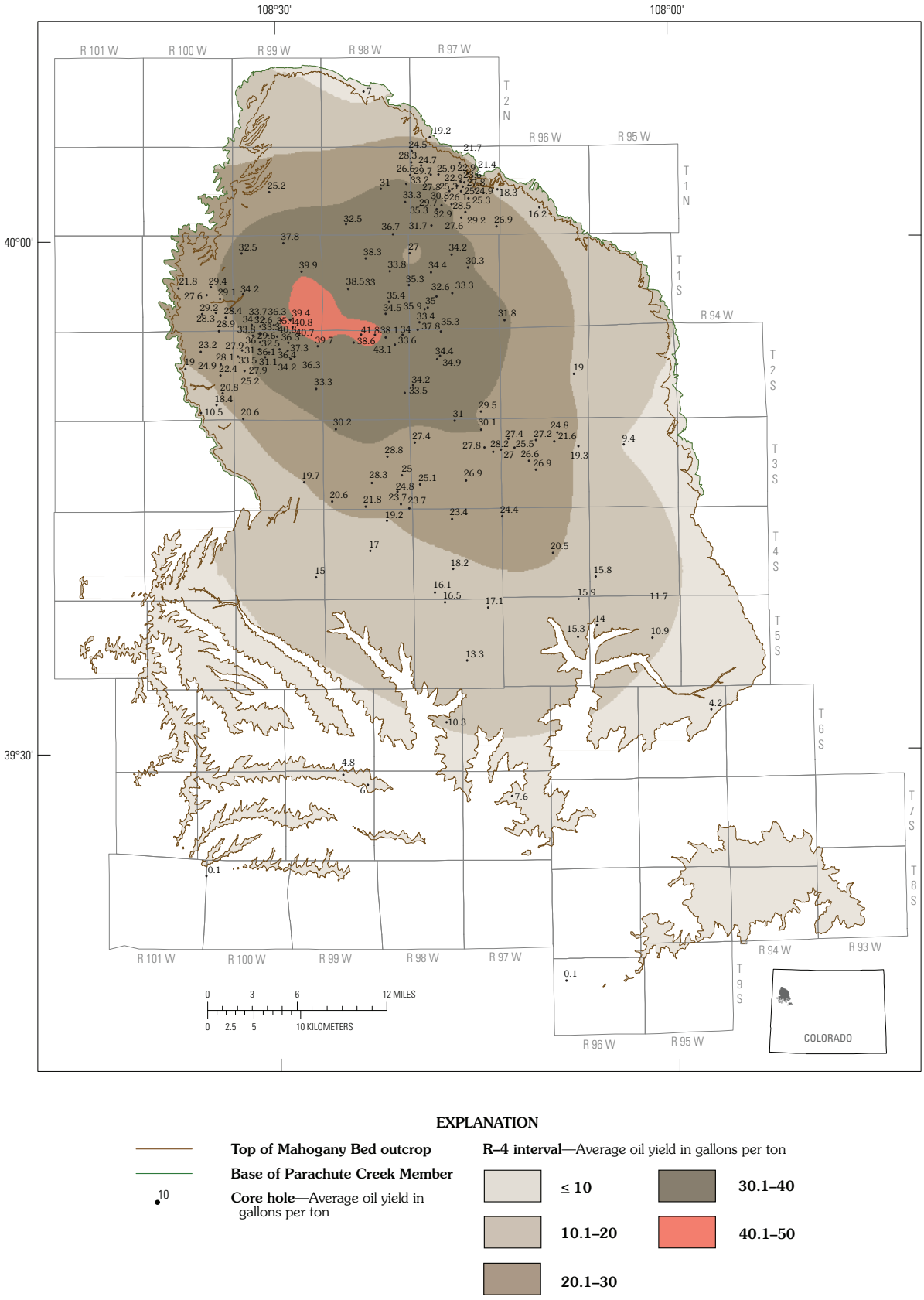


Figure 74. Isoresource map of the R-4 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

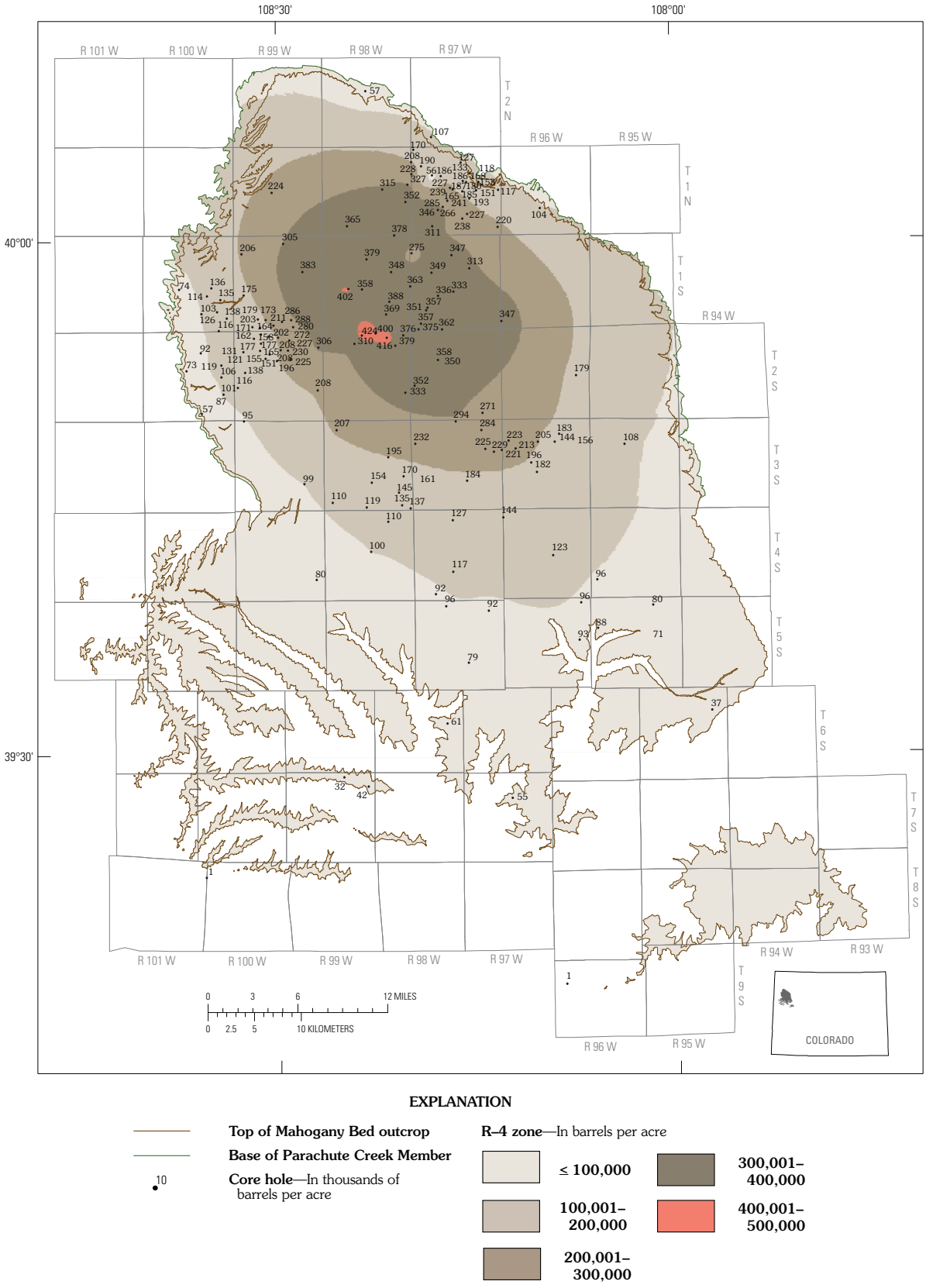


Figure 75. Isoresource map of the R-4 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

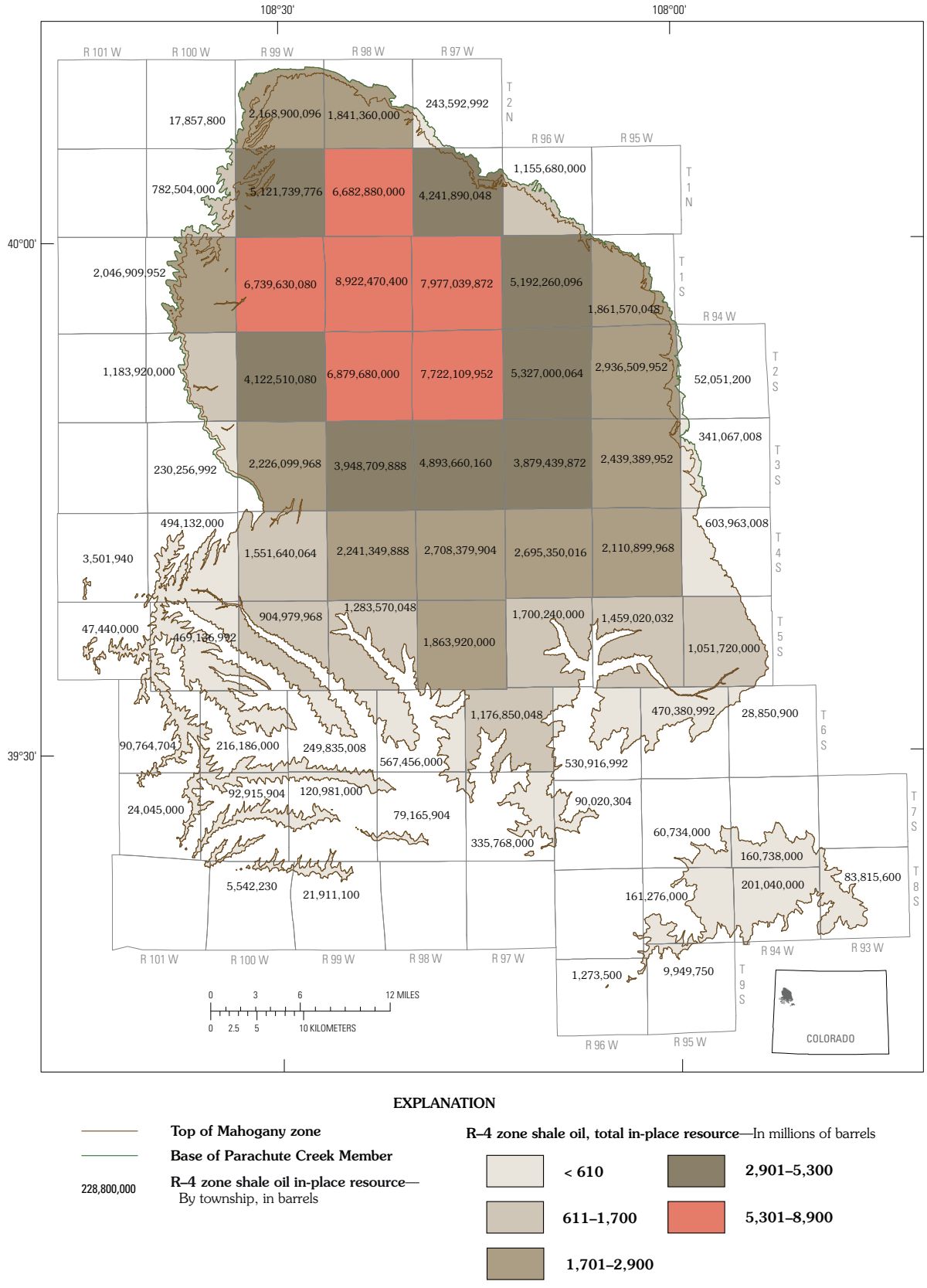


Figure 76. Isoresource map of the R-4 zone showing total number of barrels of oil in each township using only core hole data.

Table 18. Total number of in-place barrels of oil per acre (BPA) in each township for the R-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM R-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	1,155,680,000	822,500,000	333,180,000	41	884,370,000	±20	-61,870,000	-7
1N 97W	4,241,890,000	4,171,420,000	70,470,000	2	4,179,006,000	±4	-7,586,000	0
1N 98W	6,682,880,000	6,745,200,000	-62,320,000	-1	6,328,486,000	±11	416,714,000	7
1N 99W	5,121,740,000	4,699,640,000	422,100,000	9	5,006,541,000	±15	-306,901,000	-6
1N 100W	782,504,000	210,980,000	571,524,000	271	202,729,000	±50	8,251,000	4
2N 97W	243,593,000	86,025,000	157,568,000	183	129,359,000	±46	-43,334,000	-33
2N 98W	1,841,360,000	703,950,000	1,137,410,000	162	1,069,300,000	±125	-365,350,000	
2N 99W	2,168,900,000							
2N 100W	17,857,800							
1S 95W	1,861,570,000	968,400,000	893,170,000	92				
1S 96W	5,192,260,000	3,793,120,000	1,399,140,000	37	4,701,730,000	±25	-908,610,000	-19
1S 97W	7,977,040,000	7,994,025,000	-16,985,000	0	7,978,416,000	±5	15,609,000	0
1S 98W	8,922,470,000	8,951,250,000	-28,780,000	0	8,809,130,000	±3	142,120,000	2
1S 99W	6,739,630,000	6,734,750,000	4,880,000	0	6,510,680,000	±6	224,070,000	3
1S 100W	2,046,910,000	1,570,065,000	476,845,000	30	1,653,401,000	±31	-83,336,000	-5
2S 94W	52,051,200							
2S 95W	2,936,510,000	2,649,700,000	286,810,000	11	3,107,714,000	±62	-458,014,000	-15
2S 96W	5,327,000,000	5,517,123,000	-190,123,000	-3	5,339,945,000	±13	177,178,000	3
2S 97W	7,722,110,000	7,642,026,000	80,084,000	1	7,479,641,000	±7	162,385,000	2
2S 98W	6,879,680,000	6,440,544,000	439,136,000	7	6,578,515,000	7	-137,971,000	-2
2S 99W	4,122,510,000	3,699,360,000	423,150,000	11	3,866,316,000	±14	-166,956,000	-4
2S 100W	1,183,920,000	1,097,910,000	86,010,000	8	858,717,000	±63	239,193,000	28
3S 94W	341,067,000							
3S 95W	2,439,390,000	2,113,085,000	326,305,000	15	1,922,713,000	±72	190,372,000	10
3S 96W	3,879,440,000	3,990,272,000	-110,832,000	-3	3,772,921,000	±11	217,351,000	6
3S 97W	4,893,660,000	4,776,290,000	117,370,000	2	4,831,391,000	±7	-55,101,000	-1
3S 98W	3,948,710,000	3,879,976,000	68,734,000	2	3,817,762,000	±14	62,214,000	2
3S 99W	2,226,100,000	1,895,940,000	330,160,000	17	1,594,671,000	±64	301,269,000	19
3S 100W	230,257,000	171,090,000	59,167,000	35	52,442,000	±376	118,648,000	226
4S 94W	603,963,000							

Table 18. Total number of in-place barrels of oil per acre (BPA) in each township for the R-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM R-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 95W	2,110,900,000	1,996,563,000	114,337,000	6	1,976,776,000	±64	19,787,000	1
4S 96W	2,695,350,000	2,715,240,000	-19,890,000	-1	2,647,708,000	±35	67,532,000	3
4S 97W	2,708,380,000	2,680,305,000	28,075,000	1	2,650,651,000	±18	29,654,000	1
4S 98W	2,241,350,000	2,158,052,000	83,298,000	4	1,963,386,000	±38	194,666,000	10
4S 99W	1,551,640,000	1,651,500,000	-99,860,000	-6	1,745,768,000	±210	-94,268,000	-5
4S 100W	494,132,000							
4S 101W	3,501,940							
5S 94W	1,051,720,000							
5S 95W	1,459,020,000							
5S 96W	1,700,240,000	1,608,266,000	91,974,000	6	1,572,093,000	±59	36,173,000	2
5S 97W	1,863,920,000	1,878,046,000	-14,126,000	-1	1,813,757,000	±38	64,289,000	4
5S 98W	1,283,570,000	1,228,663,000	54,907,000	4	1,188,388,000	±167	40,275,000	3
5S 99W	904,980,000							
5S 100W	469,137,000							
5S 101W	47,440,000							
6S 94W	28,850,900							
6S 95W	470,381,000							
6S 96W	530,917,000							
6S 97W	1,176,850,000							
6S 98W	567,456,000	540,640,000	26,816,000	5	78,746,000	±282	461,894,000	587
6S 99W	249,835,000							
6S 100W	216,186,000							
6S 101W	90,764,700							
7S 93W	80,964							
7S 94W	160,738,000							
7S 95W	60,734,000							
7S 96W	90,020,300							
7S 97W	335,768,000							
7S 98W	79,165,900							
7S 99W	120,981,000							

Table 18. Total number of in-place barrels of oil per acre (BPA) in each township for the R-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM R-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 100W	92,915,900							
7S 101W	24,045,000							
8S 93W	83,815,600							
8S 94W	201,040,000							
8S 95W	161,276,000							
8S 96W	1,183,320							
8S 99W	21,911,100							
8S 100W	5,542,230							
8S 101W	238,005							
9S 94W	325,506							
9S 95W	9,949,750							
9S 96W	1,273,500							
Total:	127,150,178,615	107,781,916,000			106,313,169,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	114,265,185,000	Sum of townships used here and kriging:	112,403,615,000
Percent difference using RBF here and Pitman and others (1989) extrapolated:	6.02	Percent difference between RBF and kriging:	5.73

Sum of best townships RBF (20 percent):	80,322,820,000	Sum of best townships extrapolated:	78,744,681,000	Sum of best townships kriging:	78,033,771,000
Percent difference RBF vs extrapolation for best TSPS:	2.00				
Percent difference RBF vs kriging for best TSPS:	2.93				

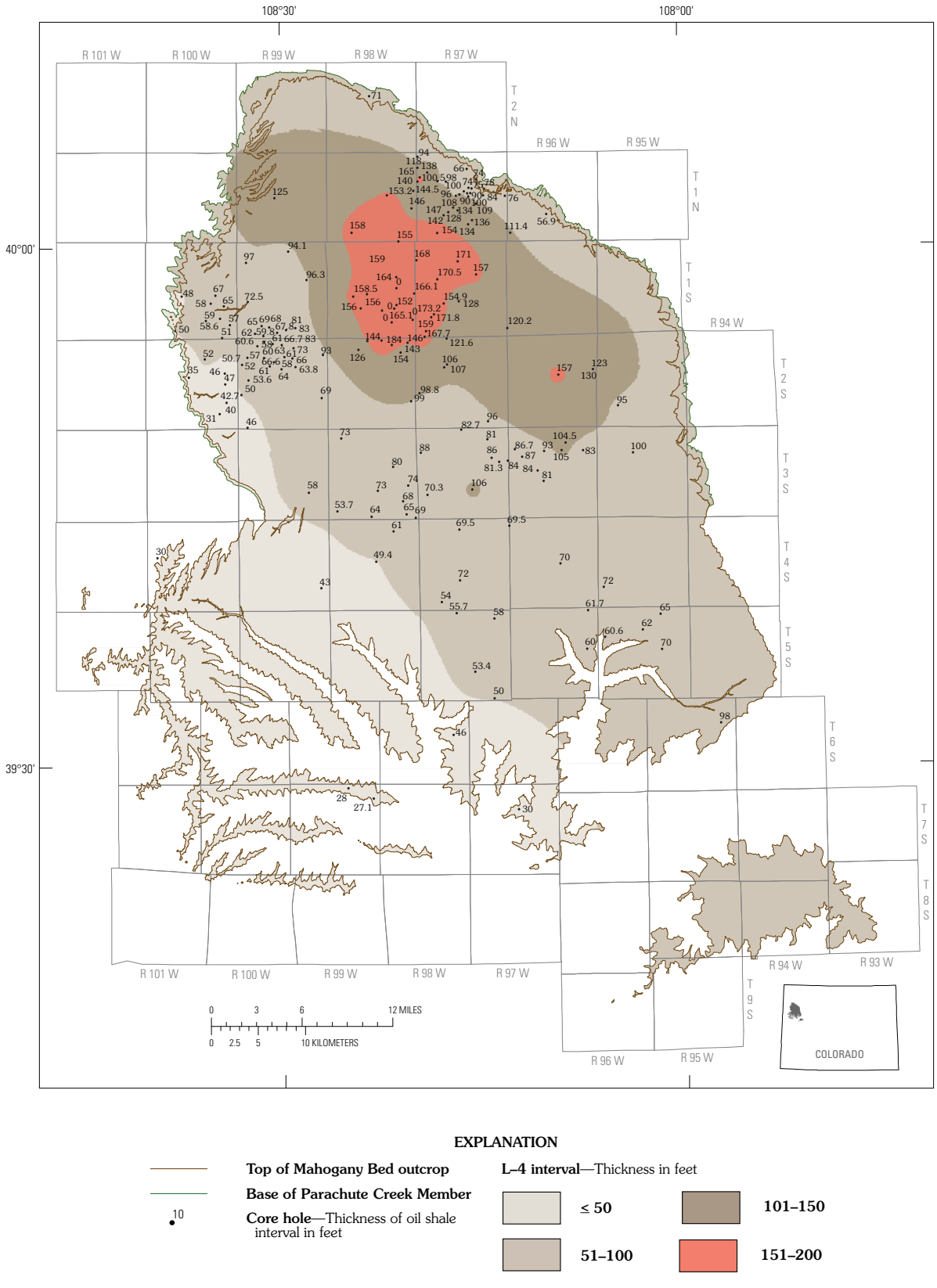


Figure 77. Isopach map of the L-4 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

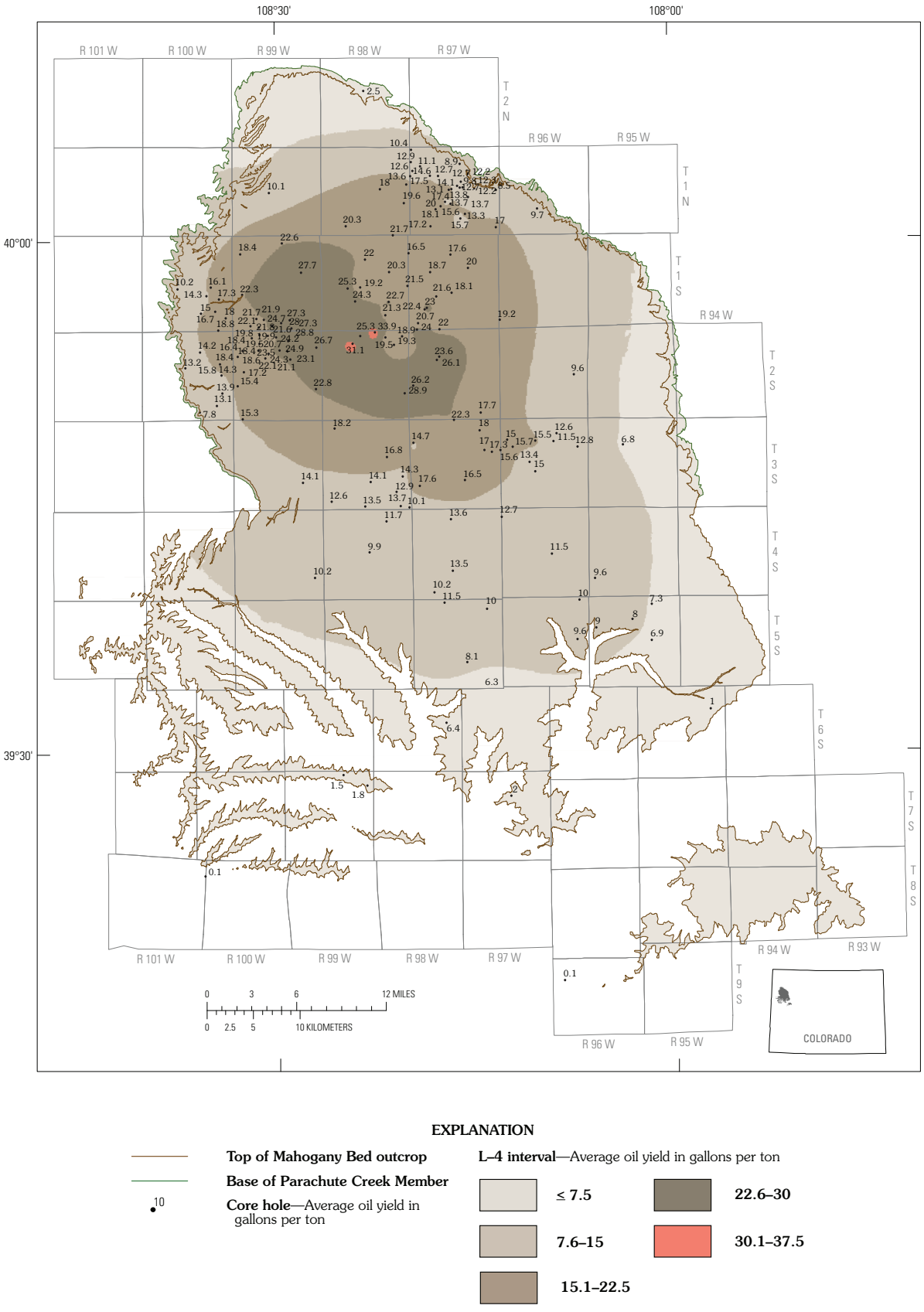


Figure 78. Isoresource map of the L-4 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

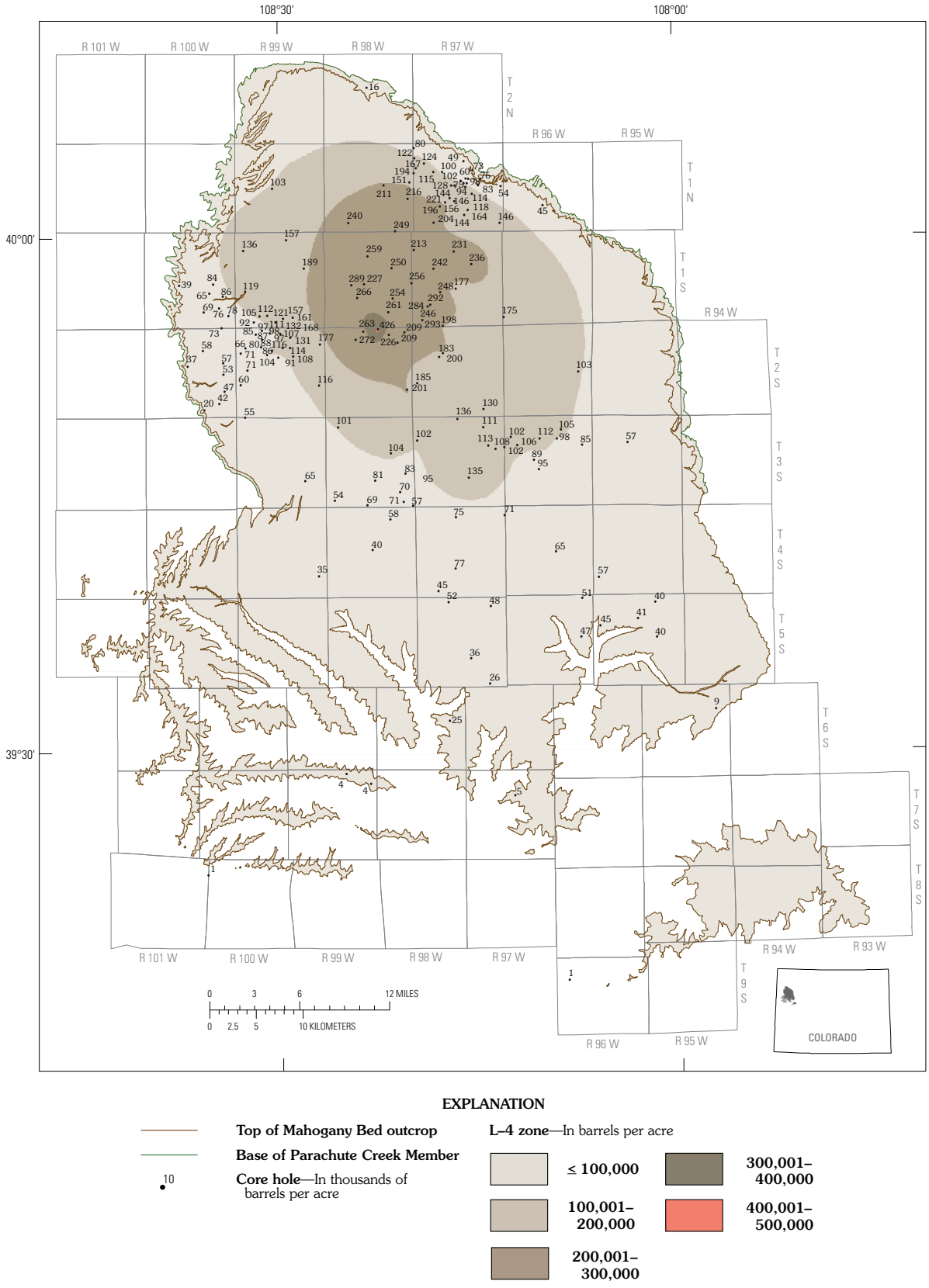
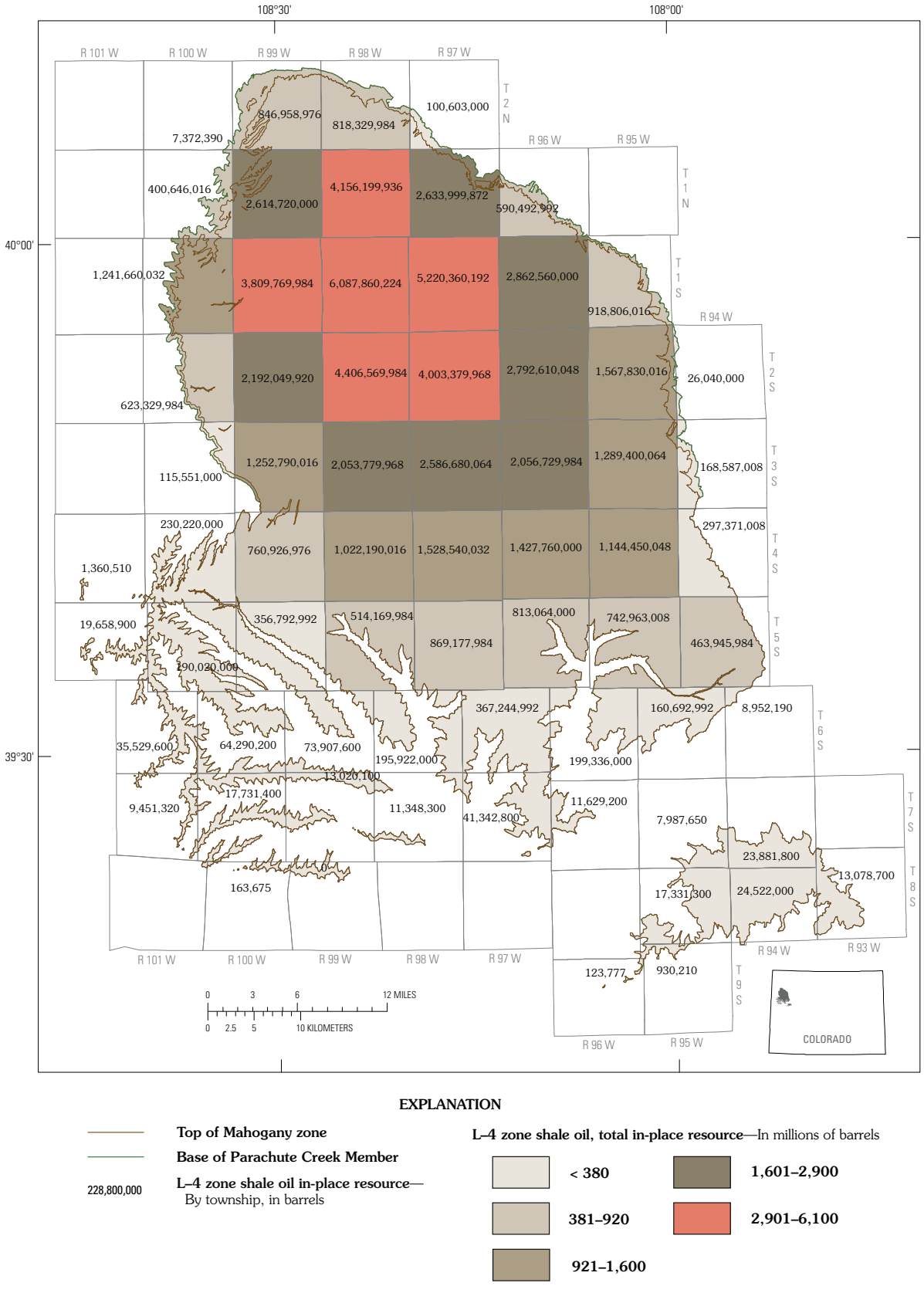


Figure 79. Isoresource map of the L-4 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.



EXPLANATION

Top of Mahogany zone

Base of Parachute Creek Member

228,800,000 L–4 zone shale oil in-place resource—By township, in barrels

L–4 zone shale oil, total in-place resource—In millions of barrels

- < 380
- 381–920
- 921–1,600
- 1,601–2,900
- 2,901–6,100

Figure 80. Isoresource map of the L-4 zone showing total number of barrels of oil in each township using only core hole data.

Table 19. Total number of in-place barrels of oil per acre (BPA) in each township for the L-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM L-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	590,493,000	493,500,000	96,993,000	20	449,032,000	±49	141,461,000	32
1N 97W	2,634,000,000	2,237,398,000	396,602,000	18	2,390,068,000	±9	243,932,000	10
1N 98W	4,156,200,000	4,047,120,000	109,080,000	3	3,892,694,000	±21	263,506,000	7
1N 99W	2,614,720,000	2,563,440,000	51,280,000	2	2,445,509,000	±39	169,211,000	7
1N 100W	400,646,000	82,885,000	317,761,000	383	117,631,000	±108	283,015,000	241
2N 97W	100,603,000	40,145,000	60,458,000	151	44,700,000	±164	55,903,000	125
2N 98W	818,330,000	281,580,000	536,750,000	191	1,113,185,000	±117	-294,855,000	-26
2N 99W	846,959,000					—-		
2N 100W	7,372,390							
1S 95W	918,806,000	1,162,080,000	-243,274,000	-21		—-		
1S 96W	2,862,560,000	1,778,025,000	1,084,535,000	61	2,474,188,000	±60	388,372,000	16
1S 97W	5,220,360,000	5,165,370,000	54,990,000	1	5,080,789,000	±9	139,571,000	3
1S 98W	6,087,860,000	6,158,460,000	-70,600,000	-1	5,845,892,000	±7	241,968,000	4
1S 99W	3,809,770,000	3,722,480,000	87,290,000	2	3,581,630,000	±14	228,140,000	6
1S 100W	1,241,660,000	897,180,000	344,480,000	38	1,094,622,000	±59	147,038,000	13
2S 94W	26,040,000							
2S 95W	1,567,830,000	1,059,880,000	507,950,000	48	1,770,113,000	±136	-202,283,000	-11
2S 96W	2,792,610,000	2,793,480,000	-870,000	0	2,847,929,000	±32	-55,319,000	-2
2S 97W	4,003,380,000	3,892,212,000	111,168,000	3	3,972,225,000	±16	31,155,000	1
2S 98W	4,406,570,000	3,958,251,000	448,319,000	11	4,023,784,000	±15	382,786,000	10
2S 99W	2,192,050,000	1,919,043,000	273,007,000	14	2,040,114,000	±33	151,936,000	7
2S 100W	623,330,000	585,552,000	37,778,000	6	482,466,000	±139	140,864,000	29
3S 94W	168,587,000					—-		
3S 95W	1,289,400,000	1,000,935,000	288,465,000	29	1,019,020,000	±168	270,380,000	27
3S 96W	2,056,730,000	1,949,792,000	106,938,000	5	1,883,547,000	±29	173,183,000	9
3S 97W	2,586,680,000	2,175,340,000	411,340,000	19	2,357,505,000	±21	229,175,000	10
3S 98W	2,053,780,000	2,030,220,000	23,560,000	1	1,992,887,000	±30	60,893,000	3
3S 99W	1,252,790,000	1,032,234,000	220,556,000	21	942,027,000	±134	310,763,000	33
3S 100W	115,551,000	47,525,000	68,026,000	143	51,756,000	±474	63,795,000	123
4S 94W	297,371,000				306,684,000	±595	-9,313,000	-3

Table 19. Total number of in-place barrels of oil per acre (BPA) in each township for the L-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 95W	1,144,450,000	1,032,705,000	111,745,000	11	1,008,033,000	±155	136,417,000	14
4S 96W	1,427,760,000	1,470,755,000	-42,995,000	-3	1,365,793,000	±85	61,967,000	5
4S 97W	1,528,540,000	1,561,569,000	-33,029,000	-2	1,500,457,000	±39	28,083,000	2
4S 98W	1,022,190,000	1,010,152,000	12,038,000	1	1,013,869,000	±91	8,321,000	1
4S 99W	760,927,000	770,700,000	-9,773,000	-1	416,019,000	±881	344,908,000	83
4S 100W	230,220,000					--		
4S 101W	1,360,510					--		
5S 94W	463,946,000					--		
5S 95W	742,963,000	825,084,000	-82,121,000	-10	807,997,000	±108	-65,034,000	-8
5S 96W	813,064,000	784,520,000	28,544,000	4	775,926,000	±146	37,138,000	5
5S 97W	869,178,000	893,217,000	-24,039,000	-3	868,413,000	±97	765,000	0
5S 98W	514,170,000	420,775,000	93,395,000	22	382,440,000	±644	131,730,000	34
5S 99W	356,793,000					--		
5S 100W	190,020,000					--		
5S 101W	19,658,900					--		
6S 94W	8,952,190							
6S 95W	160,693,000					--		
6S 96W	199,336,000	460,350,000	-261,014,000	-57	234,311,000	±425	-34,975,000	-15
6S 97W	367,245,000	367,140,000	105,000	0		--		
6S 98W	195,922,000	174,400,000	21,522,000	12	173,299,000	±397	22,623,000	13
6S 99W	73,907,600							
6S 100W	64,290,200							
6S 101W	35,529,600							
7S 93W	12,779							
7S 94W	23,881,800							
7S 95W	7,987,650							
7S 96W	11,629,200							
7S 97W	41,342,800							
7S 98W	11,348,300							
7S 99W	13,020,100							

Table 19. Total number of in-place barrels of oil per acre (BPA) in each township for the L-4 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-4 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-4	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 100W	17,731,400							
7S 101W	9,451,320							
8S 93W	13,078,700							
8S 94W	24,522,000							
8S 95W	17,331,300							
8S 96W	120,131							
8S 99W	0							
8S 100W	163,675							
8S 101W	87,442							
9S 94W	32,789							
9S 95W	930,210							
9S 96W	123,777							
Totals:	69,126,949,762	60,845,494,000			60,766,554,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	65,391,961,000	Sum of townships used here and kriging:	64,403,281,000		
Percent difference using RBF here and Pitman and others (1989) extrapolated:	7.47	Percent difference between RBF and kriging:	5.98		
Sum of best townships RBF (20 percent):	26,161,940,000	Sum of best townships extrapolated	25,134,171,000	Sum of best townships kriging:	24,894,388,000
Percent difference RBF vs extrapolation for best TSPS:	4.09				
Percent difference RBF vs kriging for best TSPS:	5.09				

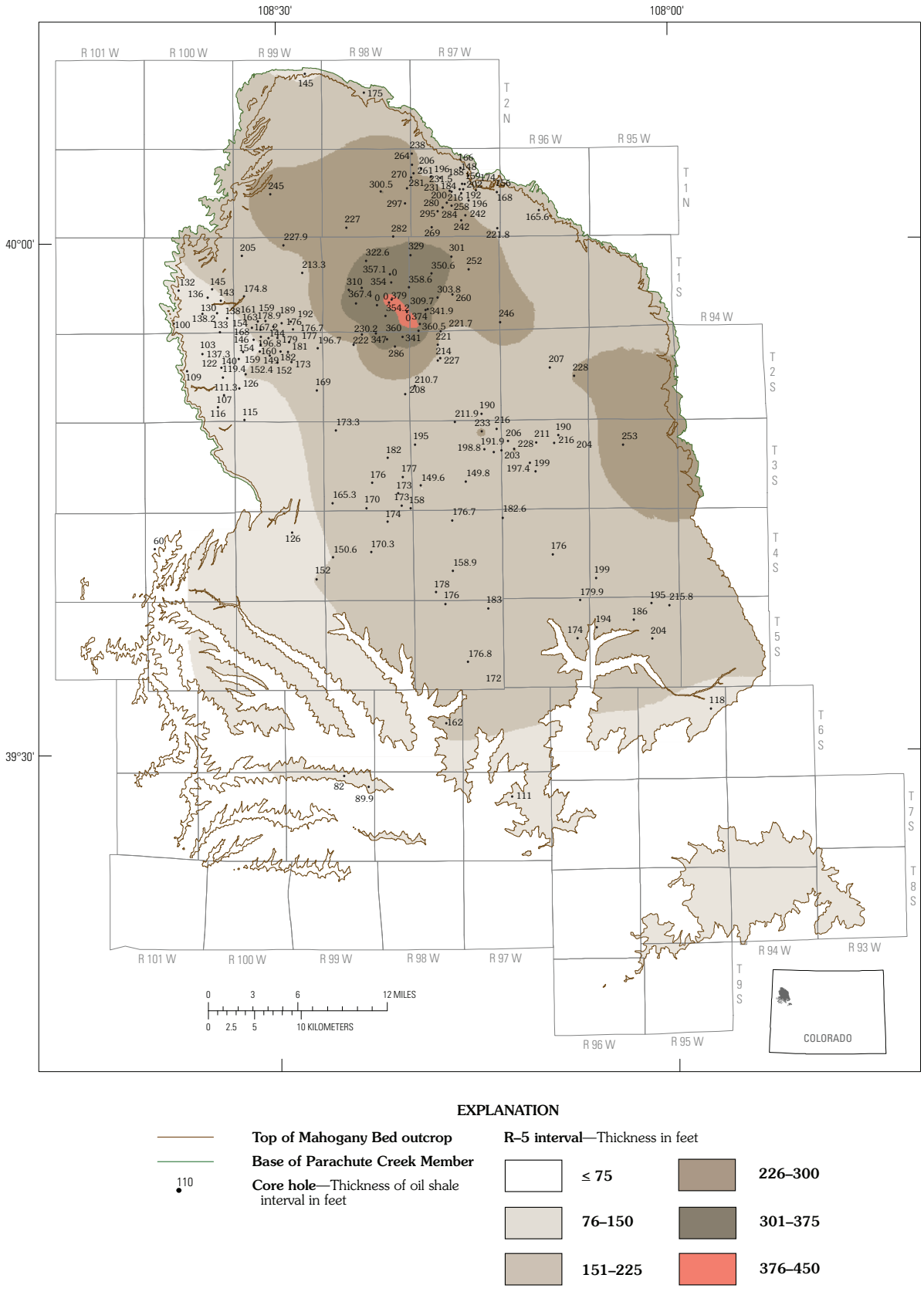


Figure 81. Isopach map of the R-5 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

1974; 1981). These two beds are the highest preserved saline beds in the section, but there is a persistent collapse breccia near the top of the L-5 zone indicating that a saline bed was probably once present. The two thick nahcolite and halite beds have been leached out over much of their previous extent and replaced by collapse breccias.

One hundred eighty six core holes were used to assess the R-5 zone here as compared to 105 core holes in the previous assessment (Pitman and others, 1989). The isopach map for the L-5 zone (fig. 85) shows complex thickening trends that are significantly different from underlying oil shale zones and highly modified by the relatively recent leaching of the thick nahcolite and halite beds. Throughout much of the basin, the L-5 zone thickens in a fairly regular pattern to the east-northeast. The approximate area where the two beds are preserved forms a conspicuous "bulls eye" in T. 1 S., R. 97 and 98 W. The L-5 zone thickens from about 80 to 100 ft where the beds have been leached to nearly 230 ft where the beds are still preserved. This thick area may once have covered much of the saline depocenter as the thickest areas in many of the previous isopach maps. In a completely new trend, the L-5 zone thickens markedly toward the northern part of the basin (fig. 85). This thickening is due to an influx of clastics from the north that Johnson (1985; 2007) suggested may be related to outflow from Lake Gosiute to the north.

Estimated GPT for the L-5 zone ranges from 14.2 to 22.4 in the oil shale and saline depocenter with values decreasing outward in a general radial pattern (fig. 86). In-place oil ranges to as high as 274,000 BPA in the depocenter with values decreasing rapidly toward the southwest and northeast and more slowly towards the southeast (fig. 87). Maximum in-place oil in a township is over 4 billion barrels in T. 1 S., R. 98 W. (fig. 88). Total in-place oil in the L-5 zone is estimated to be just over 66 billion barrels (table 21).

Using only those townships that were assessed in both this assessment and the previous assessment by Pitman and others (1989) our assessment of in-place oil for the L-5 zone is 5.31 percent higher than the manually extrapolated results and 9.35 percent higher than the kriged assessment of Pitman and others (1989) (table 21). When only the townships with the best control are compared (those with 20 percent or less estimated error in the kriged results of Pitman and others, 1989), our results are 7.97 percent higher than the manually extrapolated results and 18.10 percent higher than the kriged results of Pitman and others (1989) (table 21).

R-6 Zone

The R-6 zone contains no preserved nahcolite or halite, but some solution cavities that may once have been filled with nahcolite were described in the upper part of the R-6 zone in outcrop near the mouth of Piceance Creek in the north-central part of the basin (Pipiringos and Johnson, 1976). There are no breccia zones in the R-6 zone (Dyni, 1974), thus it is doubtful that thick beds of halite and nahcolite, like those found in the underlying L-5 zone, ever existed in the R-6 zone. According to Dyni (1974, p. 119) the highest solution breccia occurs in the middle of his zone 12 (the L-5 zone) and "No unleached saline beds equivalent to this breccia, or younger solution breccias, are known to exist in the Piceance Creek basin."

Two hundred thirty five core holes were used to assess the R-6 zone here as compared to just 67 for the previous assessment (Pitman, 1979). One reason that so few holes were used in the previous assessment was that it was published a decade prior to the assessment of the zones below the R-6 zone (Pitman and others, 1989), and there were far fewer core holes available. The R-6 zone thickens generally towards the east-northeast across the basin to a maximum of about 250 ft in the eastern part of the basin, then thins abruptly to 106 ft along the northeast margin (fig. 89). There is no thickening towards the saline depocenter in the north-central part of the basin as in previous oil shale zones that contain abundant saline minerals. There is a pronounced thickening to 537 ft towards the north-central part of the basin, in the vicinity of where the underlying L-5 zone thickened, suggesting again a source of sediment from the north.

Maximum oil yields for the R-6 zone range from about 23 to 33 GPT through an elongate south-southeast-trending area that extends for a considerable distance to the southeast from the former oil shale and saline mineral depocenter (fig. 90). This trend toward expansion of the oil shale depocenter towards the southeast was apparent in the underlying L-5 zone (figs. 86, 87) but less pronounced. The southeast expansion of the oil shale depocenter is very conspicuous on the map showing estimated BPA with the area of maximum in-place oil, from about 300,000 to 425,000 BPA, extending to the upper reaches of the Parachute Creek drainage north of the Colorado River (fig. 91). Maximum in-place oil in a township is over 8.5 billion barrels in T. 1 S., R. 97 W. (fig. 92, table 22). Total in-place oil in the R-6 zone is estimated to be over 185 billion barrels (table 22).

The R-6 zone was originally assessed by Pitman (1979) by manual extrapolation. Pitman and others (1989) did not reassess the R-6 zone using kriging but instead included the extrapolated numbers from the 1979 publication in their final assessment for the basin. Using only those townships that were assessed in both this assessment and the assessment of Pitman (1979) our results are 16.99 percent higher than the manually extrapolated results of Pitman (1979). Pitman (1979) had very few control points to use for the assessment (67 as compared to 235 here), and thus it is difficult to compare the two assessments. Five townships were visually picked out that seemed to have adequate control in the 1979 assessment, and using only those townships, our assessment is 7.43 percent higher than the assessment of Pitman (1979) (table 22).

B-Groove

B-groove is a comparatively thin interval that represents a major decrease in oil yields that occurs throughout the oil

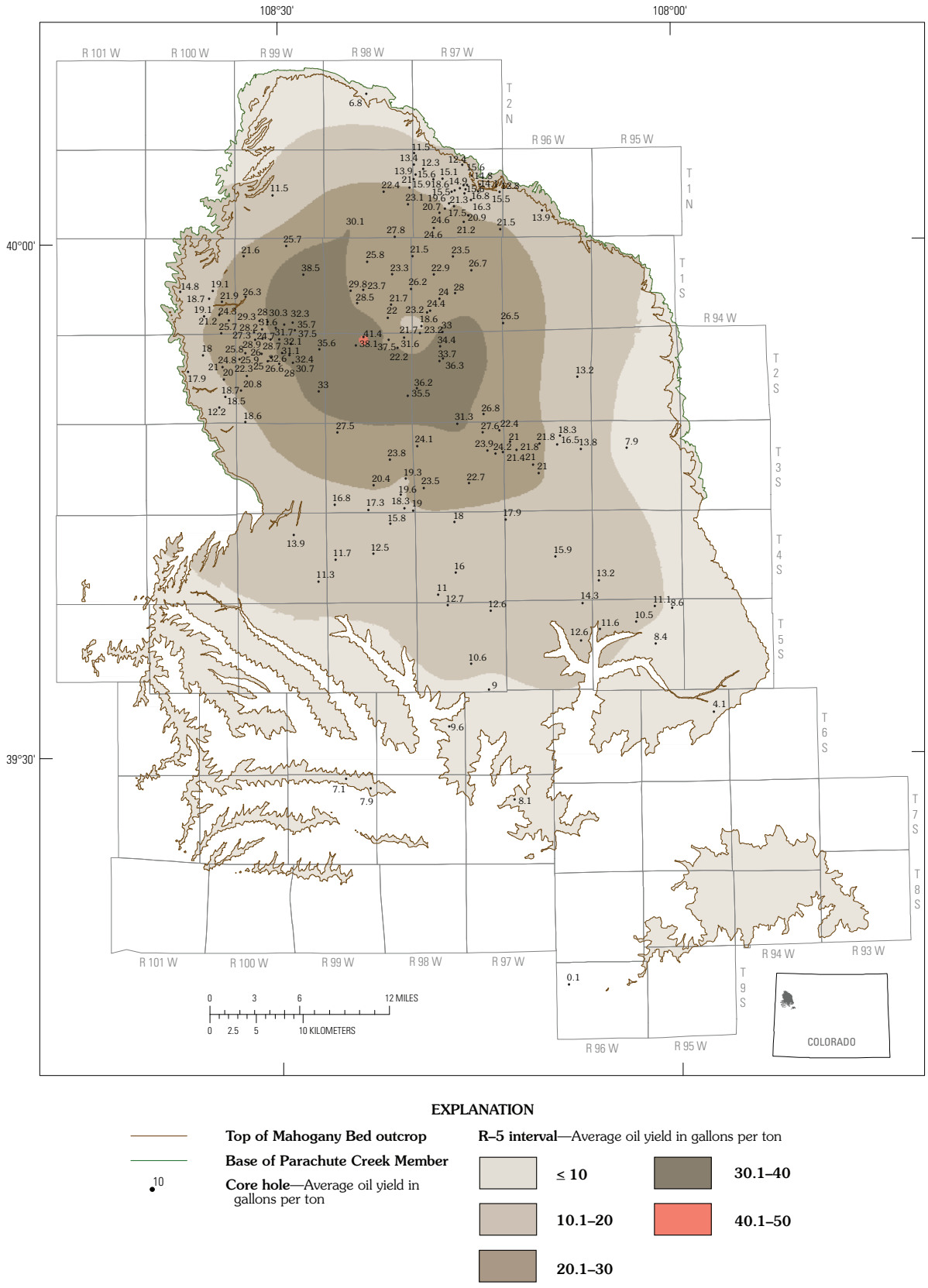


Figure 82. Isoresource map of the R-5 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

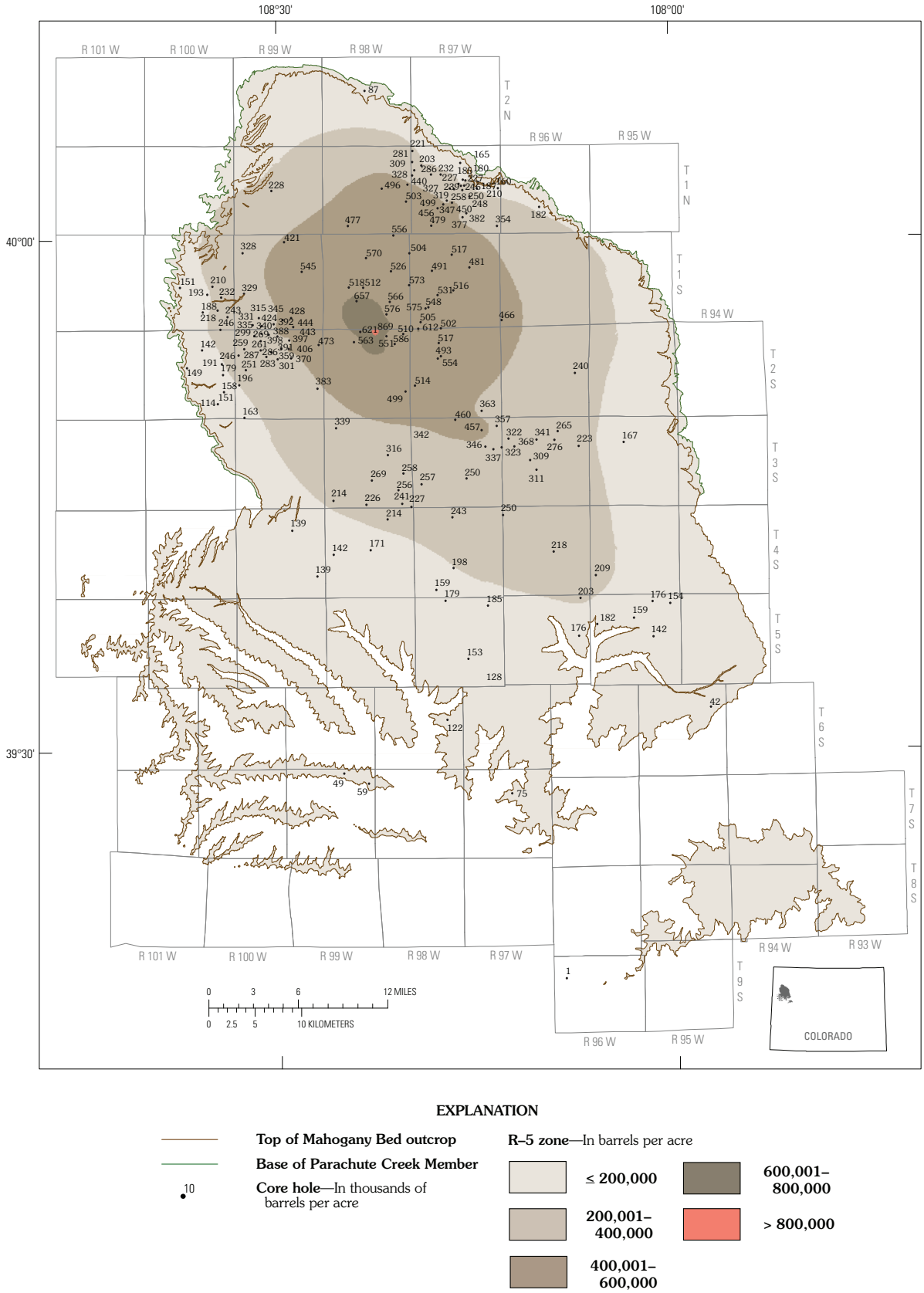


Figure 83. Isoresource map of the R-5 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

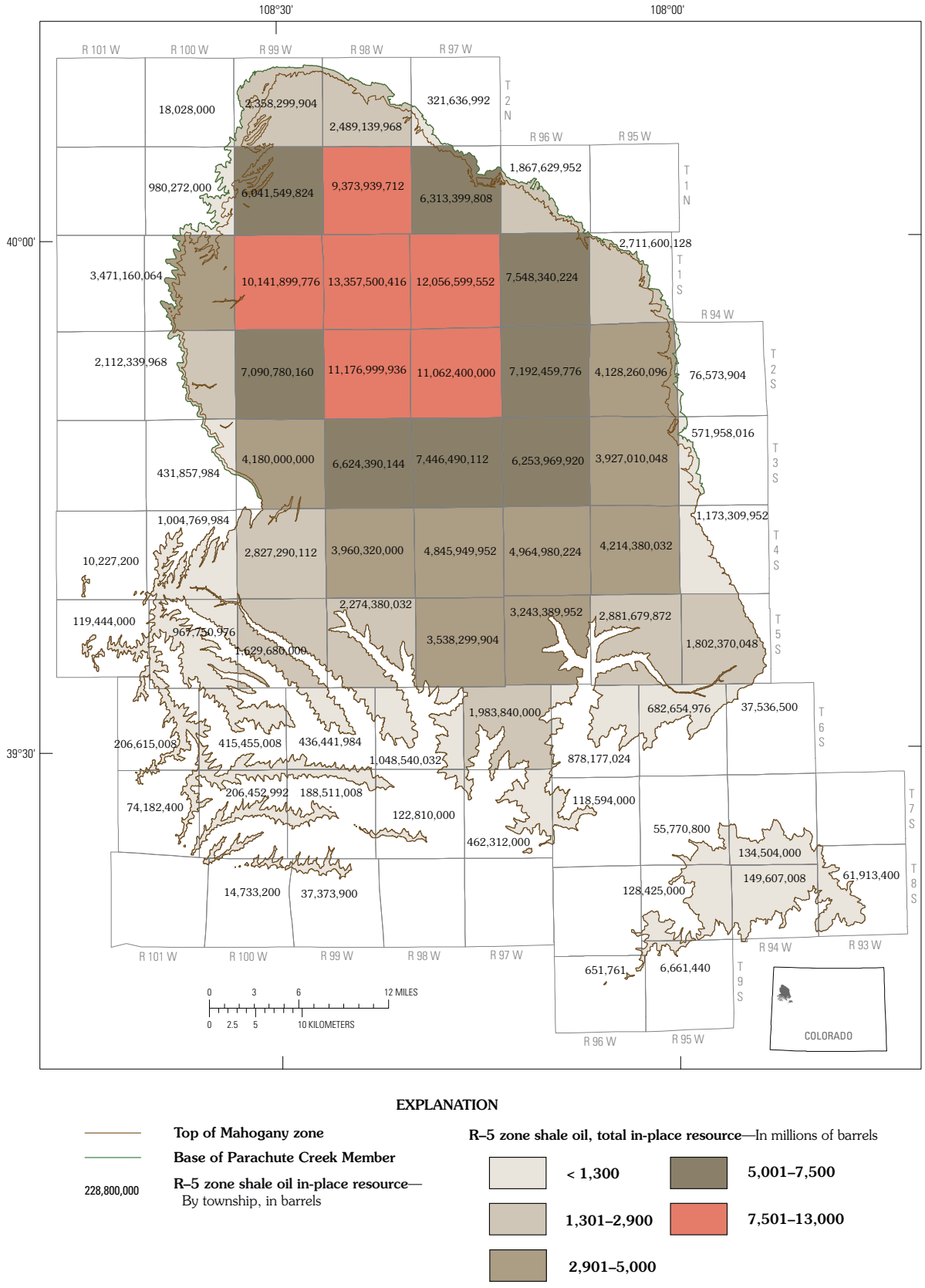


Figure 84. Isoresource map of the R-5 zone showing total number of barrels of oil in each township using only core hole data.

Table 20. Total number of in-place barrels of oil per acre (BPA) in each township for the R-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM R-5	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
1N 96W	1,867,630,000	1,908,200,000	-40,570,000	-2.13	1,419,119,000	±22	448,511,000	31.60
1N 97W	6,313,400,000	6,636,350,000	-322,950,000	-4.87	5,921,871,000	±5	391,529,000	6.61
1N 98W	9,373,940,000	9,443,280,000	-69,340,000	-0.73	8,882,764,000	±14	491,176,000	5.53
1N 99W	6,041,550,000	6,088,170,000	-46,620,000	-0.77	5,785,083,000	±23	256,467,000	4.43
1N 100W	980,272,000	233,585,000	746,687,000	319.66	220,454,000	±82	759,818,000	344.66
2N 97W	321,637,000	172,050,000	149,587,000	86.94	187,961,000	±85	133,676,000	71.12
2N 98W	2,489,140,000	1,126,320,000	1,362,820,000	121.00	218,723,000	±1298	2,270,417,000	1,038.03
2N 99W	2,358,300,000	1,525,480,000	832,820,000	54.59		—-		
2N 100W	18,028,000							
1S 95W	2,711,600,000	1,291,200,000	1,420,400,000	110.01		—-		
1S 96W	7,548,340,000	6,519,425,000	1,028,915,000	15.78	6,708,348,000	±31	839,992,000	12.52
1S 97W	12,056,600,000	11,929,545,000	127,055,000	1.07	11,746,252,000	±5	310,348,000	2.64
1S 98W	13,357,500,000	12,412,400,000	945,100,000	7.61	12,581,545,000	±4	775,955,000	6.17
1S 99W	10,141,900,000	9,183,750,000	958,150,000	10.43	9,627,029,000	±7	514,871,000	5.35
1S 100W	3,471,160,000	2,990,600,000	480,560,000	16.07	2,743,627,000	±33	727,533,000	26.52
2S 94W	76,573,900							
2S 95W	4,128,260,000	3,444,610,000	683,650,000	19.85	3,875,865,000	±88	252,395,000	6.51
2S 96W	7,192,460,000	7,449,280,000	-256,820,000	-3.45	7,483,801,000	±17	-291,341,000	-3.89
2S 97W	11,062,400,000	10,917,180,000	145,220,000	1.33	10,877,714,000	±9	184,686,000	1.70
2S 98W	11,177,000,000	10,622,425,000	554,575,000	5.22	10,094,247,000	±8	1,082,753,000	10.73
2S 99W	7,090,780,000	6,705,090,000	385,690,000	5.75	6,651,097,000	±15	439,683,000	6.61
2S 100W	2,112,340,000	1,829,850,000	282,490,000	15.44	1,676,860,000	±57	435,480,000	25.97
3S 94W	571,958,000					—-		
3S 95W	3,927,010,000	2,669,160,000	1,257,850,000	47.13	3,085,710,000	±79	841,300,000	27.26
3S 96W	6,253,970,000	6,236,160,000	17,810,000	0.29	5,834,195,000	±13	419,775,000	7.20
3S 97W	7,446,490,000	7,684,625,000	-238,135,000	-3.10	7,077,905,000	±8	368,585,000	5.21
3S 98W	6,624,390,000	6,203,450,000	420,940,000	6.79	5,882,000,000	±12	742,390,000	12.62
3S 99W	4,180,000,000	3,791,880,000	388,120,000	10.24	4,045,525,000	±49	134,475,000	3.32
3S 100W	431,858,000	209,110,000	222,748,000	106.52	150,523,000	±216	281,335,000	186.90
4S 94W	1,173,310,000	813,240,000	360,070,000	44.28	1,406,316,000	±153	-233,006,000	-16.57

Table 20. Total number of in-place barrels of oil per acre (BPA) in each township for the R-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM R-5	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
4S 95W	4,214,380,000	3,442,350,000	772,030,000	22.43	3,709,025,000	±60	505,355,000	13.63
4S 96W	4,964,980,000	4,977,940,000	-12,960,000	-0.26	4,733,460,000	±35	231,520,000	4.89
4S 97W	4,845,950,000	5,011,005,000	-165,055,000	-3.29	4,840,702,000	±16	5,248,000	0.11
4S 98W	3,960,320,000	3,673,280,000	287,040,000	7.81	3,626,276,000	±31	334,044,000	9.21
4S 99W	2,827,290,000	2,422,200,000	405,090,000	16.72	2,211,771,000	±119	615,519,000	27.83
4S 100W	1,004,770,000					—-		
4S 101W	10,227,200					—-		
5S 94W	1,802,370,000	1,407,700,000	394,670,000	28.04	1,659,768,000	±175	142,602,000	8.59
5S 95W	2,881,680,000	2,686,320,000	195,360,000	7.27	2,635,176,000	±33	246,504,000	9.35
5S 96W	3,243,390,000	3,138,080,000	105,310,000	3.36	3,099,056,000	±53	144,334,000	4.66
5S 97W	3,538,300,000	3,435,450,000	102,850,000	2.99	3,375,428,000	±35	162,872,000	4.83
5S 98W	2,274,380,000	1,683,100,000	591,280,000	35.13	1,760,651,000	±198	513,729,000	29.18
5S 99W	1,629,680,000	1,732,800,000	-103,120,000	-5.95		—-		
5S 100W	967,751,000					—-		
5S 101W	119,444,000					—-	119,444,000	
6S 94W	37,536,500					—-		
6S 95W	682,655,000	697,550,000	-14,895,000	-2.14	561,821,000	±199	120,834,000	21.51
6S 96W	878,177,000	1,841,400,000	-963,223,000	-52.31	838,119,000	±142	40,058,000	4.78
6S 97W	1,983,840,000	1,835,700,000	148,140,000	8.07		—-		
6S 98W	1,048,540,000	697,600,000	350,940,000	50.31	856,785,000	±114	191,755,000	22.38
6S 99W	436,442,000							
6S 100W	415,455,000							
6S 101W	206,615,000							
7S 93W	59,871							
7S 94W	134,504,000							
7S 95W	55,770,800							
7S 96W	118,594,000							
7S 97W	462,312,000							
7S 98W	122,810,000							
7S 99W	188,511,000							

Table 20. Total number of in-place barrels of oil per acre (BPA) in each township for the R-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM R-5	"Extrapolated" (Pitman and others, 1989)	Difference	Percent difference	Kriging (Pitman and others, 1989)	95 percent confidence	Difference	Percent difference
7S 100W	206,453,000							
7S 101W	74,182,400							
8S 93W	61,913,400							
8S 94W	149,607,000							
8S 95W	128,425,000							
8S 96W	942,763							
8S 99W	37,373,900							
8S 100W	14,733,200							
8S 101W	1,814,340							
9S 94W	178,871							
9S 95W	6,661,440							
9S 96W	651,761							
	198,239,468,346	178,718,890,000			168,092,572,000			

Sum of townships used here and Pitman and others (1989) extrapolated:	192,609,169,000	Sum of townships used here and in kriging:	183,925,749,000		
Percent difference using RBF here and Pitman and others (1989) extrapolated:	6.32	Percent difference between RBF and kriging:	8.61		
Sum of best townships RBF (20 percent):	105,744,320,000	Sum of best townships extrapolated:	103,020,820,000	Sum of best townships kriging:	100,017,321,000
Percent difference RBF vs extrapolation for best TSPS:	2.64				
Percent difference RBF vs kriging for best TSPS:	5.73				

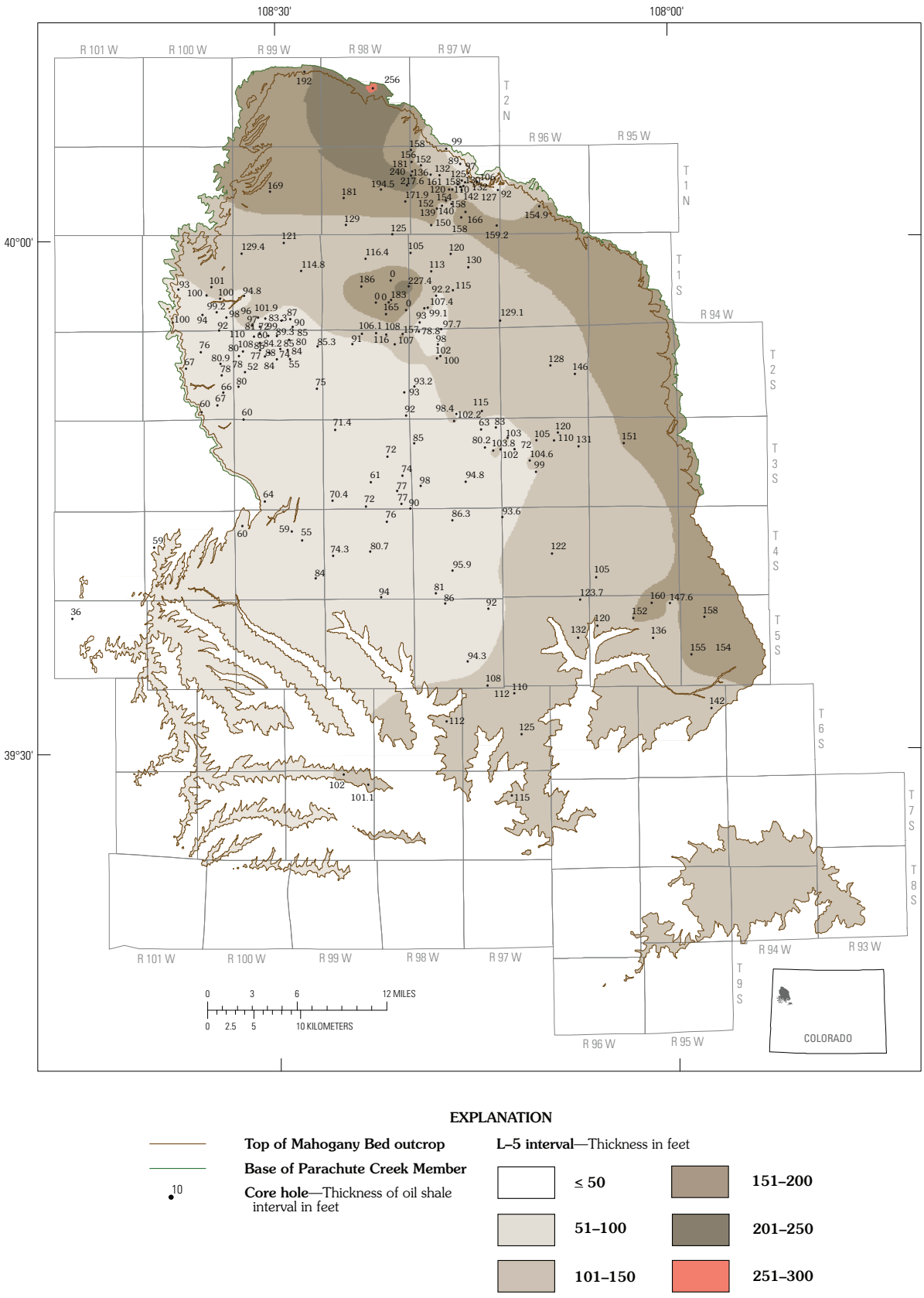


Figure 85. Isopach map of the L-5 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

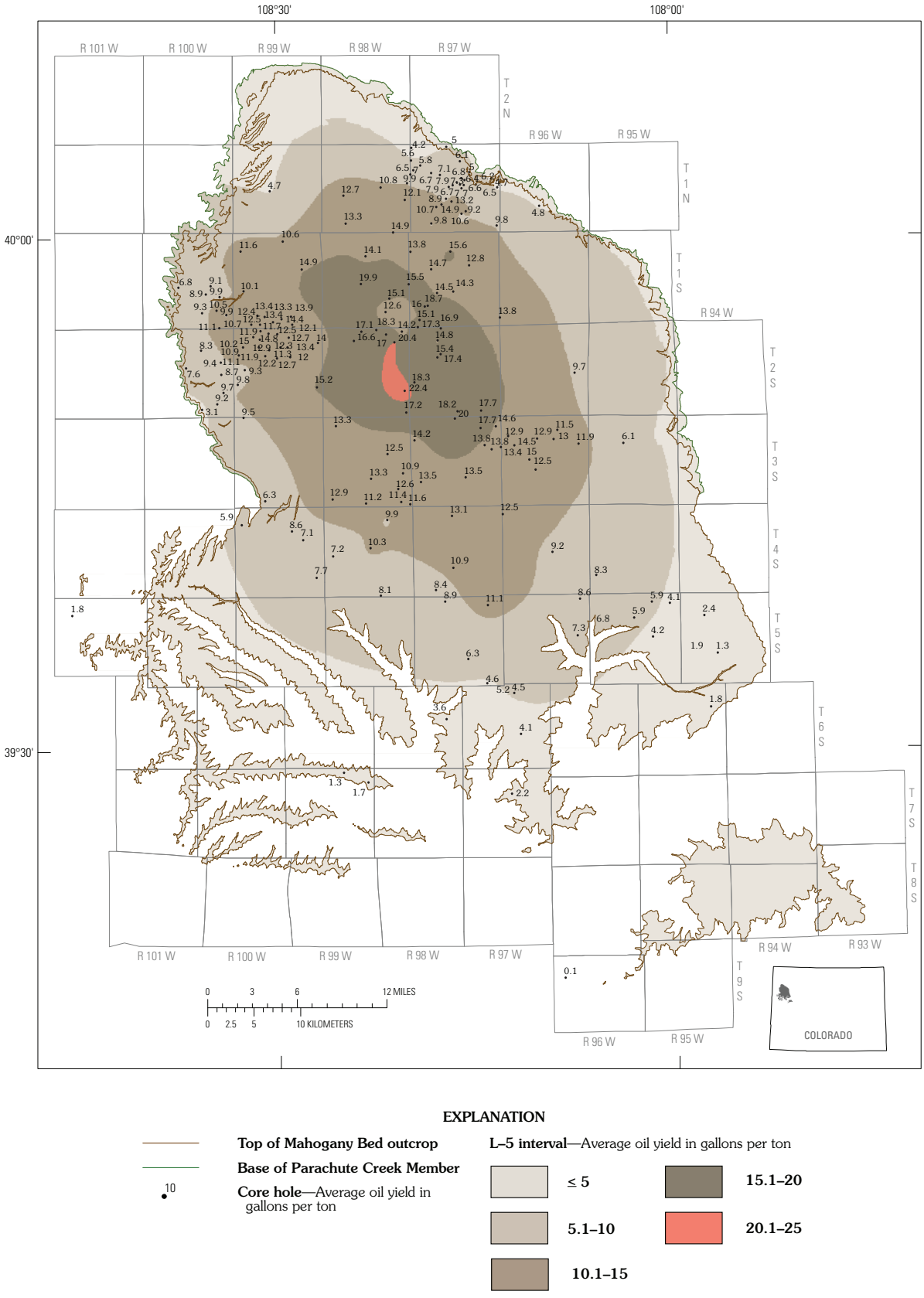


Figure 86. Isoresource map of the L-5 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

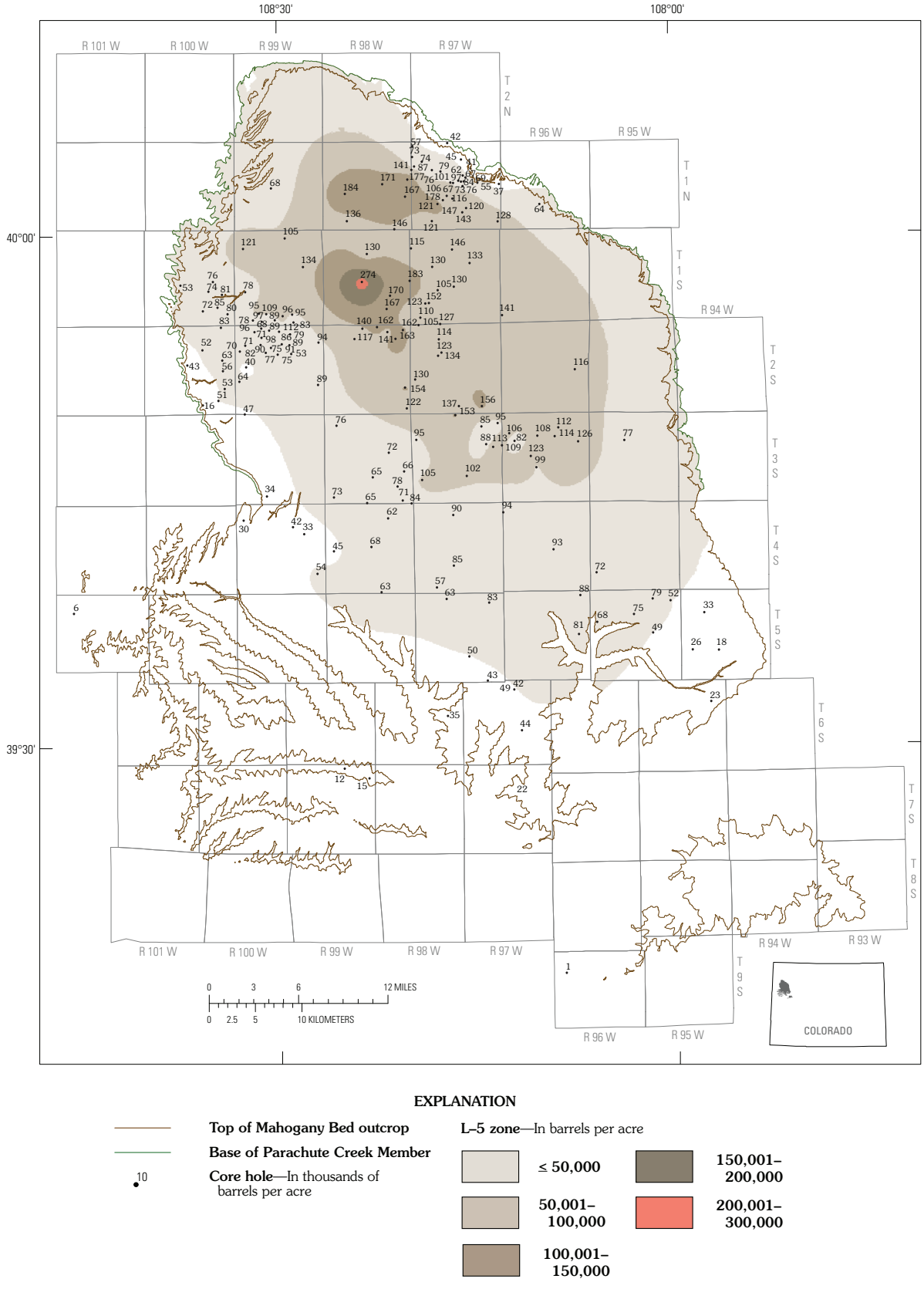


Figure 87. Isoresource map of the L-5 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

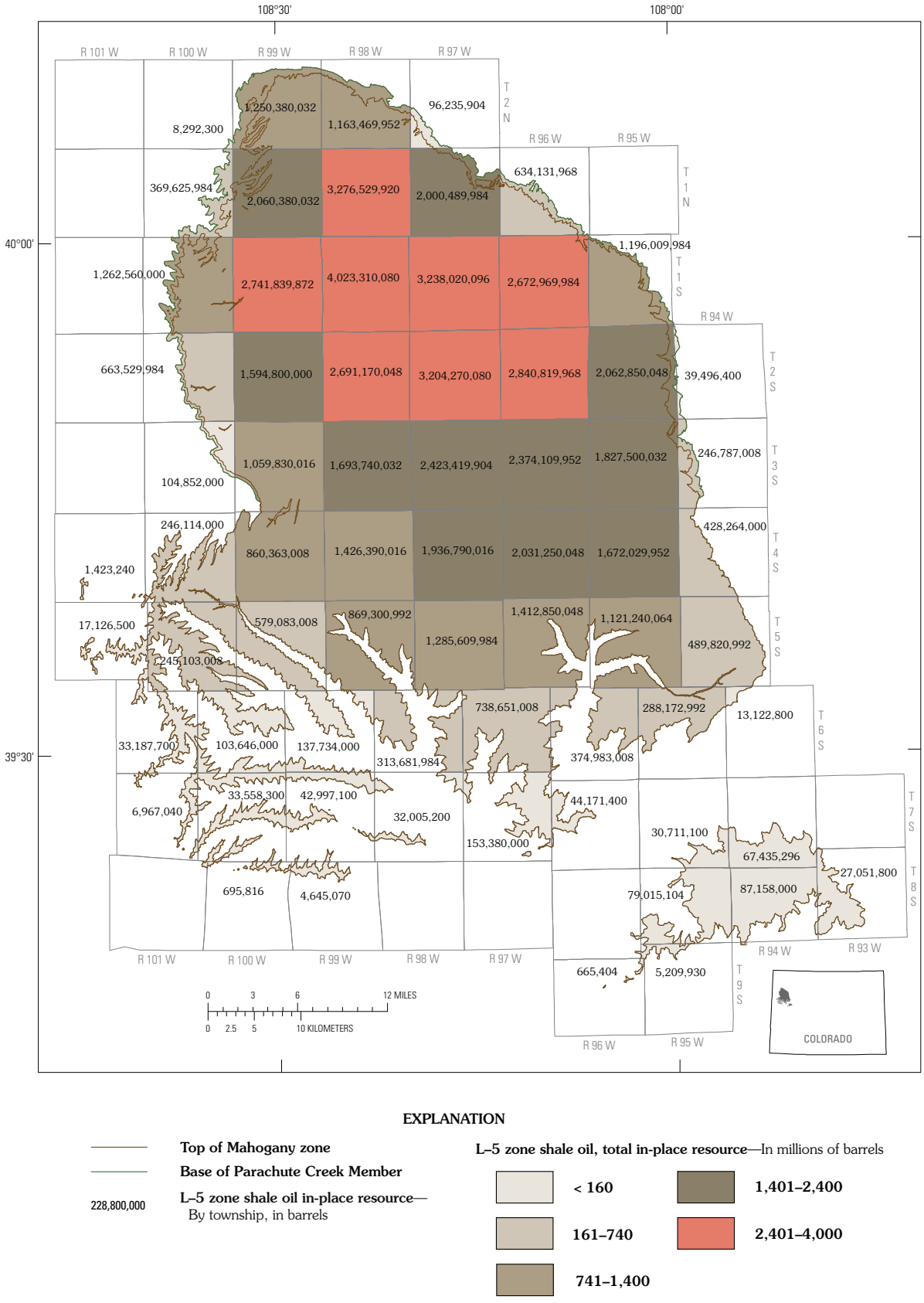


Figure 88. Isoresource map of the L-5 zone showing total number of barrels of oil in each township using only core hole data.

Table 21. Total number of in-place barrels of oil per acre (BPA) in each township for the L-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM L-5	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Township, Range	Kriging, Pitman and others, (1989)	95 percent confidence	Difference	Percent difference
1N 96W	634,132,000	473,760,000	160,372,000	34	1N 96W	481,007,000	±36	153,125,000	32
1N 97W	2,000,490,000	1,744,412,000	256,078,000	15	1N 97W	1,742,788,000	±10	257,702,000	15
1N 98W	3,276,530,000	2,585,660,000	690,870,000	27	1N 98W	2,191,041,000	±16	1,085,489,000	50
1N 99W	2,060,380,000	2,349,820,000	-289,440,000	-12	1N 99W	2,074,246,000	±33	-13,866,000	-1
1N 100W	369,626,000	45,210,000	324,416,000	718	1N 100W	120,010,000	±54	249,616,000	208
2N 97W	96,235,900	34,410,000	61,825,900	180	2N 97W	59,849,000	±54	36,386,900	61
2N 98W	1,163,470,000	281,580,000	881,890,000	313	2N 98W		--		
2N 99W	1,250,380,000				2N 99W		--		
2N 100W	8,292,300				2N 100W				
1S 95W	1,196,010,000	322,800,000	873,210,000	271	1S 95W		--		
1S 96W	2,672,970,000	237,070,000	2,435,900,000	1,028	1S 96W	2,120,861,000	±29	552,109,000	26
1S 97W	3,238,020,000	3,394,386,000	-156,366,000	-5	1S 97W	2,949,845,000	±10	288,175,000	10
1S 98W	4,023,310,000	3,389,540,000	633,770,000	19	1S 98W	2,866,351,000	±8	1,156,959,000	40
1S 99W	2,741,840,000	2,449,000,000	292,840,000	12	1S 99W	2,293,272,000	±13	448,568,000	20
1S 100W	1,262,560,000	1,046,710,000	215,850,000	21	1S 100W	1,143,711,000	±38	118,849,000	10
2S 94W	39,496,400				2S 94W				
2S 95W	2,062,850,000	1,722,305,000	340,545,000	20	2S 95W	2,533,654,000	±53	-470,804,000	-19
2S 96W	2,840,820,000	2,793,480,000	47,340,000	2	2S 96W	2,605,432,000	±18	235,388,000	9
2S 97W	3,204,270,000	3,203,955,000	315,000	0	2S 97W	2,850,288,000	±9	353,982,000	12
2S 98W	2,691,170,000	2,348,115,000	343,055,000	15	2S 98W	2,218,631,000	±10	472,539,000	21
2S 99W	1,594,800,000	1,502,865,000	91,935,000	6	2S 99W	1,663,017,000	±24	-68,217,000	-4
2S 100W	663,530,000	487,960,000	175,570,000	36	2S 100W	745,547,000	±71	-82,017,000	-11
3S 94W	246,787,000				3S 94W	57,906,000	±384	188,881,000	326
3S 95W	1,827,500,000	1,445,795,000	381,705,000	26	3S 95W	1,771,464,000	±66	56,036,000	3
3S 96W	2,374,110,000	2,267,200,000	106,910,000	5	3S 96W	2,157,516,000	±17	216,594,000	10
3S 97W	2,423,420,000	2,482,725,000	-59,305,000	-2	3S 97W	2,181,891,000	±10	241,529,000	11
3S 98W	1,693,740,000	1,556,502,000	137,238,000	9	3S 98W	1,630,335,000	±17	63,405,000	4
3S 99W	1,059,830,000	779,442,000	280,388,000	36	3S 99W	1,072,910,000	±50	-13,080,000	-1
3S 100W	104,852,000	19,010,000	85,842,000	452	3S 100W	81,431,000	±115	23,421,000	29
4S 94W	428,264,000	180,720,000	247,544,000	137	4S 94W	604,929,000	±115	-176,665,000	-29

Table 21. Total number of in-place barrels of oil per acre (BPA) in each township for the L-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-5	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Township, Range	Kriging, Pitman and others, (1989)	95 percent confidence	Difference	Percent difference
4S 95W	1,672,030,000	1,606,430,000	65,600,000	4	4S 95W	1,504,636,000	±25	167,394,000	11
4S 96W	2,031,250,000	1,923,295,000	107,955,000	6	4S 96W	1,863,716,000	±18	167,534,000	9
4S 97W	1,936,790,000	1,724,718,000	212,072,000	12	4S 97W	1,693,348,000	±20	243,442,000	14
4S 98W	1,426,390,000	1,056,068,000	370,322,000	35	4S 98W	1,064,422,000	±47	361,968,000	34
4S 99W	860,363,000	616,560,000	243,803,000	40	4S 99W	565,643,000	±235	294,720,000	52
4S 100W	246,114,000				4S 100W		--		
4S 101W	1,423,240				4S 101W		--		
5S 94W	489,821,000	361,980,000	127,841,000	35	5S 94W	462,398,000	±131	27,423,000	6
5S 95W	1,121,240,000	959,400,000	161,840,000	17	5S 95W	979,482,000	±40	141,758,000	14
5S 96W	1,412,850,000	1,274,845,000	138,005,000	11	5S 96W	1,133,047,000	±30	279,803,000	25
5S 97W	1,285,610,000	1,282,568,000	3,042,000	0	5S 97W	1,134,248,000	±46	151,362,000	13
5S 98W	869,301,000	538,592,000	330,709,000	61	5S 98W	478,075,000	±206	391,226,000	82
5S 99W	579,083,000				5S 99W		--		
5S 100W	245,103,000				5S 100W		--		
5S 101W	17,126,500				5S 101W		--		
6S 94W	13,122,800	10,092,000	3,030,800	30	6S 94W		--		
6S 95W	288,173,000	199,300,000	88,873,000	45	6S 95W	185,888,000	±259	102,285,000	55
6S 96W	374,983,000	662,904,000	-287,921,000	-43	6S 96W	270,021,000	±74	104,962,000	39
6S 97W	738,651,000	642,495,000	96,156,000	15	6S 97W	709,285,000	±74	29,366,000	4
6S 98W	313,682,000	226,720,000	86,962,000	38	6S 98W	270,399,000	±70	43,283,000	16
6S 99W	137,734,000				6S 99W				
6S 100W	103,646,000				6S 100W				
6S 101W	33,187,700				6S 101W				
7S 93W	31,560				7S 93W				
7S 94W	67,435,300				7S 94W				
7S 95W	30,711,100				7S 95W				
7S 96W	44,171,400				7S 96W				
7S 97W	153,380,000	134,694,000	18,686,000	14	7S 97W				
7S 98W	32,005,200				7S 98W				
7S 99W	42,997,100	50,592,000	-7,594,900	-15	7S 99W				

Table 21. Table listing total number of in-place barrels of oil per acre (BPA) in each township for the L-5 zone calculated here using the Radial Basis Function Method (RBF). Results for the L-5 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM L-5	Extrapolated (Pitman and others, 1989)	Difference	Percent difference	Township, Range	Kriging, Pitman and others, (1989)	95 percent confidence	Difference	Percent difference
7S 100W	33,558,300				7S 100W				
7S 101W	6,967,040				7S 101W				
8S 93W	27,051,800				8S 93W				
8S 94W	87,158,000				8S 94W				
8S 95W	79,015,100				8S 95W				
8S 96W	601,341				8S 96W				
8S 99W	4,645,070				8S 99W				
8S 100W	695,816				8S 100W				
8S 101W	11,921				8S 101W				
9S 94W	135,517				9S 94W				
9S 95W	5,209,930				9S 95W				
9S 96W	665,404				9S 96W				
Totals:	66,063,806,739	52,415,685,000		66,063,806,739	Totals:	52,532,540,000			
Sum of townships used here and Pitman and others (1989) extrapolated:		62,735,363,800	Sum of townships used here and in kriging:		60,413,170,900				
Percent difference using RBF here ahd Pitman and others (1989) extrapolated:		5.31	Percent difference between RBF and kriging:		9.35				
Sum of best townships RBF (20 percent):		32,538,970,000	Sum of best townships extraploated		30,138,270,000	Sum of best townships kriging	27,551,106,000		
Percent difference RBF vs Kriging for best townships:		18.10							
Percent difference RBF vs extrapolation for best townships:		7.97							

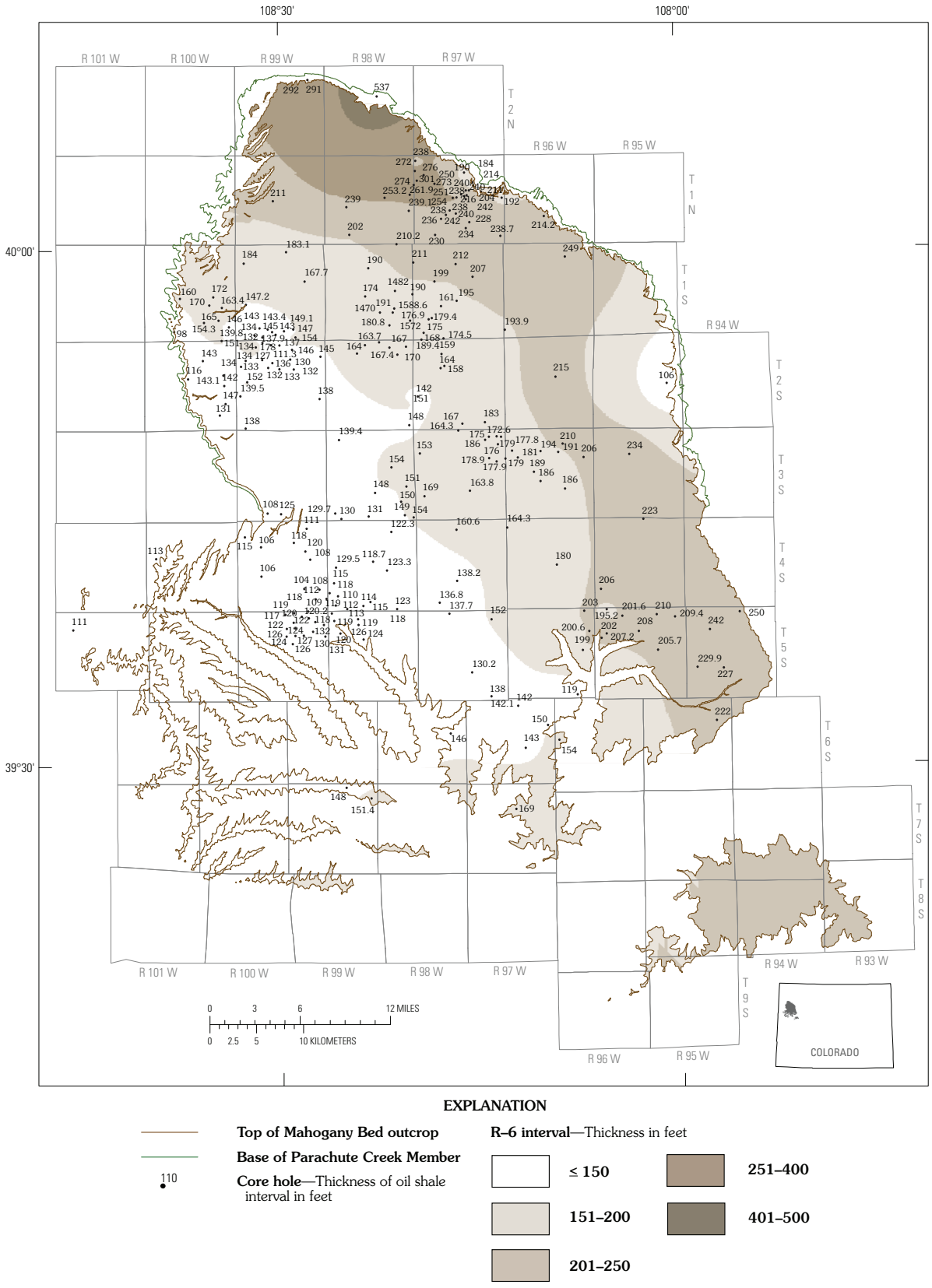


Figure 89. Isopach map of the R-6 zone using the Radial Basis Function Method (RBF) of contouring. Contour interval in feet is variable.

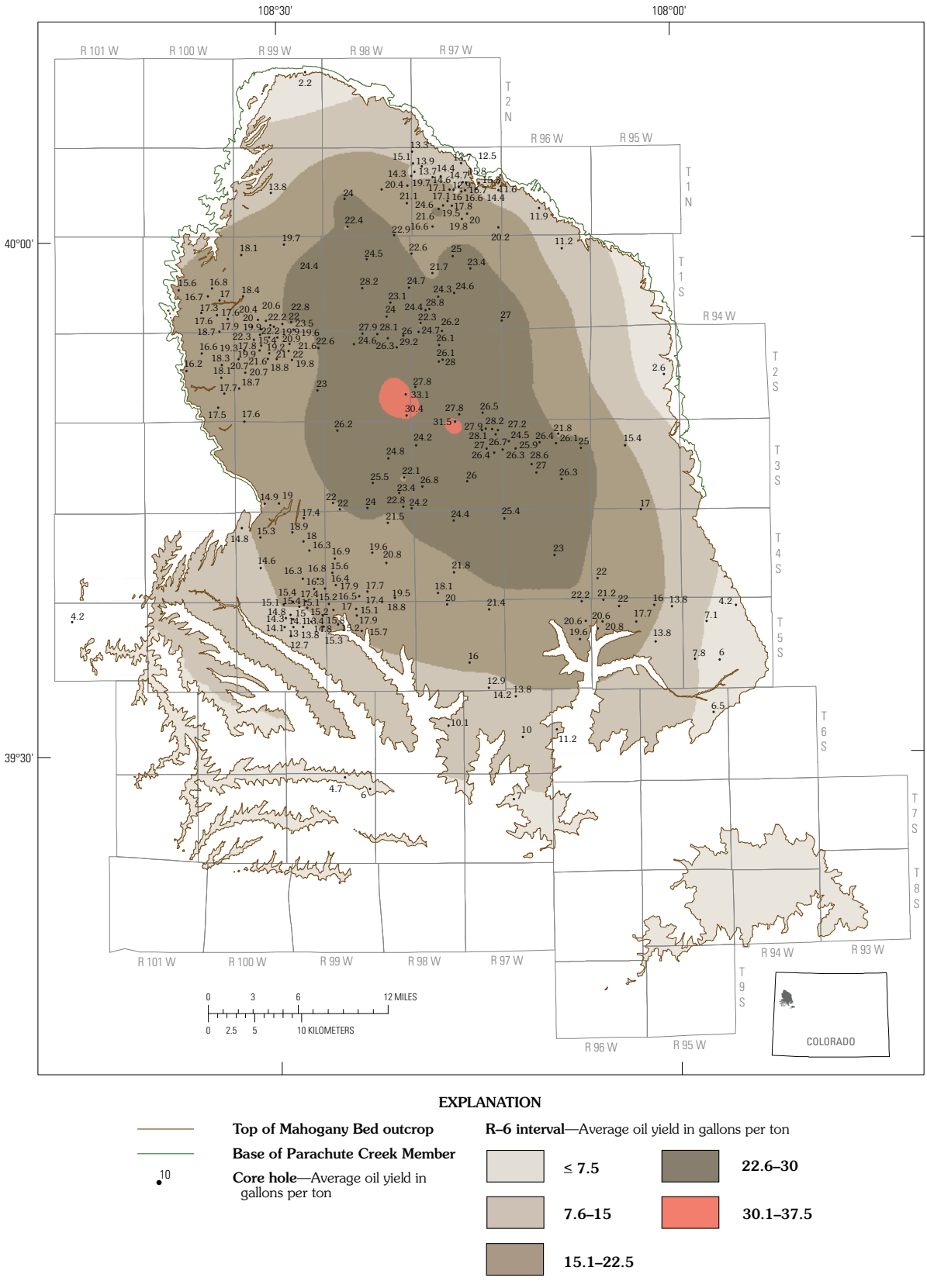


Figure 90. Isoresource map of the R-6 zone showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

shale areas of the Piceance and Uinta Basins. It is one of the most distinctive and easily recognizable units on geophysical logs and oil-yield histograms in the entire oil shale interval (fig. 7). B-groove had never been previously assessed. Three hundred fifty two core holes were used to assess B-groove here. An additional 68 rotary holes were used to construct the isopach map. B-groove varies from 5 to 40 ft thick throughout most of the basin (fig. 93) and thickens markedly towards both the north, where it reaches a thickness of almost 100 ft and towards the east, where it reaches a maximum of 90 ft thick (fig. 93). The B-groove is very sandy in these marginal areas where it is thickest (Johnson, unpub. sections; Donnell, 1961, his plate 49). It appears to represent a major contraction of the lake that brought sandy sediments much farther into the lake than during the previous R-6 interval or the Mahogany interval that followed. It is unclear why organic productivity was so much lower during this contraction of the lake than during previous contractions.

B-groove is organically poor overall, with oil yields ranging from less than 1 GPT to about 10 GPT throughout most of the basin, but oil yields of as much as 25 GPT occur locally in the central part of the basin (fig. 94). The overall pattern is a general increase in oil yield towards about the same southeast-trending oil shale depocenter as for the underlying R-6 zone (figs. 90, 94) but with a high degree of scatter. In-place oil is also higher in this depocenter (fig. 95) but again, there is a high degree of scatter. Maximum in-place oil in a township is almost 460 million barrels in T. 3 S., R. 97 W. (fig. 96, table 23). Total in-place oil in B-groove is estimated to be over 7.8 billion barrels (table 23).

Mahogany Zone

The Mahogany zone and the strata above it comprise the fifth stage of Lake Uinta as defined by Johnson (1985). The Mahogany zone has been the target of most oil shale extraction projects thus far because of its richness and because it crops out around the margins of the basin where it can be easily reached by underground mining. The base of the Mahogany zone is marked by a significant increase in oil yields (fig. 7). Oil yields generally increase upwards in the Mahogany zone culminating in deposition of the Mahogany bed, one of the richest and probably the most widespread oil shale beds in both the Piceance Basin and Uinta Basin to the west (fig. 7). The Mahogany bed is the only significant oil shale bed remaining in the Green River Formation throughout much of the southern part of the Uinta Basin to the west, where most of the Green River Formation is marginal lacustrine (Cashion, 1967, his plate 3). It represents the culmination of a major transgression of Lake Uinta that began at the base of the Mahogany zone.

The Mahogany bed can be recognized throughout most, if not all, the area where the Green River Formation is preserved except near the mouth of Yellow Creek in T. 2 N., R. 98 W. in the north-central part of the Piceance Basin were it grades into organically lean marlstone, siltstone, and sandstone. Johnson (1985; 2007) believed that the Mahogany zone graded into clastics in this area due to outflow from Lake Gosiute to the north, and that the expansion of the lake during deposition of the Mahogany was caused by the increase in water supplied to Lake Uinta due to this outflow. The Mahogany bed represents the maximum extent of Lake Uinta when oil shale was deposited across nearly all the areas that had previously been marginal lacustrine. Oil yields gradually decline in the Mahogany zone above the Mahogany bed. The expansion of the oil shale depocenter towards the southeast that began during deposition of the L-5 zone continued with the Mahogany zone with rich oil shale being deposited across much of the southeastern part of the basin.

A single core hole near the mouth of Yellow Creek in sec. 20, T. 2 N., R. 98 W. (C19 in Dyni, 1998) appears to have cored and assayed the Mahogany zone. The only significant oil shale encountered in the hole extends from a depth of 855 to 980 ft. The zone resembles the Mahogany zone in other core holes in the area but with much lower oil yields—6.9 GPT (fig. 97). Because this is the only control point in this unique area, it was included in the assessment calculation. Without it, isovalue lines for estimated gallons per ton for the Mahogany zone overestimated the richness throughout a large area of the northernmost part of the basin.

Three hundred ninety two core holes were used to assess the Mahogany zone here. An additional 73 rotary holes were used in the alternative set of resource maps that used both core holes and rotary holes. Only 131 core holes were used to assess the Mahogany zone in the previous assessment (Pitman and Johnson, 1978). The Mahogany zone varies from 150 to 250 ft thick through a broad northwest-trending swath in the middle of the Piceance basin (fig. 97). It thins towards the west, south, and east but thickens and grades into marlstone, siltstone, and sandstone near the mouth of Yellow Creek. Oil yield for the Mahogany zone varies from about 22 to 33 GPT throughout the oil shale depocenter (fig. 98). In-place oil using only the core holes shows that the Mahogany zone contains from 200,000 to 427,000 BPA in the richest part of the depocenter with values decreasing in a regular fashion outward (fig. 99). Maximum in-place oil in a township is over 8.7 billion barrels in place in T. 1 S., R. 97 W. (fig. 100, table 24). Total in-place oil in the Mahogany zone using only core holes is estimated to be 191.7 billion barrels (table 25).

The Mahogany zone was originally assessed by Pitman and Johnson (1978) using hand extrapolation and was not reassessed using kriging by Pitman and others (1989). Using only those townships that were assessed in both this assessment and the assessment of Pitman and Johnson (1978), our results are 8.97 percent higher than the manually extrapolated results of Pitman and Johnson (1978).

Nine townships were visually picked out that seemed to have adequate control in the 1978 assessment, and using only those townships, our assessment is 5.10 percent higher than the assessment of Pitman and Johnson (1978) (table 24).

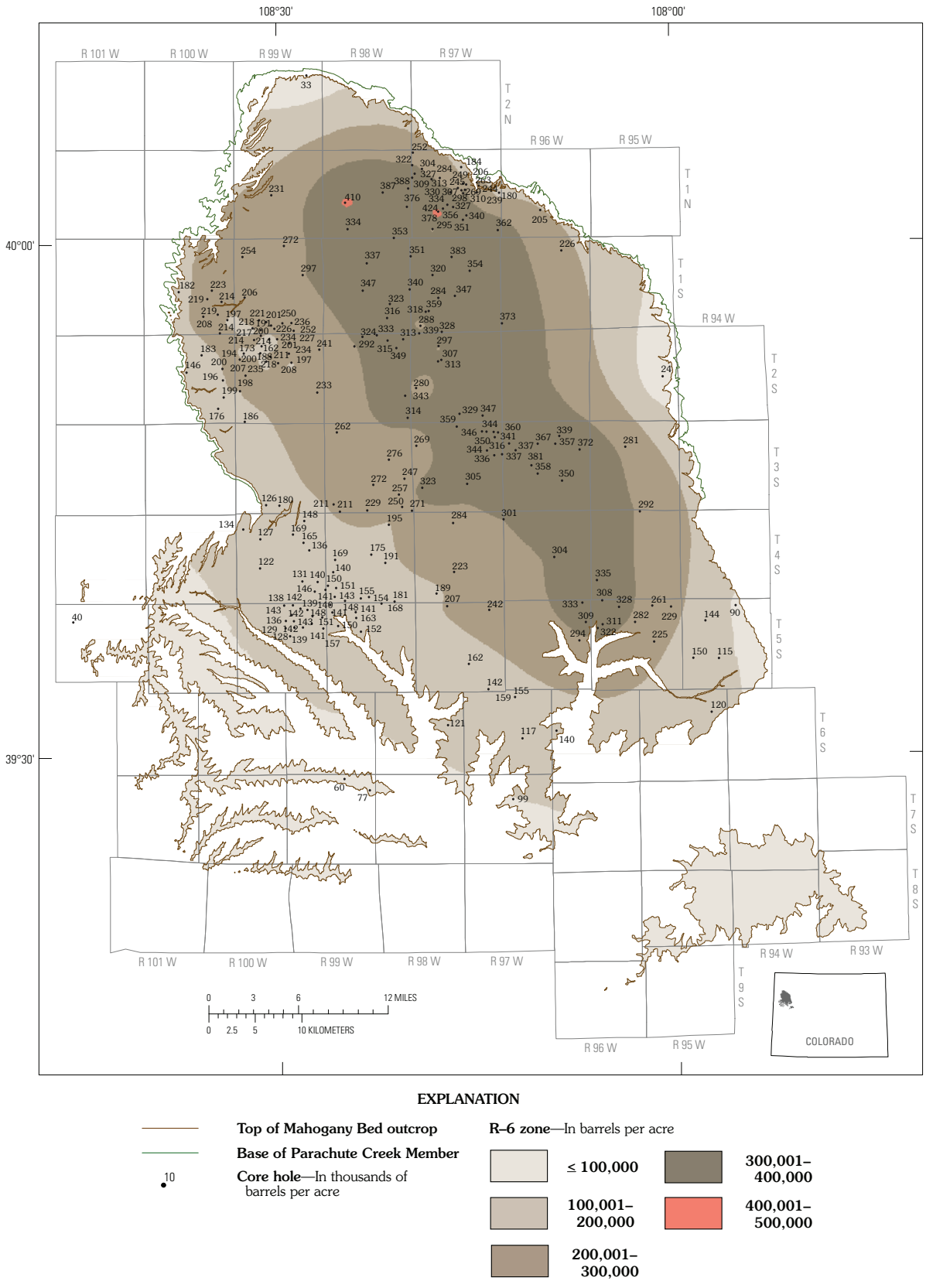


Figure 91. Isoresource map of the R-6 zone showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

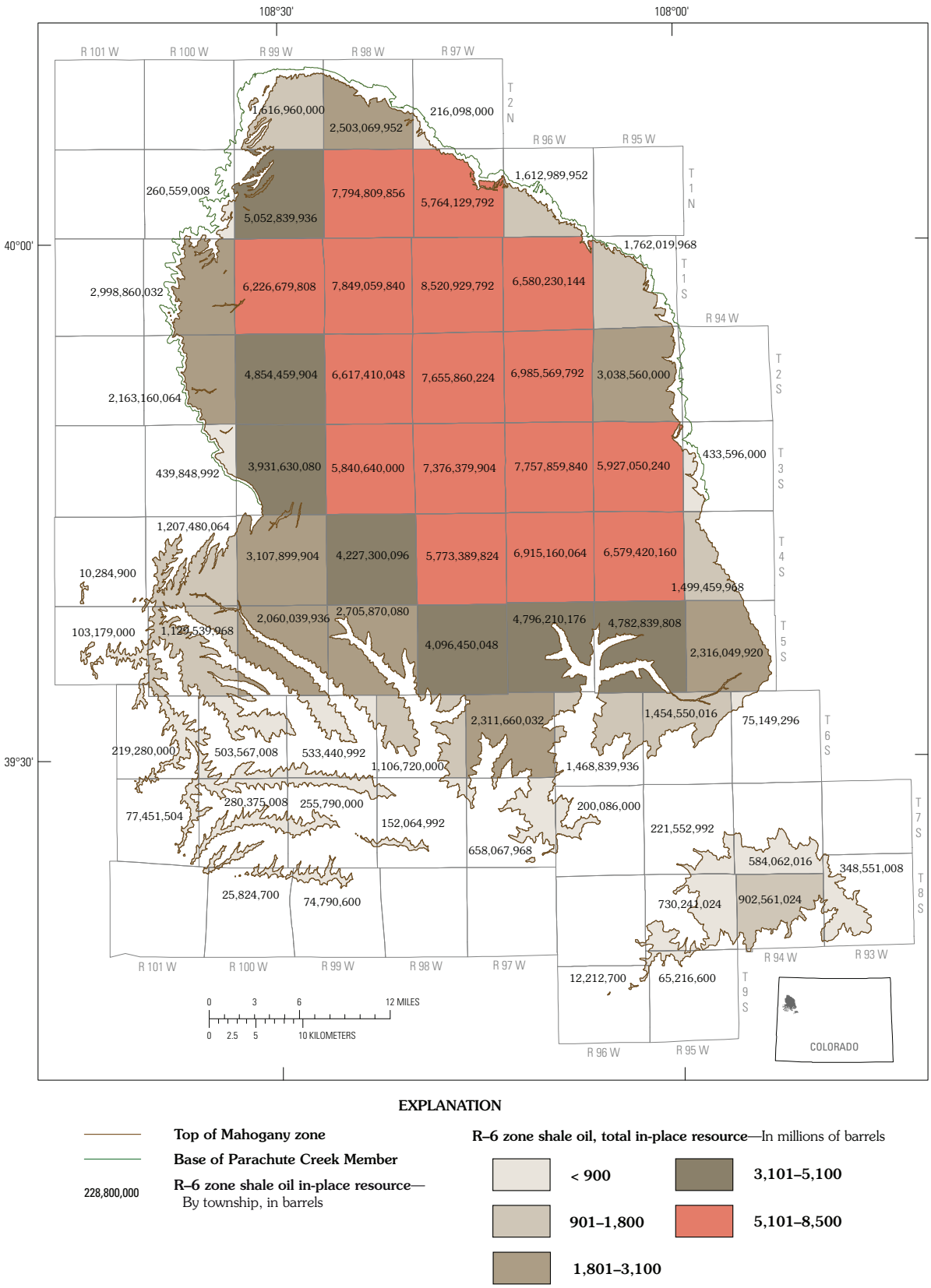


Figure 92. Isoresource map of the R-6 zone showing total number of barrels of oil in each township using only core hole data.

Table 22. Total number of in-place barrels of oil per acre (BPA) in each township for the R-6 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-6 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM R-6	Extrapolated Pitman and others, 1989	Difference	Percent difference
1N 96W	1,612,990,000	1,655,359,000	-42,369,000	-2.56
1N 97W	5,764,130,000	5,208,895,000	555,235,000	10.66
1N 98W	7,794,810,000	6,369,959,000	1,424,851,000	22.37
1N 99W	5,052,840,000	4,009,833,000	1,043,007,000	26.01
1N 100W	260,559,000	126,207,000	134,352,000	106.45
2N 97W	216,098,000	115,671,000	100,427,000	86.82
2N 98W	2,503,070,000	1,613,707,000	889,363,000	55.11
2N 99W	1,616,960,000	1,009,920,000	607,040,000	60.11
2N 100W				
1S 95W	1,762,020,000	1,295,776,000	466,244,000	35.98
1S 96W	6,580,230,000	6,007,621,000	572,609,000	9.53
1S 97W	8,520,930,000	8,131,159,000	389,771,000	4.79
1S 98W	7,849,060,000	7,282,021,000	567,039,000	7.79
1S 99W	6,226,680,000	5,812,091,000	414,589,000	7.13
1S 100W	2,998,860,000	1,597,541,000	1,401,319,000	87.72
2S 94W				
2S 95W	3,038,560,000	2,583,613,000	454,947,000	17.61
2S 96W	6,985,570,000	6,328,320,000	657,250,000	10.39
2S 97W	7,655,860,000	7,198,068,000	457,792,000	6.36
2S 98W	6,617,410,000	6,044,955,000	572,455,000	9.47
2S 99W	4,854,460,000	4,553,164,000	301,296,000	6.62
2S 100W	2,163,160,000	1,194,530,000	968,630,000	81.09
3S 94W	433,596,000	156,239,000	277,357,000	177.52
3S 95W	5,927,050,000	4,748,567,000	1,178,483,000	24.82
3S 96W	7,757,860,000	7,206,961,000	550,899,000	7.64
3S 97W	7,376,380,000	6,972,504,000	403,876,000	5.79
3S 98W	5,840,640,000	5,519,544,000	321,096,000	5.82
3S 99W	3,931,630,000	3,744,312,000	187,318,000	5.00
3S 100W	439,849,000	317,119,000	122,730,000	38.70
4S 94W	1,499,460,000	904,019,000	595,441,000	65.87
4S 95W	6,579,420,000	5,600,159,000	979,261,000	17.49
4S 96W	6,915,160,000	6,528,163,000	386,997,000	5.93
4S 97W	5,773,390,000	5,439,115,000	334,275,000	6.15
4S 98W	4,227,300,000	4,146,597,000	80,703,000	1.95
4S 99W	3,107,900,000	2,937,954,000	169,946,000	5.78
4S 100W	1,207,480,000			
4S 101W	10,284,900	1,523,000	8,761,900	575.31
5S 94W	2,316,050,000	2,189,722,000	126,328,000	5.77
5S 95W	4,782,840,000	4,165,623,000	617,217,000	14.82
5S 96W	4,796,210,000	4,520,973,000	275,237,000	6.09

Table 22. Total number of in-place barrels of oil per acre (BPA) in each township for the R-6 zone calculated here using the Radial Basis Function Method (RBF). Results for the R-6 zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM R-6	Extrapolated Pitman and others, 1989	Difference	Percent difference
5S 97W	4,096,450,000	3,909,584,000	186,866,000	4.78
5S 98W	2,705,870,000	2,177,218,000	528,652,000	24.28
5S 99W	2,060,040,000	1,490,416,000	569,624,000	38.22
5S 100W	1,129,540,000	529,666,000	599,874,000	113.26
5S 101W	103,179,000	25,244,000	77,935,000	308.73
6S 94W	75,149,300	64,327,000	10,822,300	16.82
6S 95W	1,454,550,000	910,968,000	543,582,000	59.67
6S 96W	1,468,840,000	1,150,043,000	318,797,000	27.72
6S 97W	2,311,660,000	2,137,386,000	174,274,000	8.15
6S 98W	1,106,720,000	896,155,000	210,565,000	23.50
6S 99W	533,441,000	439,179,000	94,262,000	21.46
6S 100W	503,567,000	255,751,000	247,816,000	96.90
6S 101W	219,280,000	42,813,000	176,467,000	412.18
7S 93W	272,072			
7S 94W	584,062,000			
7S 95W	221,553,000			
7S 96W	200,086,000	144,121,000	55,965,000	38.83
7S 97W	658,068,000	583,481,000	74,587,000	12.78
7S 98W	152,065,000	130,897,000	21,168,000	16.17
7S 99W	255,790,000	217,319,000	38,471,000	17.70
7S 100W	280,375,000	94,796,000	185,579,000	195.77
7S 101W	77,451,500	9,688,000	67,763,500	699.46
8S 93W	348,551,000			
8S 94W	902,561,000			
8S 95W	730,241,000			
8S 96W	7,040,600			
8S 99W	74,790,600			
8S 100W	25,824,700			
8S 101W	2,735,640	45,000	2,690,640	5,979.20
9S 94W	2,068,020			
9S 95W	65,216,600			
9S 96W	12,212,700			
Sum:	185,366,007,632	158,446,601,000		

Sum of townships used in both assessments:	181,184,134,340
Percent higher this assessment:	16.99
Best townships this assessment:	28,558,330,000
Best townships previous assessment:	26,583,077,000
Percent difference:	7.43

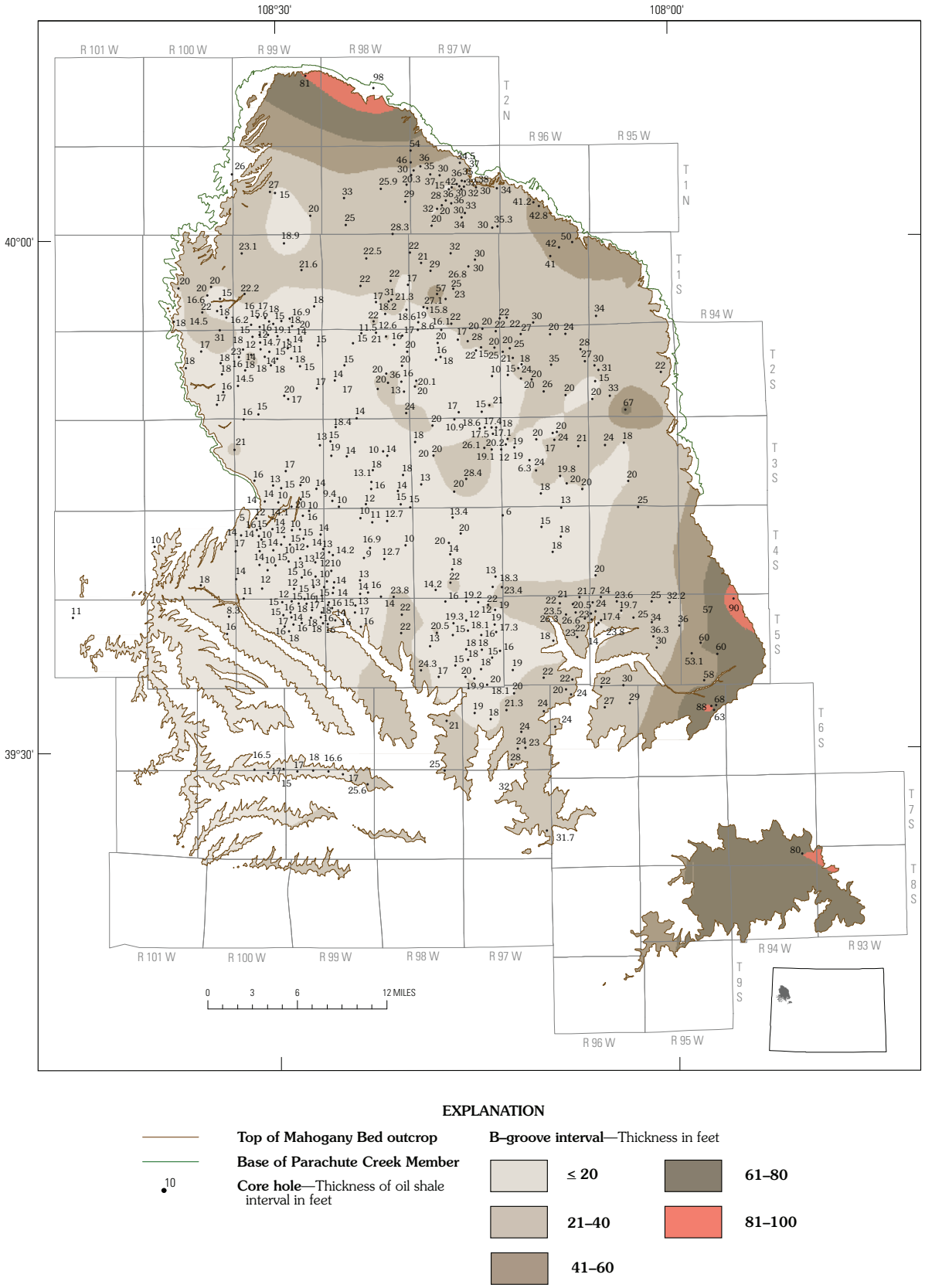


Figure 93. Isopach map of B-groove using both core hole and rotary hole data. The Radial Basis Function Method (RBF) was used for contouring.

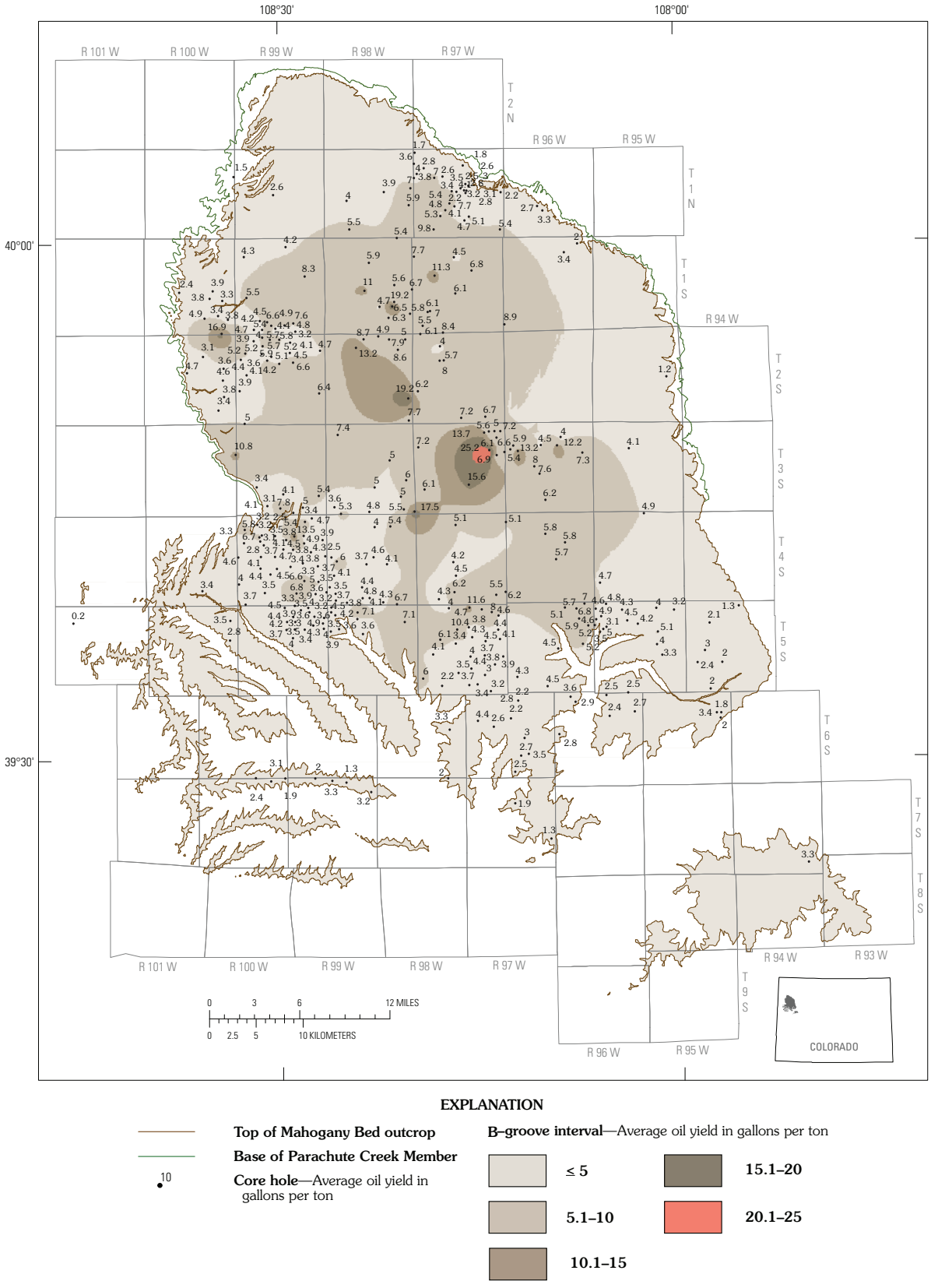


Figure 94. Isoresource map of B-groove showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

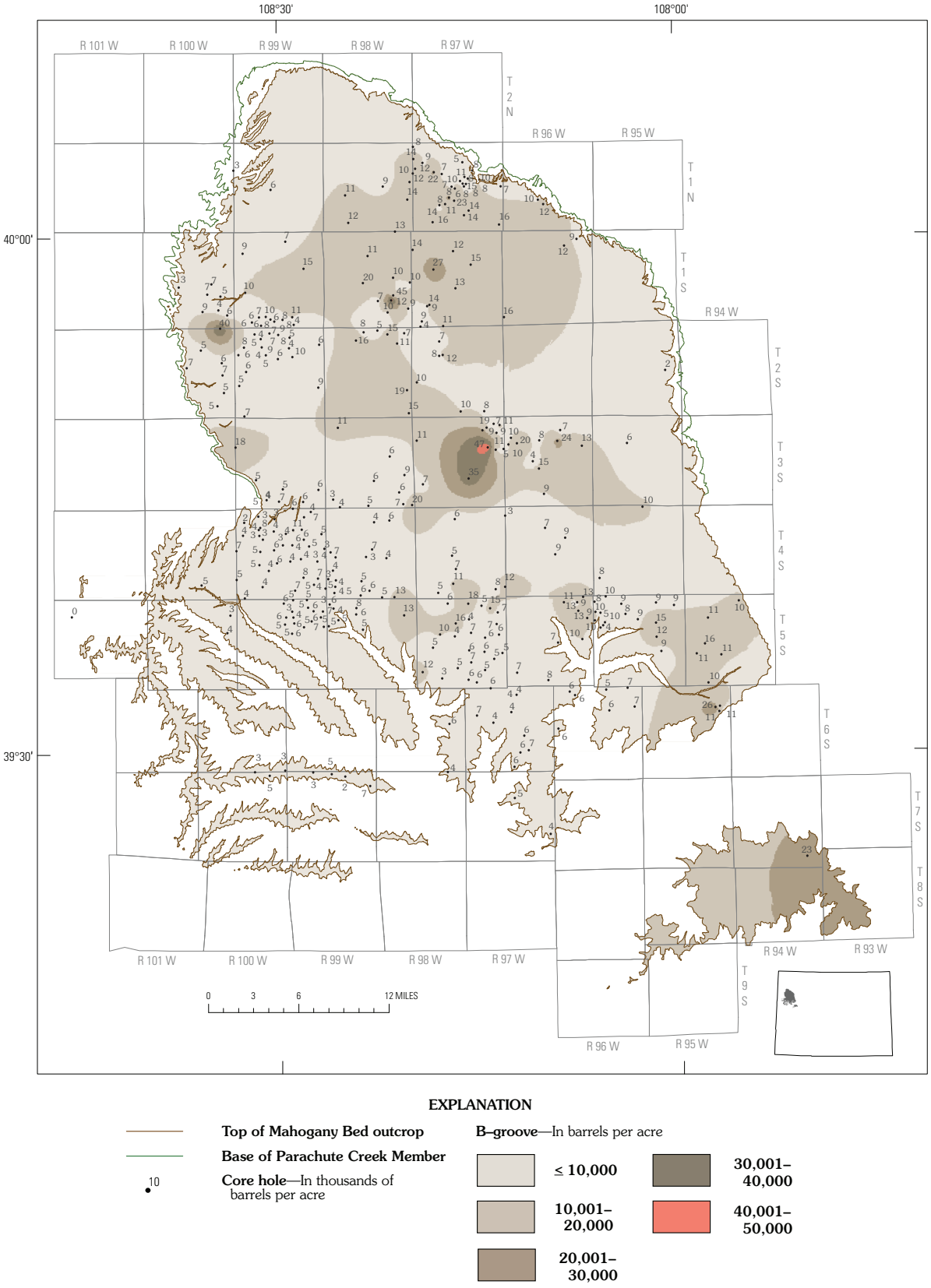


Figure 95. Isoresource map of B-groove showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

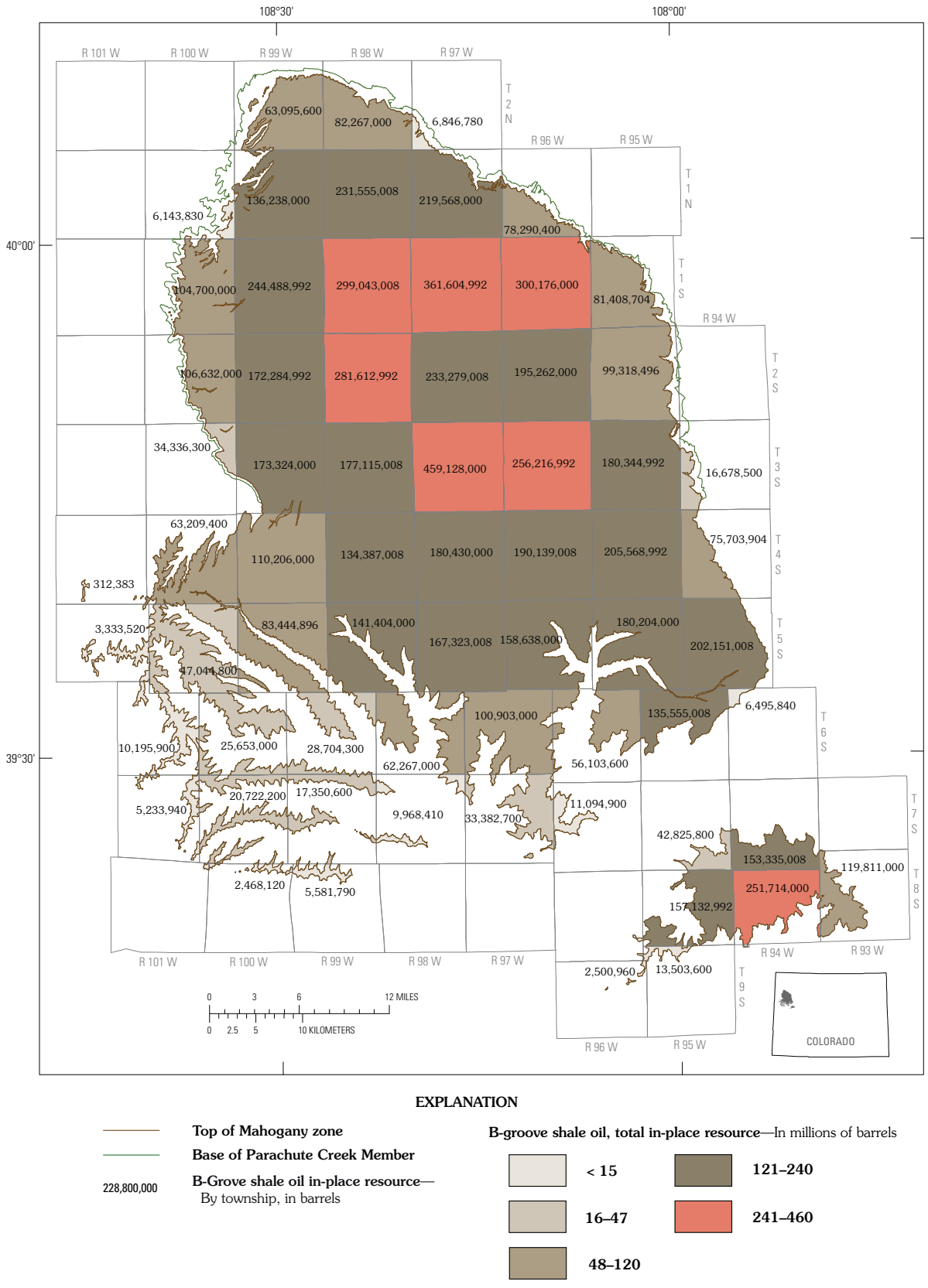


Figure 96. Isoresource map of B-groove showing total number of barrels of oil in each township using only core hole data.

Table 23. Total number of in-place barrels of oil per acre (BPA) in each township for B-groove calculated here using the Radial Basis Function Method (RBF).

Township, Range	SUM B-groove
1N 96W	78,290,400
1N 97W	219,568,000
1N 98W	231,555,000
1N 99W	136,238,000
1N 100W	6,143,830
2N 97W	6,846,780
2N 98W	82,267,000
2N 99W	63,095,600
2N 100W	
1S 95W	81,408,700
1S 96W	300,176,000
1S 97W	361,605,000
1S 98W	299,043,000
1S 99W	244,489,000
1S 100W	104,700,000
2S 94W	
2S 95W	99,318,500
2S 96W	195,262,000
2S 97W	233,279,000
2S 98W	281,613,000
2S 99W	172,285,000
2S 100W	106,632,000
3S 94W	16,678,500
3S 95W	180,345,000
3S 96W	256,217,000
3S 97W	459,128,000
3S 98W	177,115,000
3S 99W	173,324,000
3S 100W	34,336,300
4S 94W	75,703,900
4S 95W	205,569,000
4S 96W	190,139,000
4S 97W	180,430,000
4S 98W	134,387,000
4S 99W	110,206,000
4S 100W	63,209,400
4S 101W	312,383
5S 94W	202,151,000
5S 95W	180,204,000
5S 96W	158,638,000
5S 97W	167,323,000
5S 98W	141,404,000
5S 99W	83,444,900
5S 100W	47,044,800
5S 101W	3,333,520
6S 94W	6,495,840
6S 95W	135,555,000
6S 96W	56,103,600
6S 97W	100,903,000
6S 98W	62,267,000
6S 99W	28,704,300
6S 100W	25,653,000
6S 101W	10,195,900
7S 93W	88,884
7S 94W	153,335,000
7S 95W	42,825,800
7S 96W	11,094,900
7S 97W	33,382,700
7S 98W	9,968,410
7S 99W	17,350,600
7S 100W	20,722,200
7S 101W	5,233,940
8S 93W	119,811,000
8S 94W	251,714,000
8S 95W	157,133,000
8S 96W	1,285,000
8S 99W	5,581,790
8S 100W	2,468,120
8S 101W	196,117
9S 94W	520,796
9S 95W	13,503,600
9S 96W	2,500,960
Total:	7,819,053,970

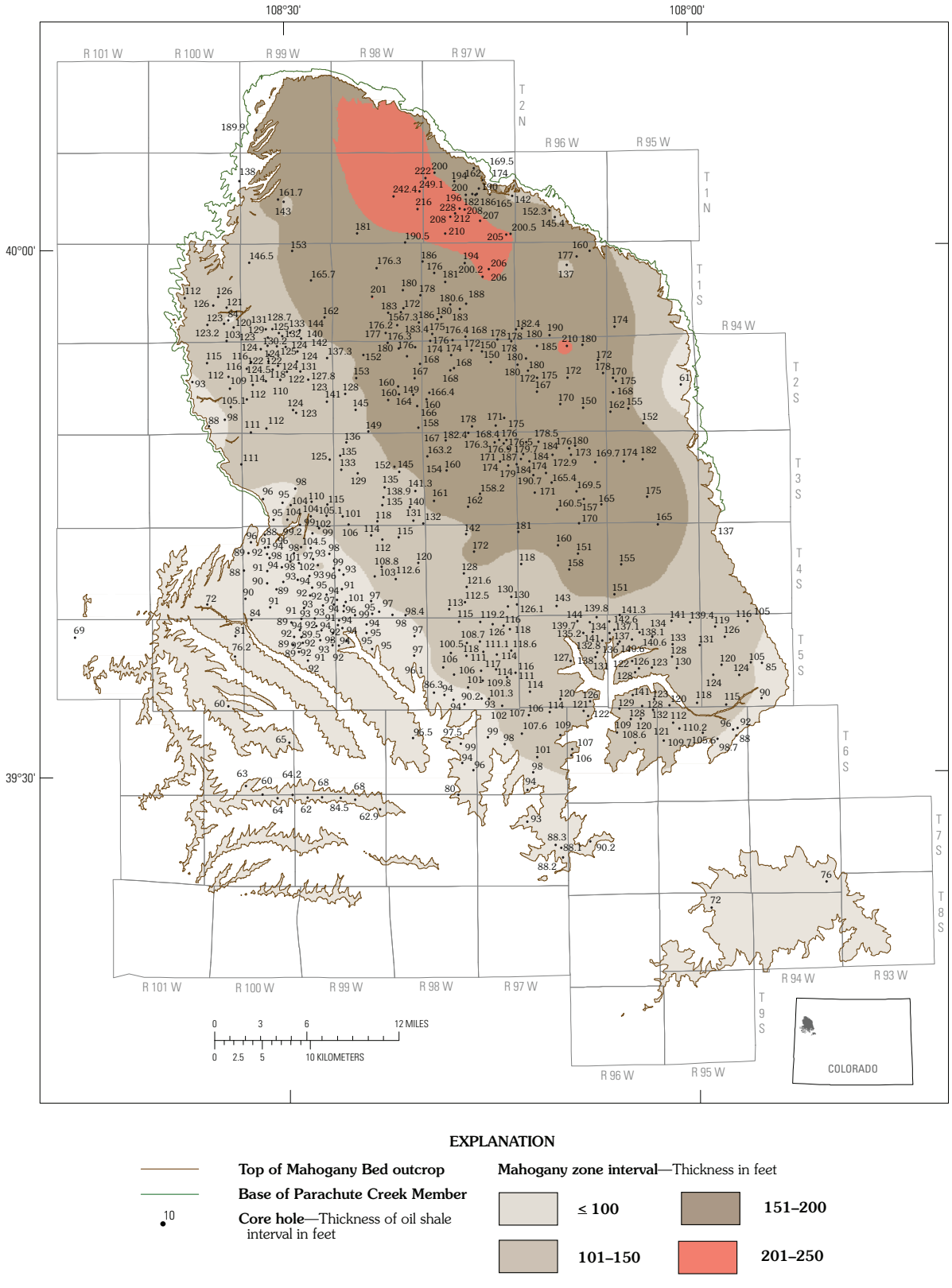


Figure 97. Isopach map of the Mahogany zone using both core hole and rotary hole data. The Radial Basis Function Method (RBF) was used for contouring. Contour interval in feet is variable.

A-Groove

A-groove represents another comparatively thin interval, similar to B-groove that contains low oil yields. Three hundred eighty four core holes were used to assess A-groove here, with an additional 36 rotary holes use for the isopach map. A-groove has never been assessed before. It varies from 5 to 25 ft throughout most of the basin (fig. 101), and thickens to the north to 71 ft in one control point about eight miles south of the mouth of Yellow Creek in the north-central part of the basin. A-groove could not be identified in outcrop near the mouth of Yellow Creek.

Oil yields for A-groove vary from less than 1 GPT to about 22 GPT in a highly irregular fashion (fig. 102). Total in-place oil also shows a high degree of irregularity, but in general, in-place oil is highest along approximately the same southeast-trending area where in-place oil was highest for the underlying Mahogany zone (fig. 103). This southeast-trending area of high in-place oil is also reflected in the map showing total barrels of oil in B-groove for each township (fig. 104). Total in-place oil in A-groove is estimated to be nearly 6.3 billion barrels (table 25).

The Interval Above A-Groove

The interval above A-groove is complex with marlstones and oil shales of the Green River Formation intertonguing with volcanic-rich sandstone and siltstone of the Uinta Formation (figs. 3, 105). The interval represents the infilling stage of Lake Uinta, when the Piceance Basin part of the lake was largely, if not completely, filled in. Thick wedges of volcaniclastic sediments derived from the Absaroka volcanic field in northwestern Wyoming prograded from north to south across the Piceance Basin starting from a point source near the mouth of Yellow Creek in the north-central part of the basin (Johnson, 1981a; 1985) (fig. 3). The southward progradation of these volcaniclastics occurred over a significant period of time, with intervals of oil shale deposited during periods when the rate of volcaniclastics supplied to the basin from the north diminished or ceased entirely. These oil shale intervals coalesce towards the south end of the basin as the intervening clastic wedges pinch out creating a nearly continuous interval of oil shale several hundred feet thick in the southern part of the basin (fig. 3).

Only the interval from the top of A-groove to the top of bed 44 of Donnell (2008) is assessed here, although there is clearly significant oil shale above this interval in the southernmost part of the basin (fig. 105). The interval above bed 44 is complexly intertongued with the Uinta Formation, and is not assessed here. As previously mentioned, Pitman and Donnell (1973) also assessed the interval from the top of A-groove to the top of bed 44 and estimated that it contained 128.5 billion barrels of oil in place. They subdivided the interval into four units that were assessed separately. In this report the entire interval is assessed as a single unit. Pitman and Donnell (1973) did not define the exact area that was assessed, but their assessment did not apparently extend as far north as our assessment of this interval here.

Figure 106 is an isopach map of the interval from the top of A-groove to the top of the "Big Three" oil shale beds of Cashion and Donnell (1972) or bed 44 of Donnell (2008). The map used a significant number of previously unpublished surface points that were used by Johnson (1981a) when he created an isopach map for the interval from the base of A-groove or top of the Mahogany zone to the top the Thirteenmile Creek Tongue of the Green River Formation (Johnson, 1981a, his fig. 2), the top of which is just slightly above the top of bed 44 (fig. 105). The interval includes much of the richest oil shale above the Mahogany zone, but there is clearly significant oil shale above the top of bed 44 particularly in the southernmost part of the basin (fig. 105). The interval thickens from about 150 ft along the southwest margin of the basin to over 1,500 ft in the north-central part of the basin (fig. 106) where it consists of predominantly volcaniclastic sandstone with a few thin zones of marlstone. The interval is similar to the one isopached by Johnson (1981a, his fig. 2) but does not include A-groove.

Typically only part of this interval is cored and assayed, thus some additional points from partial cored intervals were added to constrain the resource maps. Six core holes were used, and for these six core holes data had to be assigned to the missing intervals based on geologic inference. In core holes C0011 and C0158 only the lower part of the Thirteenmile Creek Tongue of the Green River Formation was cored. The tongue was assumed to be 90 ft thick and averaged 10 GPT based on C0176 in sec. 21, T. 3 S., R. 96 W. where the entire tongue was cored and assayed. In C0176 the tongue averages about 12–13 GPT, but based on the partial interval of the Thirteenmile Creek Tongue in core holes C0011 and C0158 the tongue is somewhat leaner in these two core holes. The top of bed 44 is estimated to be at 550 ft in C0174 based on surface mapping and sample descriptions. The assayed interval in C0174 begins at 900 ft, but visual estimates of oil yields were made for the interval from 500 ft to 900 ft by the geologist processing the core. These visual estimates are clearly approximations, but these are the only data available and are used here. In C0034, the top of bed 44 or the Thirteenmile Creek Tongue is 420 ft above the well bore based on surface mapping. This interval is largely sandstone, and thus it is assumed that it contains only a trace of oil. In C0293, the top of the Thirteenmile Creek Tongue is at about 125 ft in the hole based on surface mapping. In C0035, the top of the Thirteenmile Creek Tongue is assumed to be at 150 ft based on surface mapping. Assays start at 315 ft, and the interval from 150 to 315 ft is assumed to contain only a trace of oil.

Estimated oil yield for the interval varies from about 16 GPT to 22 GPT throughout much of the south central part of the basin with oil yields dropping off rapidly to the north, as the interval becomes intertongued with the Uinta Formation, and more gradually to the east, south, and west, due to an overall decrease in oil yields (fig. 107). In-place oil varies

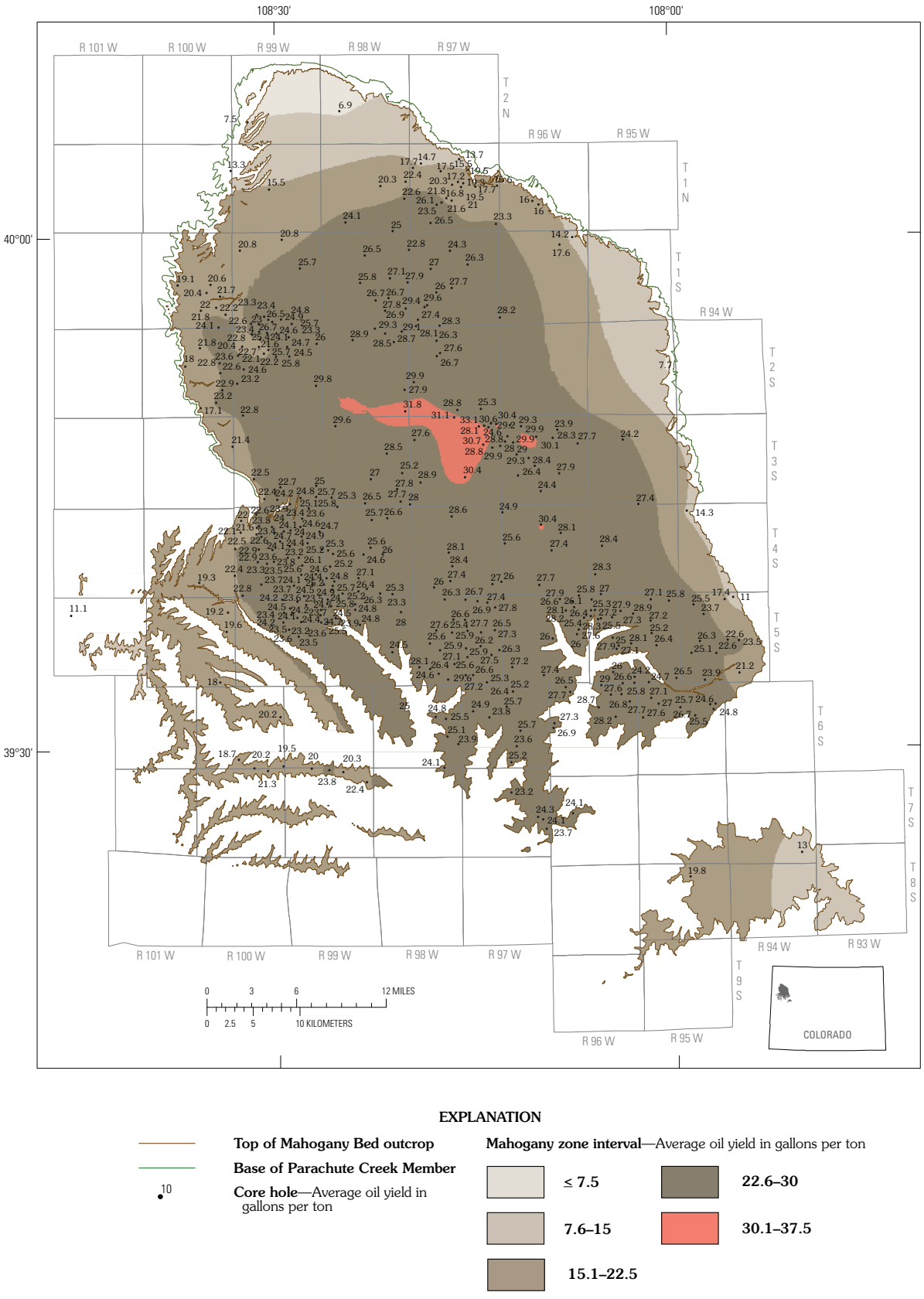


Figure 98. Isoresource map of the Mahogany zone showing the oil yield in gallons per ton (GPT). The Radial Basis Function Method (RBF) was used for contouring.

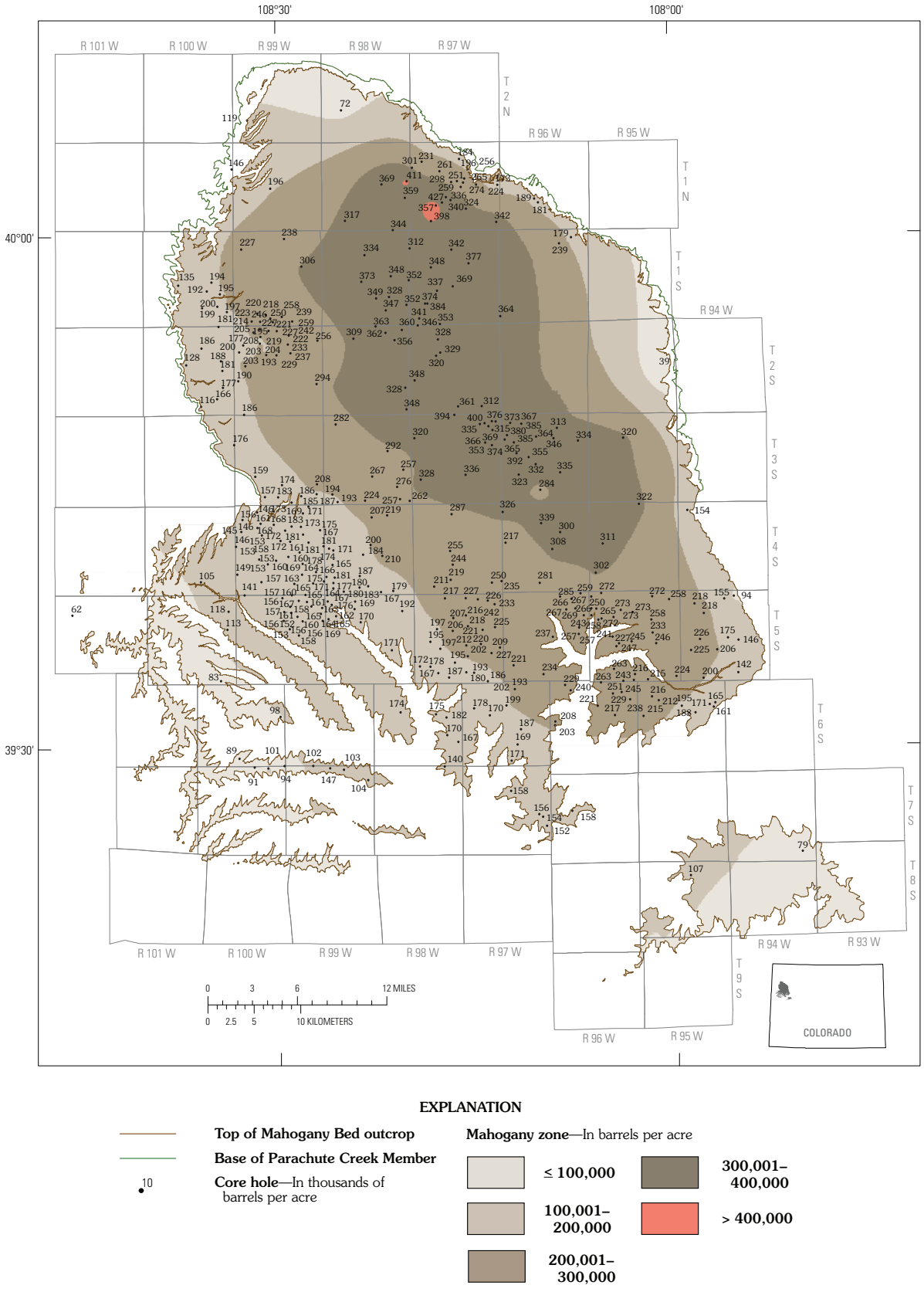


Figure 99. Isoresource map of the Mahogany zone showing oil yields in barrels per acre (BPA). The Radial Basis Function Method (RBF) was used for contouring.

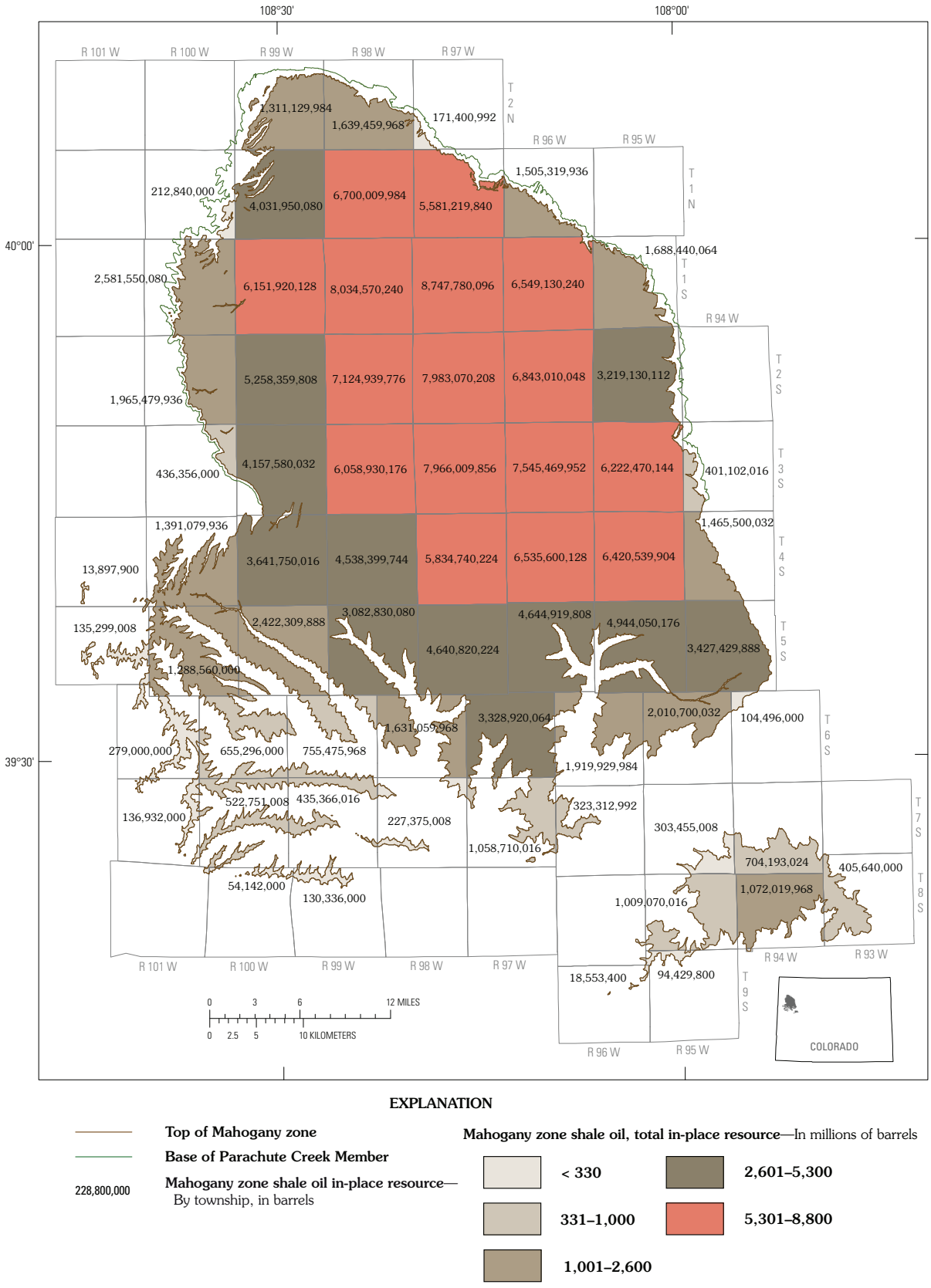


Figure 100. Isoresource map of the Mahogany zone showing total number of barrels of oil in each township using only core hole data.

Table 24. Total number of in-place barrels of oil per acre (BPA) in each township for the Mahogany zone calculated here using the Radial Basis Function Method (RBF). Results for the Mahogany zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.

Township, Range	SUM Mhg, no rotary holes	"Extrapolated" Pitman and others, (1989)	Difference	Percent difference
1N 96W	1,505,320,000	1,503,776,000	1,544,000	0
1N 97W	5,581,220,000	5,097,122,000	484,098,000	9
1N 98W	6,700,010,000	5,740,681,000	959,329,000	17
1N 99W	4,031,950,000	3,464,872,000	567,078,000	16
1N 100W	212,840,000	167,481,000	45,359,000	27
2N 97W	171,401,000	161,069,000	10,332,000	6
2N 98W	1,639,460,000	1,053,367,000	586,093,000	56
2N 99W	1,311,130,000	786,834,000	524,296,000	67
2N 100W				
1S 95W	1,688,440,000	1,272,147,000	416,293,000	33
1S 96W	6,549,130,000	6,108,594,000	440,536,000	7
1S 97W	8,747,780,000	8,349,431,000	398,349,000	5
1S 98W	8,034,570,000	7,472,206,000	562,364,000	8
1S 99W	6,151,920,000	5,812,983,000	338,937,000	6
1S 100W	2,581,550,000	2,044,619,000	536,931,000	26
2S 94W				
2S 95W	3,219,130,000	2,557,731,000	661,399,000	26
2S 96W	6,843,010,000	6,378,481,000	464,529,000	7
2S 97W	7,983,070,000	7,680,361,000	302,709,000	4
2S 98W	7,124,940,000	6,869,942,000	254,998,000	4
2S 99W	5,258,360,000	5,234,224,000	24,136,000	0
2S 100W	1,965,480,000	1,767,740,000	197,740,000	11
3S 94W	401,102,000	226,265,000	174,837,000	77
3S 95W	6,222,470,000	4,835,740,000	1,386,730,000	29
3S 96W	7,545,470,000	7,098,816,000	446,654,000	6
3S 97W	7,966,010,000	7,447,163,000	518,847,000	7
3S 98W	6,058,930,000	5,819,722,000	239,208,000	4
3S 99W	4,157,580,000	4,160,823,000	-3,243,000	0
3S 100W	436,356,000	425,763,000	10,593,000	2
4S 94W	1,465,500,000	1,281,420,000	184,080,000	14
4S 95W	6,420,540,000	5,918,413,000	502,127,000	8
4S 96W	6,535,600,000	6,255,423,000	280,177,000	4
4S 97W	5,834,740,000	5,708,767,000	125,973,000	2
4S 98W	4,538,400,000	4,538,500,000	-100,000	0
4S 99W	3,641,750,000	3,540,981,000	100,769,000	3
4S 100W	1,391,080,000	1,104,739,000	286,341,000	26
4S 101W	13,897,900	8,142,000	5,755,900	71
5S 94W	3,427,430,000	3,123,880,000	303,550,000	10
5S 95W	4,944,050,000	4,443,359,000	500,691,000	11
5S 96W	4,644,920,000	4,440,714,000	204,206,000	5
5S 97W	4,640,820,000	4,474,505,000	166,315,000	4

Table 24. Total number of in-place barrels of oil per acre (BPA) in each township for the Mahogany zone calculated here using the Radial Basis Function Method (RBF). Results for the Mahogany zone from Pitman and others (1989) using manual extrapolation and kriging are also listed with percent difference using the RBF method here. Townships highlighted in yellow are those in which kriging by Pitman and others (1989) indicated an error of 20 percent or less at the at the 95 percent confidence level.—Continued

Township, Range	SUM Mhg, no rotary holes	"Extrapolated" Pitman and others, (1989)	Difference	Percent difference
5S 98W	3,082,830,000	2,759,827,000	323,003,000	12
5S 99W	2,422,310,000	2,185,995,000	236,315,000	11
5S 100W	1,288,560,000	1,028,917,000	259,643,000	25
5S 101W	135,299,000	114,055,000	21,244,000	19
6S 94W	104,496,000	106,495,000	-1,999,000	-2
6S 95W	2,010,700,000	1,750,875,000	259,825,000	15
6S 96W	1,919,930,000	1,856,525,000	63,405,000	3
6S 97W	3,328,920,000	3,251,134,000	77,786,000	2
6S 98W	1,631,060,000	1,331,957,000	299,103,000	22
6S 99W	755,476,000	661,725,000	93,751,000	14
6S 100W	655,296,000	544,470,000	110,826,000	20
6S 101W	279,000,000	154,240,000	124,760,000	81
7S 93W	560,240			
7S 94W	704,193,000	461,287,000	242,906,000	53
7S 95W	303,455,000	1,030,937,000	-727,482,000	-71
7S 96W	323,313,000	252,052,000	71,261,000	28
7S 97W	1,058,710,000	391,432,000	667,278,000	170
7S 98W	227,375,000	390,007,000	-162,632,000	-42
7S 99W	435,366,000	90,079,000	345,287,000	383
7S 100W	522,751,000			
7S 101W	136,932,000			
8S 93W	405,640,000			
8S 94W	1,072,020,000			
8S 95W	1,009,070,000			
8S 96W	11,006,200			
8S 99W	130,336,000	130,982,000	-646,000	0
8S 100W	54,142,000	64,696,000	-10,554,000	-16
8S 101W	5,344,020	3,077,000	2,267,020	74
9S 94W	2,250,500			
9S 95W	94,429,800			
9S 96W	18,553,400			
Sum:	191,716,681,060	172,937,560,000		

Sum of townships used in both assessments	188,443,467,920
Percent higher this assessment	8.97
Best townships this assessment	43,344,160,000
Best townships previous assessment	41,242,220,000
Percent difference	5.10

Table 25. Total number of in-place barrels of oil per acre (BPA) in each township for A-groove calculated here using the Radial Basis Function Method (RBF).

Township, Range	SUM A-Groove
1N 96W	27,325,600
1N 97W	102,764,000
1N 98W	173,953,000
1N 99W	160,764,000
1N 100W	8,491,410
2N 97W	3,881,950
2N 98W	81,503,600
2N 99W	86,044,300
1S 95W	118,608,000
1S 96W	305,327,000
1S 97W	265,201,000
1S 98W	189,827,000
1S 99W	161,456,000
1S 100W	89,708,200
2S 94W	
2S 95W	194,306,000
2S 96W	281,241,000
2S 97W	228,800,000
2S 98W	139,030,000
2S 99W	140,256,000
2S 100W	63,972,700
3S 94W	18,355,000
3S 95W	180,307,000
3S 96W	203,941,000
3S 97W	176,088,000
3S 98W	178,398,000
3S 99W	180,859,000
3S 100W	15,663,800
4S 94W	98,852,300
4S 95W	198,158,000
4S 96W	180,224,000
4S 97W	150,252,000
4S 98W	148,461,000
4S 99W	137,507,000
4S 100W	57,933,300
4S 101W	632,008
5S 94W	150,121,000
5S 95W	164,825,000
5S 96W	116,492,000
5S 97W	133,574,000
5S 98W	98,785,300
5S 99W	90,309,600
5S 100W	67,244,000
5S 101W	7,936,200
6S 94W	4,110,210
6S 95W	71,477,200
6S 96W	45,456,200
6S 97W	87,814,100
6S 98W	49,263,200
6S 99W	23,809,500
6S 100W	36,409,300
6S 101W	19,021,900
7S 93W	37,909
7S 94W	59,871,200
7S 95W	14,211,200
7S 96W	9,194,890
7S 97W	33,481,600
7S 98W	14,512,700
7S 99W	26,374,100
7S 100W	30,199,900
7S 101W	8,608,690
8S 93W	45,042,000
8S 94W	79,982,000
8S 95W	28,895,200
8S 96W	278,680
8S 99W	10,060,000
8S 100W	3,889,010
8S 101W	396,943
9S 94W	119,303
9S 95W	2,612,740
9S 96W	586,794
Total	6,283,095,737

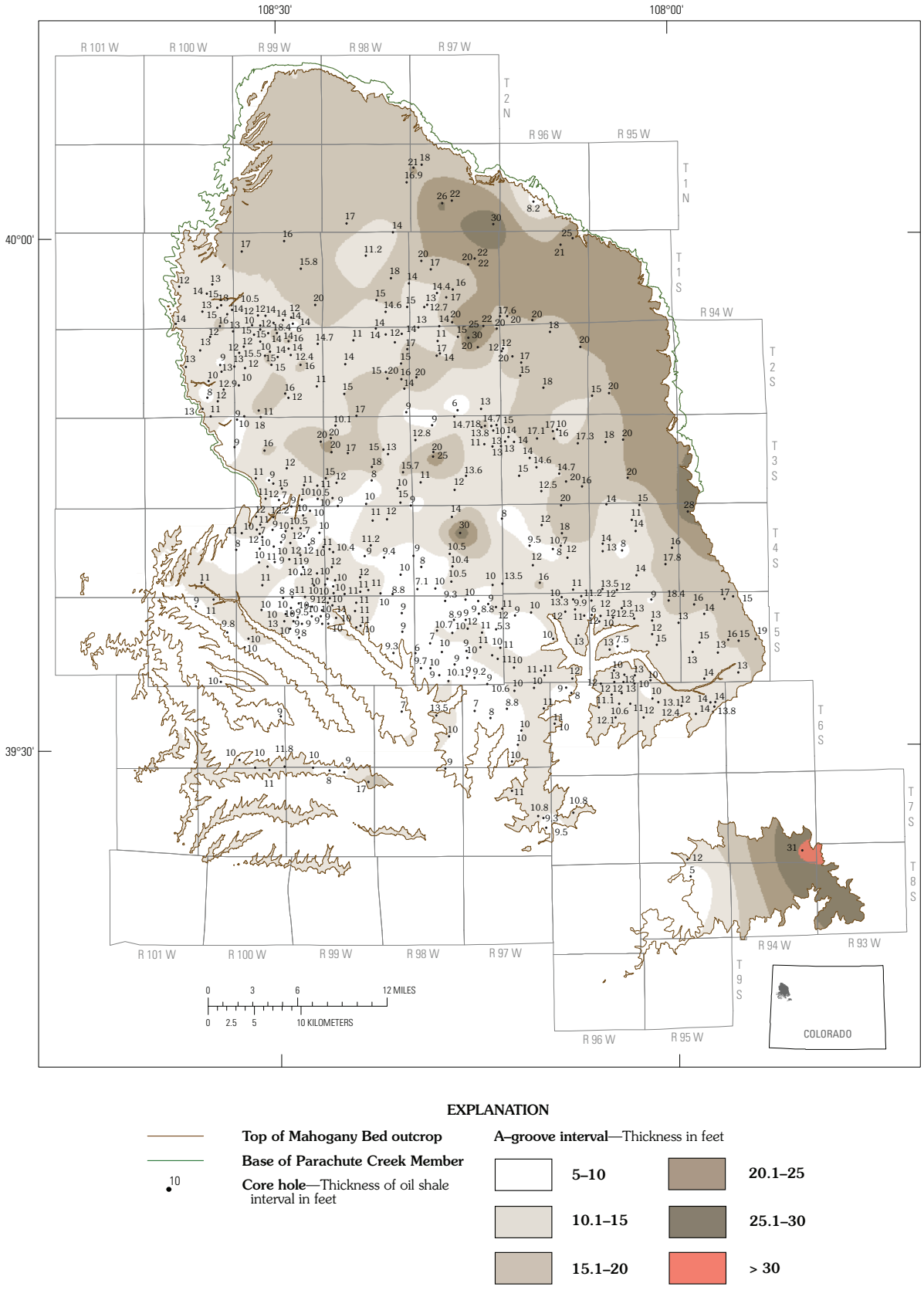


Figure 101. Isopach map of A-groove using both core hole and rotary hole data. The Radial Basis Function Method (RBF) was used for contouring.

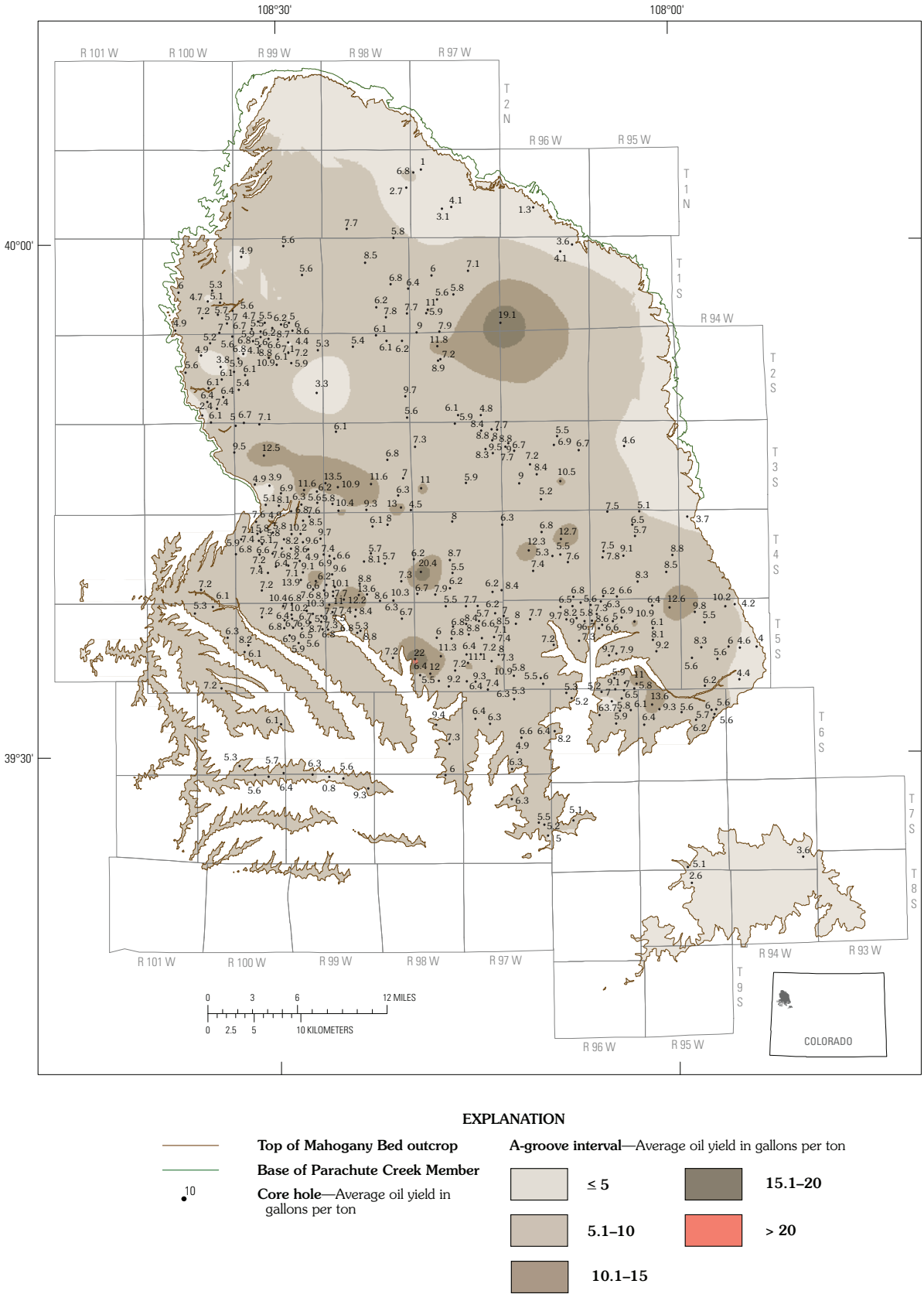


Figure 102. Isoresource map of A-groove showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

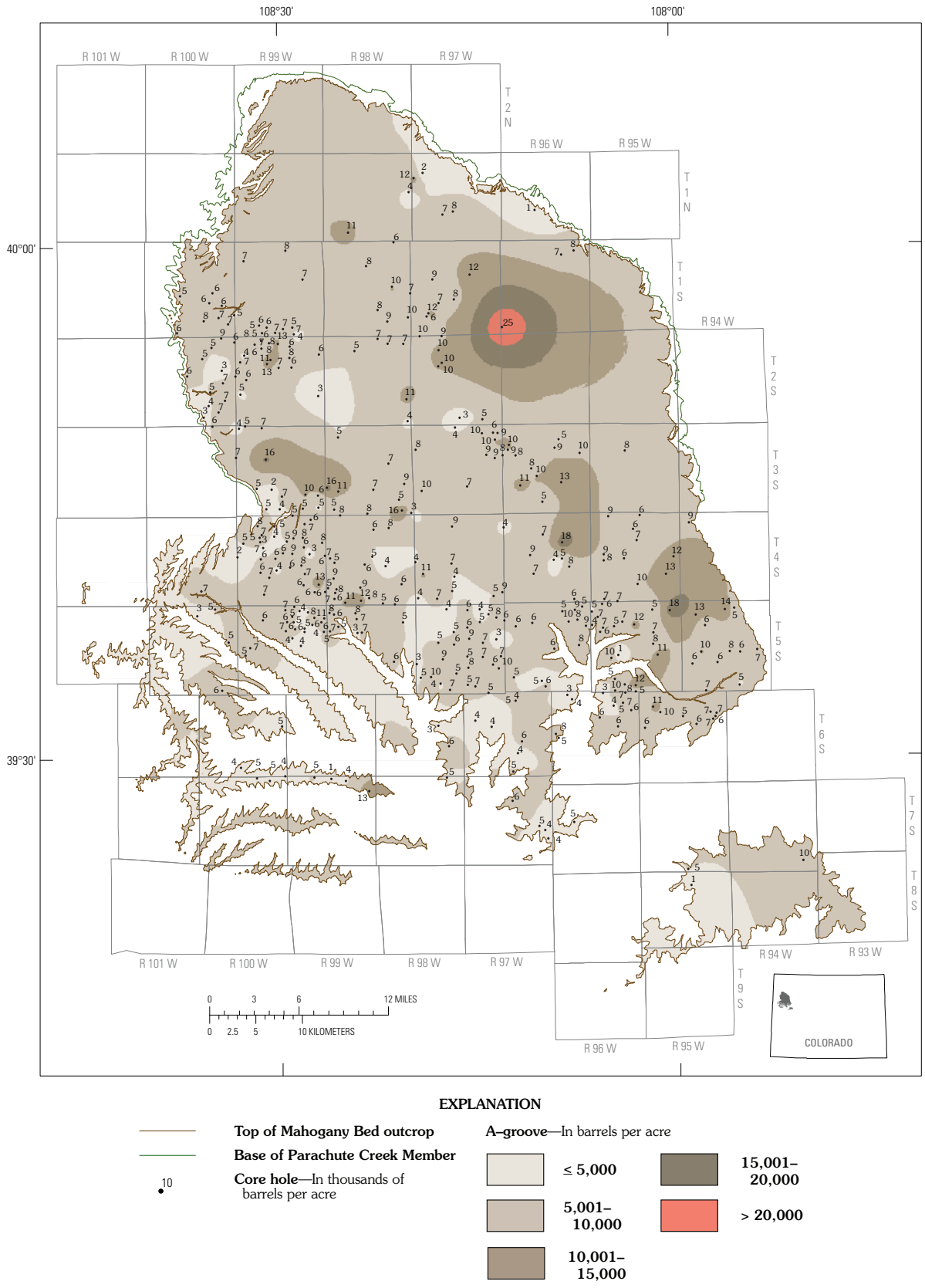


Figure 103. Isoresource map of A-groove showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used for contouring.

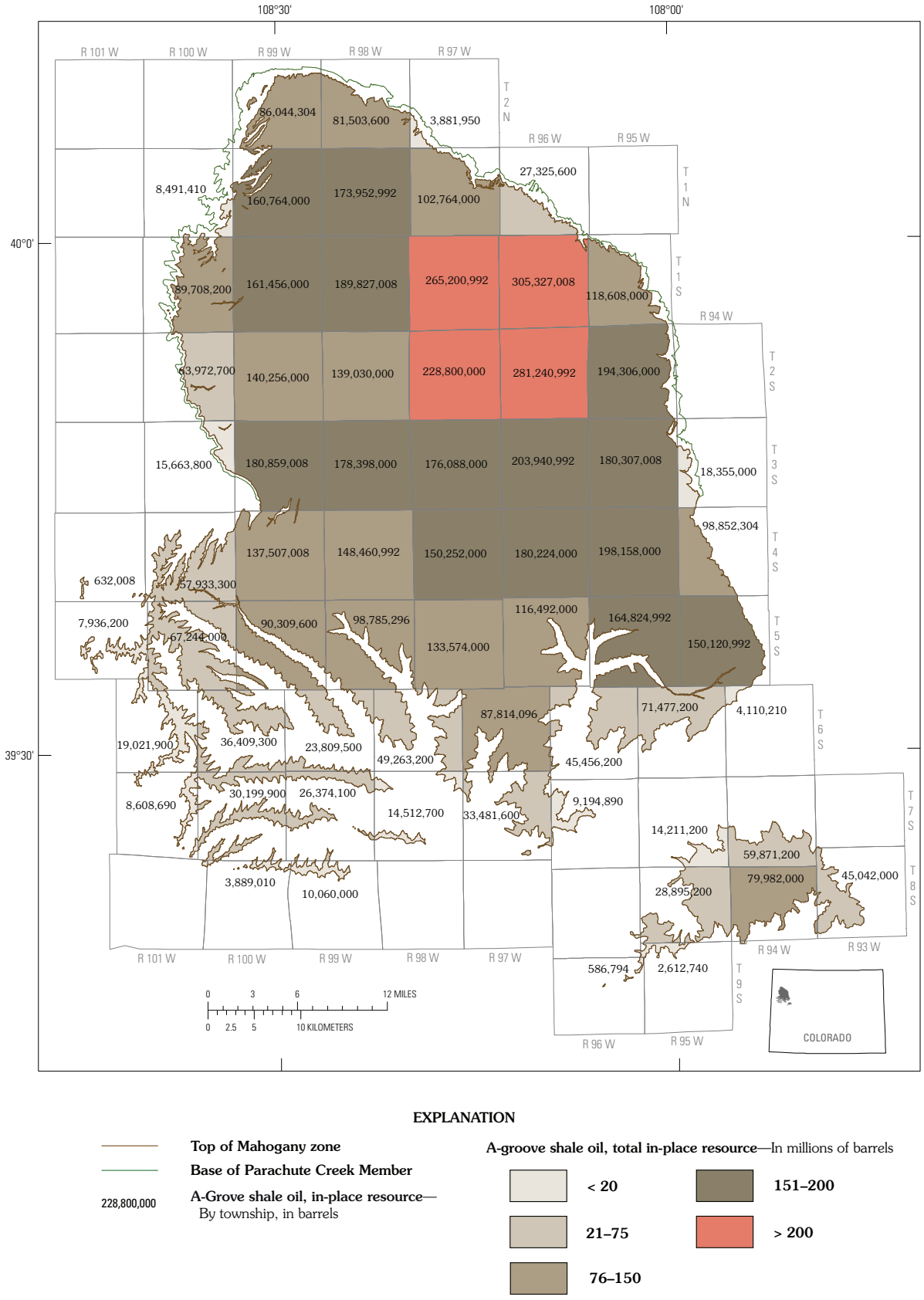


Figure 104. Isoresource map of A-groove showing total number of barrels of oil in each township using only core hole data.

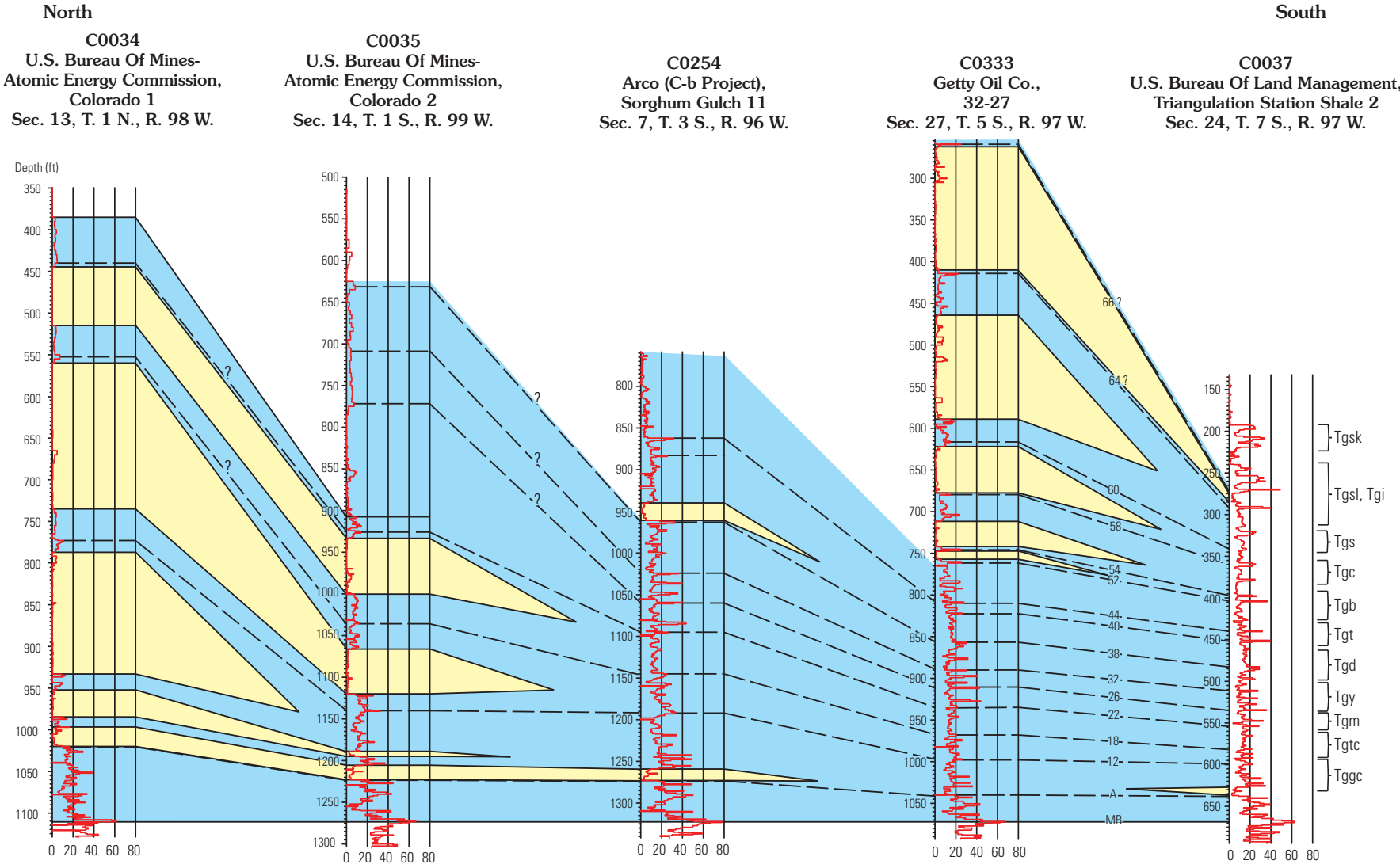


Figure 105. Detailed north-south cross section showing the intertonguing of the Uinta Formation (yellow) with the upper part of the Green River Formation in the Piceance Basin, Colorado (blue) (from Donnell, 2008). Abbreviations used: MB, Mahogany bed; A, base of A-groove; Tggc, Marlstone at Greasewood Creek; Tgtc, Marlstone at Trail Canyon; Tgm, Marsltone at Mare Canyon; Tgy, Yellow Creek Tongue; Tgd, Dry Fork Tongue; Tgt, Thirteenmile Creek Tongue; Tgb, Black Sulfur Tongue; Tgc, Cough's Creek Tongue; Tgs, Stewart Gulch Tongue; Tgsl, Tgi, Marlstone at Barnes Ridge and Marder bed at Bull Fork; Tgsk, Marlstone at Skinner Ridge. Numbers between C0333 and C0037 are persistent oil shale beds defined by Donnell (2008).

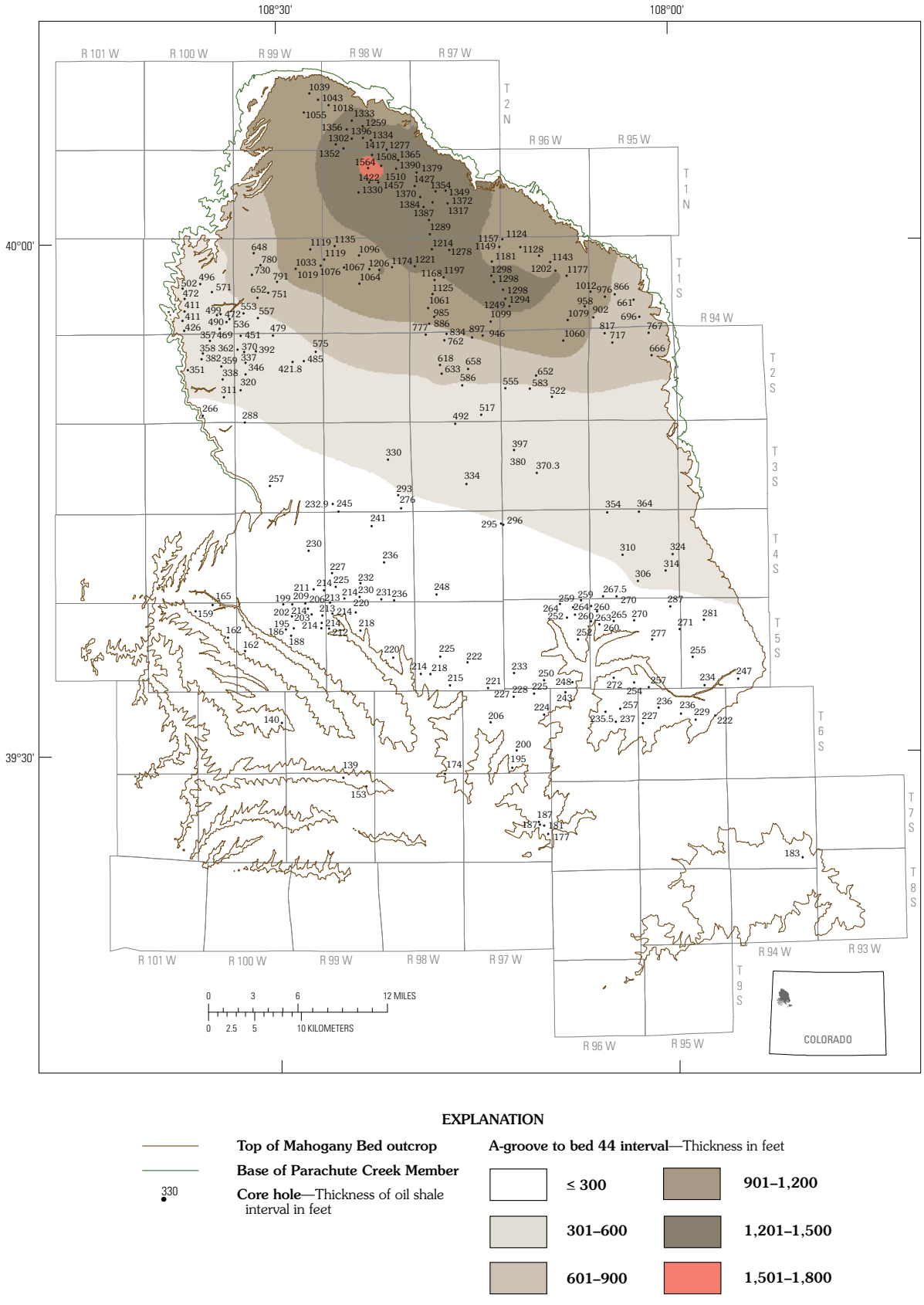


Figure 106. Isopach map of Bed 44 to A-groove using both core hole and rotary hole data. The Radial Basis Function Method (RBF) was used for contouring.

from 375,000 to 475,000 BPA in this area and diminishes in a more-or-less radial pattern outward (fig. 107). Interestingly, the area with maximum in-place oil is about 12 miles to the north of the area with maximum oil yields (figs. 107 and 108). Maximum in-place oil in a township is over 10 billion barrels in T. 2 S., R. 97 W. (fig. 109). Figures 107 and 108 show total in-place oil assuming that the entire assessed interval is preserved. However, the interval crops out in the townships north of the blue line in figure 109, and thus the interval is only partially preserved. The outcrop pattern for this interval in this area is highly complex, and it is difficult to assess exactly how much of the oil shale is preserved. As a result, we included only those townships south of this line in the final assessment (table 26). Total in-place oil in the interval from the top of A-groove to bed 44 of Donnell (2008) is estimated to be nearly 186.6 billion barrels (table 26). This is nearly as much oil in place as in the Mahogany zone (table 24).

Discussion

This study presents a comprehensive assessment of in-place oil in the Green River Formation of the Piceance Basin that includes most oil shale zones and nearly all the oil-shale-bearing part of the Piceance Basin. Total in-place oil for all zones assessed using oil core-hole data is over 1.5 trillion barrels (table 27), making the oil shale deposits of the Piceance Basin by far the largest oil shale deposit in the world (see Dyni, 2003). Total in-place oil in each township in the Piceance Basin is shown on Figure 110 and listed in table 28. Maximum in-place oil in a township is over 74.4 billion barrels in T. 2 S., R. 97 W. Most of the increase over the previous assessment of just over one trillion barrels (Pitman and others, 1989) is due to: 1) areas being assessed here that had too little data to assess in the previous assessment, and 2) intervals being assessed here that were not assessed previously: R-0 zone, A-groove, B-groove, and the interval above A-groove. Some of the differences in the results are from the townships around the basin margins where Pitman and others (1989) appear to have only calculated resources to the outcrop of the Mahogany zone, whereas we extended the assessment outward to the base of the Parachute Creek Member for the lower oil shale zones. These increases are limited, because oil yields for most of the oil shale zones are quite low in the marginal areas.

Using only those townships and those oil shale zones that were assessed both here and by Pitman and others (1989) the assessment presented here is 8.86 percent higher than the manually extrapolated assessment and 4.83 percent higher than the kriged assessment of Pitman and others (1989). If only the best townships are used, the assessment presented here is 5.87 percent higher than the manually extrapolated assessment and 6.27 percent higher than the kriged assessment of Pitman and others (1989) (table 29). Our results are higher for all the oil shale zones assessed here and by Pitman and others (1989) except for the L-2 zone where our results were 0.41 percent lower than theirs using manual extrapolation in only the townships with the most control. These slightly higher results for our assessment appear to be largely the result of the method used to convert GPT into BPA. As shown for the R-5 and L-5 zones, our barrels-per-acre calculations for the same core holes are overall somewhat higher than those of Pitman and others (1989). Because Pitman and others (1989) did not publish the formula that they used to convert GPT to BPA, we cannot explore the causes of this consistent but fairly minor discrepancy. Using the Access form presented in Mercier and others (chapter 3, this CD-ROM), future workers could easily insert a different formula for this conversion and calculate different in-place resources.

In-place resources in the leached zone have almost certainly been overestimated in this assessment as well as in previous assessments because the void space created by the leaching of saline minerals was not taken into account. This void space can occur in collapse breccias, formed by the collapse of overlying rock once a thick halite and nahcolite bed has been leached out, and vugs and other void spaces formed by the leaching of nahcolite aggregates and disseminated nahcolite. The volume of this void space is not measured prior to submitting samples for Fischer assay, and it does not appear that the amount of void space in core has been systematically recorded in the past. Evaluating void space in the leached zone may require a re-examination of a significant amount of the core taken of the leached zone.

Although we assessed more intervals and more areas than previous assessments, there are still significant intervals that have yet to be assessed in this remarkably hydrocarbon-rich basin. The interval from A-groove to bed 44 was assessed only in townships where the interval is complete, and the interval above bed 44 was not assessed at all, yet it contains significant resources in the southern part of the basin. There is also a significant thickness of low-grade oil shale in the Cow Ridge Member of the Green River Formation that was not assessed. The Cow Ridge Member was deposited in the freshwater lacustrine lakes that proceeded the development of saline Lake Uinta. About 330 ft of the Cow Ridge Member was cored and assessed in the Humble Oil No. 1 Yellow Creek hole (C-157) in sec. 2, T. 1 S., R. 97 W. where it consists of mostly low-grade oil shale in the range of 5 to 10 GPT.

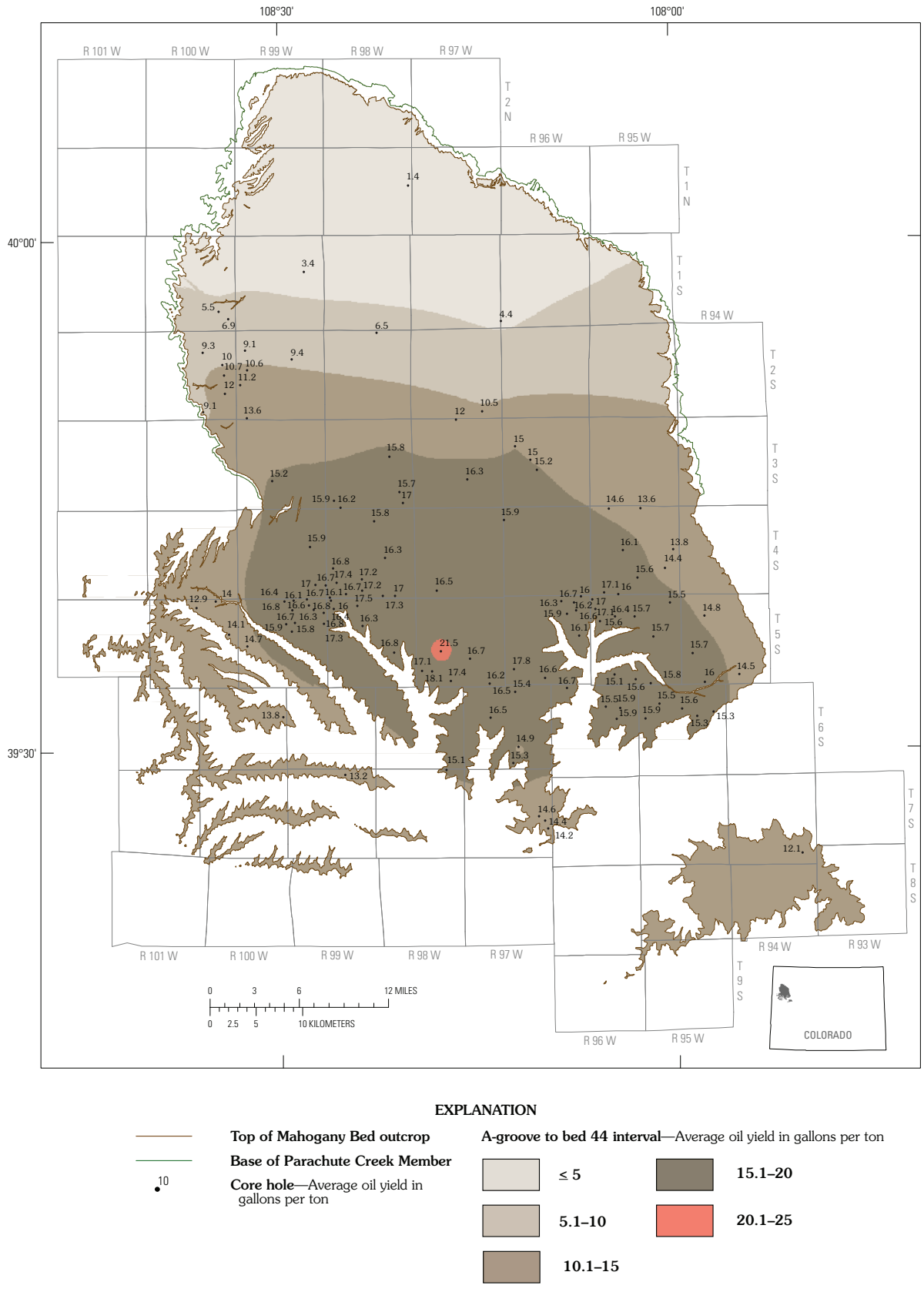


Figure 107. Isoresource map of bed 44 to A-groove showing the oil yield in gallons per ton (GPT) using only core hole data. The Radial Basis Function Method (RBF) was used to construct the map.

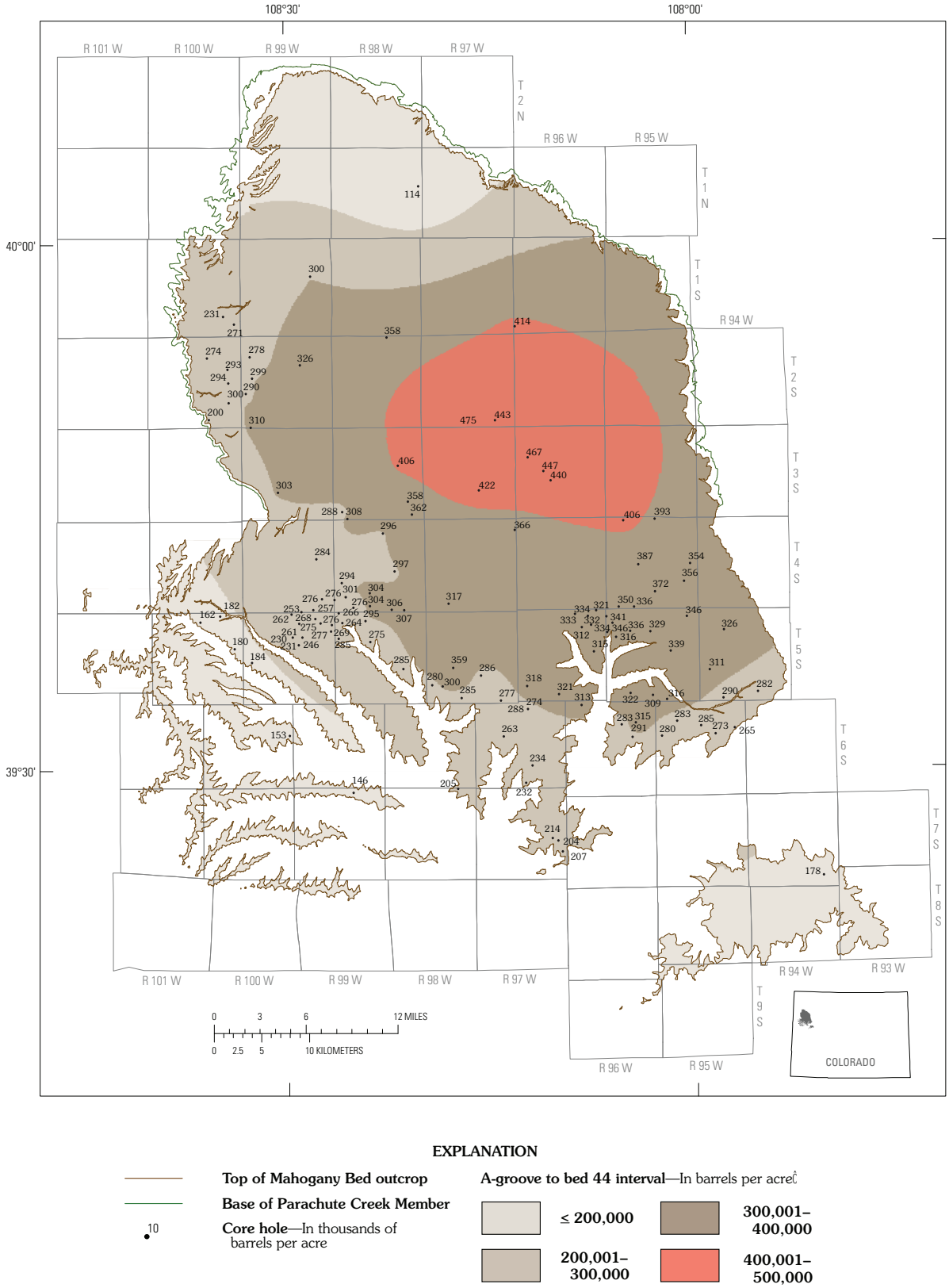


Figure 108. Isoresource map of bed 44 to A-groove showing oil yields in barrels per acre (BPA) using only core hole data. The Radial Basis Function Method (RBF) was used to construct the map.

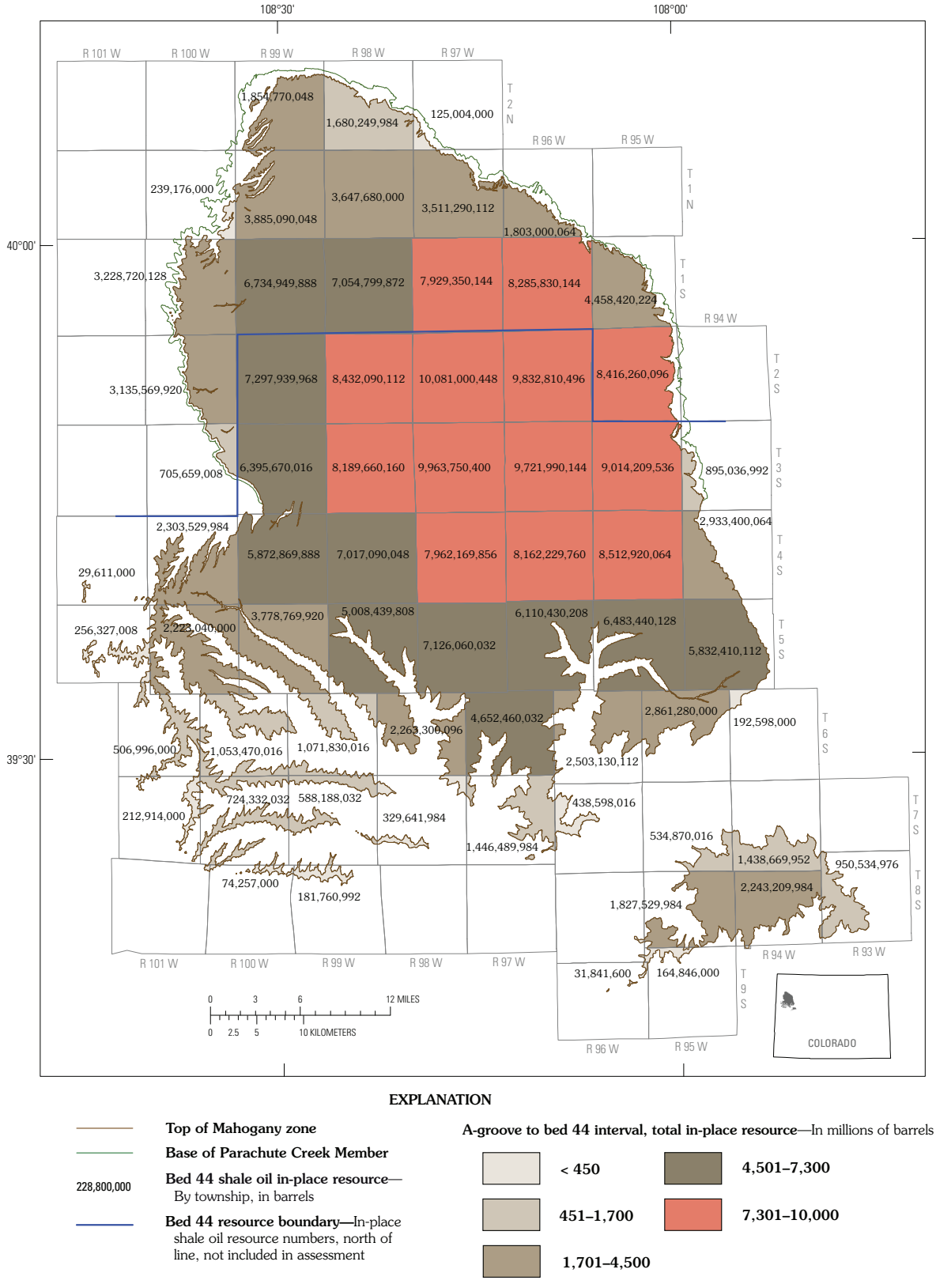


Figure 109. Isoresource map of bed 44 to A-groove showing total number of barrels of oil in each township using only core hole data. The interval is only partially preserved north of the blue line, and because of complexities in determining how much of the original resource is preserved in these townships the resources in these townships were not included in the total.

Table 26. Total number of in-place barrels of oil per acre (BPA) in each township for the interval from the top of A-groove to the top of bed 44 of Donnell (2008) calculated here using the Radial Basis Function Method (RBF).

Township and Range	In-place gas in townships where interval complete
2S 96W	9,832,810,000
2S 97W	10,081,000,000
2S 98W	8,432,090,000
2S 99W	7,297,940,000
3S 100W	705,659,000
3S 94W	895,037,000
3S 95W	9,014,210,000
3S 96W	9,721,990,000
3S 97W	9,963,750,000
3S 98W	8,189,660,000
3S 99W	6,395,670,000
4S 100W	2,303,530,000
4S 101W	29,611,000
4S 94W	2,933,400,000
4S 95W	8,512,920,000
4S 96W	8,162,230,000
4S 97W	7,962,170,000
4S 98W	7,017,090,000
4S 99W	5,872,870,000
5S 100W	2,223,040,000
5S 101W	256,327,000
5S 94W	5,832,410,000
5S 95W	6,483,440,000
5S 96W	6,110,430,000
5S 97W	7,126,060,000
5S 98W	5,008,440,000
5S 99W	3,778,770,000
6S 100W	1,053,470,000
6S 101W	506,996,000
6S 94W	192,598,000
6S 95W	2,861,280,000
6S 96W	2,503,130,000
6S 97W	4,652,460,000
6S 98W	2,263,300,000
6S 99W	1,071,830,000
7S 100W	724,332,000
7S 101W	212,914,000
7S 93W	1,279,450
7S 94W	1,438,670,000
7S 95W	534,870,000
7S 96W	438,598,000
7S 97W	1,446,490,000
7S 98W	329,642,000
7S 99W	588,188,000
8S 100W	74,257,000
8S 101W	8,163,650
8S 93W	950,535,000
8S 94W	2,243,210,000
8S 95W	1,827,530,000
8S 96W	18,650,600
8S 99W	181,761,000
9S 94W	4,525,830
9S 95W	164,846,000
9S 96W	31,841,600
Total	186,467,922,130

Table 27. Total in-place oil for each of the rich and lean oil shale zones in the Piceance Basin, Colorado. Total in-place oil estimated here is 1.52 trillion barrels. Most of the increase from the previous assessment by Pitman and others (1989) is because more townships and more zones were assessed here.

Oil shale zone	Oil in place (barrels)
Top A-groove-top bed 44	186,467,922,130
A-groove	6,283,095,737
Mahogany zone	191,716,681,060
B-groove	7,819,053,970
R-6	185,366,007,632
L-5	66,063,806,739
R-5	198,239,468,346
L-4	69,126,949,762
R-4	127,150,178,615
L-3	22,504,056,571
R-3	68,084,658,284
L-2	24,216,677,409
R-2	66,768,689,056
L-1	15,066,851,989
R-1	195,372,090,899
L-0	8,265,472,203
R-0	83,416,642,063
Total this assessment:	1,521,928,302,463
Total of same townships and zones assessed by Pitman and others (1989):	1,097,395,260,860
Total of new townships and zones assessed here:	424,533,041,603

Table 28. Barrels of in-place oil in each township in the Piceance Basin, Colorado.

Township, Range	Total
1N 100W	6,036,961,940
1N 96W	10,580,261,100
1N 97W	39,786,532,000
1N 98W	58,143,829,000
1N 99W	41,771,811,000
1S 100W	23,930,842,200
1S 95W	15,198,880,300
1S 96W	46,360,433,000
1S 97W	68,166,838,000
1S 98W	73,270,942,000
1S 99W	56,282,758,000
2N 100W	120,362,128
2N 97W	1,941,758,130
2N 98W	18,746,052,600
2N 99W	19,071,980,900
2S 100W	15,478,364,700
2S 94W	352,949,050
2S 95W	27,985,579,500
2S 96W	60,564,766,000
2S 97W	74,430,168,000
2S 98W	69,927,302,000
2S 99W	50,264,972,000
3S 100W	4,139,053,800
3S 94W	3,903,083,700
3S 95W	41,267,276,000
3S 96W	58,561,675,000
3S 97W	64,779,254,000
3S 98W	54,308,290,000
3S 99W	37,246,154,000
4S 100W	10,455,659,900
4S 101W	92,787,637
4S 94W	9,590,565,900
4S 95W	38,640,538,000
4S 96W	46,927,565,000
4S 97W	48,511,796,000
4S 98W	39,030,221,000
4S 99W	29,649,688,000
5S 100W	9,643,476,500
5S 101W	926,068,600
5S 94W	17,091,087,400
5S 95W	27,288,119,300
5S 96W	31,331,184,000
5S 97W	35,112,948,000
5S 98W	24,305,139,500
5S 99W	17,894,381,300
6S 100W	4,468,497,590
6S 101W	1,851,081,510
6S 94W	491,120,802
6S 95W	9,160,820,100
6S 96W	9,832,814,000
6S 97W	20,284,023,500
6S 98W	10,492,102,100
6S 99W	4,977,324,800
7S 100W	2,588,315,790
7S 101W	688,700,410
7S 93W	2,423,814
7S 94W	3,334,217,413
7S 95W	1,289,931,030
7S 96W	1,544,319,410
7S 97W	5,451,079,000
7S 98W	1,347,109,440
7S 99W	2,443,651,270
8S 100W	223,969,841
8S 101W	21,997,678
8S 93W	2,055,713,132
8S 94W	5,019,633,143
8S 95W	4,177,070,568
8S 96W	41,957,336
8S 99W	584,342,600
9S 94W	10,173,846
9S 95W	366,519,671
9S 96W	69,036,584
Grand total	1,521,928,302,462

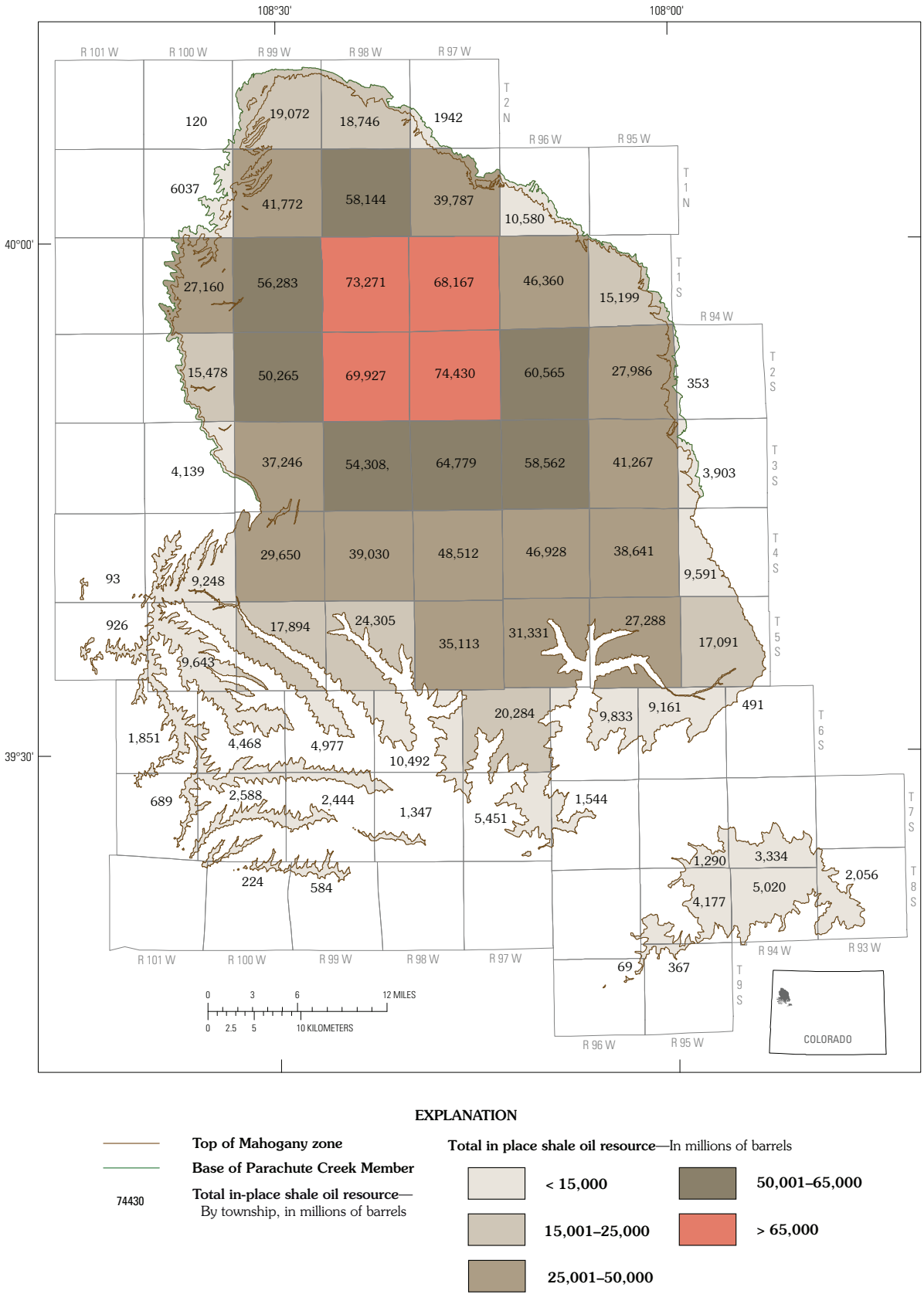


Figure 110. Map showing total in-place oil in millions of barrels for each township in the Piceance Basin, Colorado.

Table 29. Comparing the results of this assessment using the Radial Basis Function Method (RBF) with the results from the previous assessment of Pitman and others (1989) using kriging. Only those townships that were assessed in both assessments are used. When only those townships and zones that were assessed both here and by Pitman and others (1989) are compared, our assessment is 8.86 percent higher than the hand-extrapolated results and 4.83 percent higher than the kriged results of Pitman and others (1989). When only those townships in which kriging by Pitman and others (1989) estimated an error of 20 percent or less are compared, our assessment is 5.87 percent higher than the hand-extrapolated results and 6.27 percent higher than the kriged results of Pitman and others (1989).

	Barrels
Sum all townships used here and in Pitman extrapolation:	1,097,395,260,860
Sum all townships used here and in Pitman kriging:	721,997,242,700
Total Pitman extrapolation:	1,008,089,335,000
Total Pitman kriging:	688,761,145,000
Percent difference using RBF vs extrapolation:	8.86
Percent difference using RBF versus kriging:	4.83
Sum of best townships RBF here and extrapolated:	492,652,335,000
Sum of best townships extrapolated Pitman:	465,350,950,000
Percent difference RBF vs extrapolation best townships:	5.87
Sum of best townships here and kriging Pitman:	420,749,845,000
Sum of best townships kriging Pitman:	395,936,440,000
Percent difference RBF vs kriging best townships:	6.27

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