HETEROGENEOUS SHALLOW-SHELF CARBONATE BUILDUPS IN THE PARADOX BASIN, UTAH AND COLORADO: TARGETS FOR INCREASED OIL PRODUCTION AND RESERVES USING HORIZONTAL DRILLING TECHNIQUES

(Contract No. DE-2600BC15128)

DELIVERABLE 1.1.1
REGIONAL PARADOX FORMATION STRUCTURE AND ISOCHORE MAPS, BLANDING SUB-BASIN, UTAH

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84114
December 2003

Contracting Officer's Representative

Gary D. Walker, Contract Manager
U.S. Department of Energy
National Petroleum Technology Office
1 West 3rd Street
Tulsa, OK 74103-3532

DISCLAIMER

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Kevin McClure,
Craig D. Morgan,
Thomas C. Chidsey, Jr., Principal Investigator/Program Manager,
Utah Geological Survey,
and
David E. Eby, Eby Petrography & Consulting, Inc.,

CONTENTS

FIGURES

TABLE

INTRODUCTION

Over 400 million barrels (64 million m^3) of oil have been produced from the shallow-shelf carbonate reservoirs in the Pennsylvanian (Desmoinesian) Paradox Formation in the Paradox Basin, Utah and Colorado. With the exception of the giant Greater Aneth field, the other 100 plus oil fields in the basin typically contain 2 to 10 million barrels (0.3-1.6 million m^3) of original oil in place. Most of these fields are characterized by high initial production rates followed by a very short productive life (primary), and hence premature abandonment. Only 15 to 25 percent of the original oil in place is recoverable during primary production from conventional vertical wells.

An extensive and successful horizontal drilling program has been conducted in the giant Greater Aneth field (figure 1). However, to date, only two horizontal wells have been drilled in small Ismay and Desert Creek fields. The results from these wells were disappointing due to poor understanding of the carbonate facies and diagenetic fabrics that create reservoir heterogeneity. These small fields, and similar fields in the basin, are at high risk of premature abandonment. At least 200 million barrels (31.8 million m^3) of oil will be left behind in these small fields because current development practices leave compartments of the heterogeneous reservoirs undrained. Through proper geological evaluation of the reservoirs, production may be increased by 20 to 50 percent through the drilling of low-cost single or multilateral horizontal legs from existing vertical development wells. In addition, horizontal drilling from existing wells minimizes surface disturbances and costs for field development, particularly in the environmentally sensitive areas of southeastern Utah and southwestern Colorado.

GEOLOGIC SETTING

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado with a small portion in northeastern Arizona and the northwestern most corner of New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast trending evaporitic basin that predominately developed during the Pennsylvanian (Desmoinesian), about 330 to 310 million years ago (Ma). During the Pennsylvanian, a pattern of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The Uncompahgre Highlands (uplift) is bounded along the southwestern flank by a large basement-involved, high-angle reverse fault identified from geophysical seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest — the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and then continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993). The Paradox Basin is surrounded by other uplifts and basins that formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1).

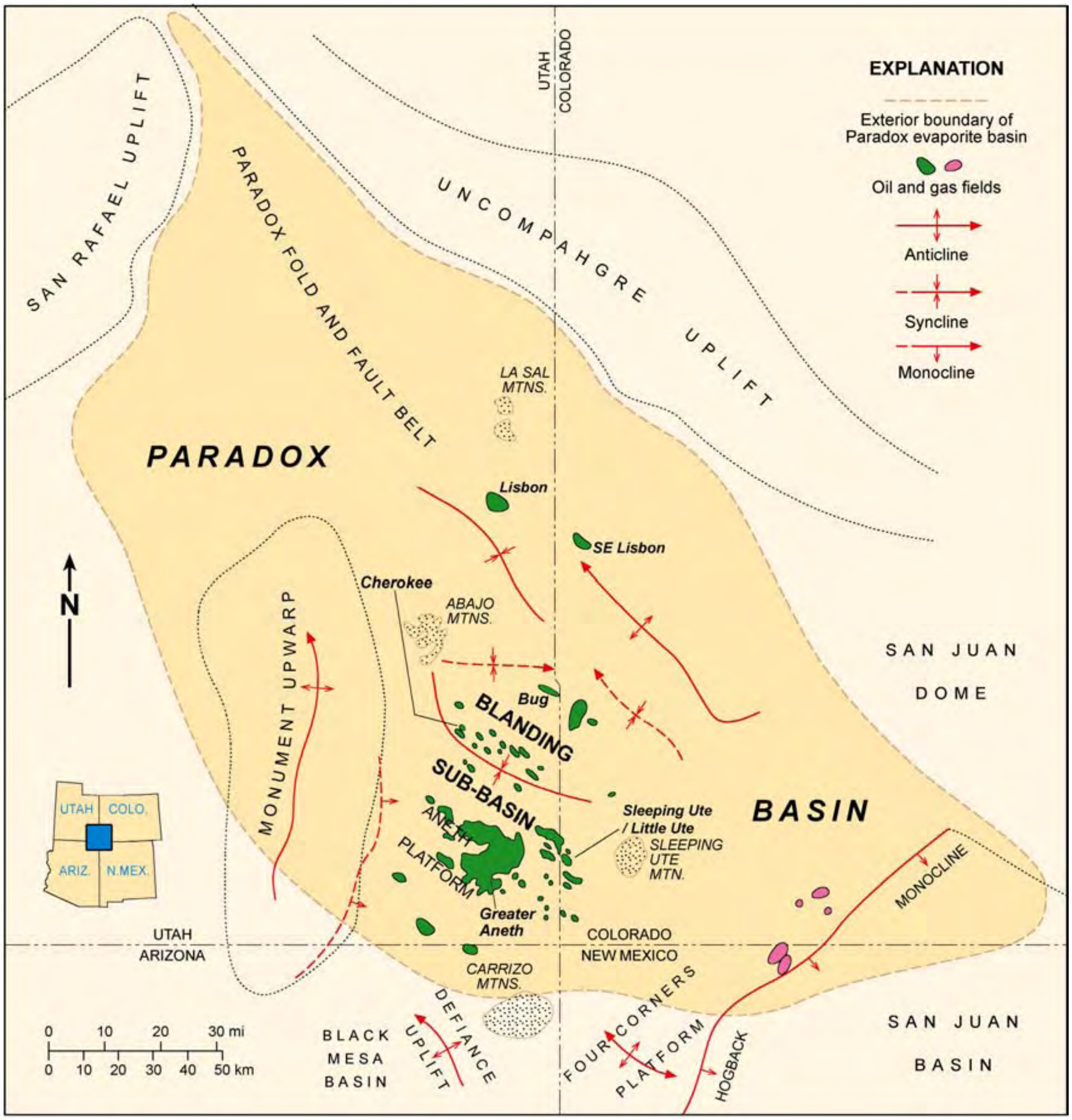


Figure 1. Location map of the Paradox Basin, Utah, Colorado, Arizona, and New Mexico showing producing oil and gas fields, the Paradox fold and fault belt, and Blanding sub-basin as well as surrounding Laramide basins and uplifts (modified from Harr, 1996).

The Paradox Basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the Aneth platform in southeasternmost Utah (figure 1). The relatively undeformed Blanding sub-basin and Aneth platform developed on a subtropical shallow-marine shelf and shelf-margin that locally contained algal-mound and other carbonate facies buildups. The codiacean green algae *Ivanovia* was the dominant genus in the algal buildups of the Paradox Formation. Hydrocarbons are stratigraphically trapped in porous and permeable units within carbonate buildups. These units are effectively sealed by impermeable marine mud and/or anhydrite at the base, flank, and top of the buildup. The source of the oil is several black, organic-rich shales within the Paradox Formation (Hite and others, 1984; Nuccio and Condon, 1996).

The two main producing zones of the Paradox Formation in the Blanding sub-basin are informally named the Ismay and the Desert Creek (figure 2). Reservoirs within the Utah portion of the upper Ismay zone of the Paradox Formation are dominantly limestones composed of small, phylloid-algal buildups; locally variable, inner-shelf, skeletal calcarenites; and rare, open-marine, bryozoan mounds (figure 3A). The Ismay produces oil from fields in the southern Blanding sub-basin (figure 4). The Desert Creek zone is dominantly dolomite comprising regional, nearshore, shoreline trends with highly aligned, linear facies tracts (figure 3B). The Desert Creek produces oil in fields in the central Blanding sub-basin (figure 4). Both the Ismay and Desert Creek buildups generally trend northwest-southeast. Various facies changes and extensive diagenesis have created complex reservoir heterogeneity within these two diverse zones.

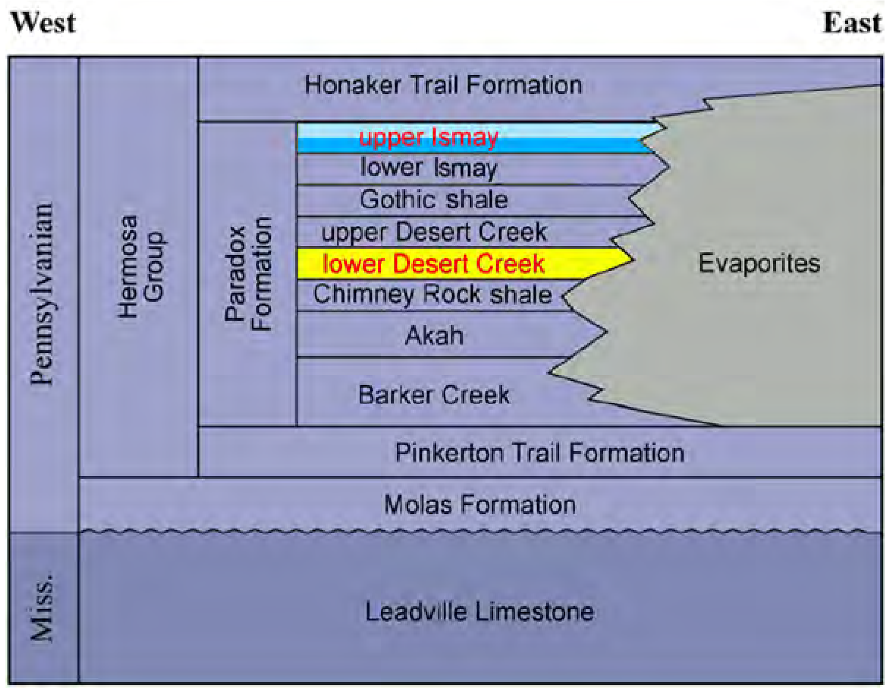
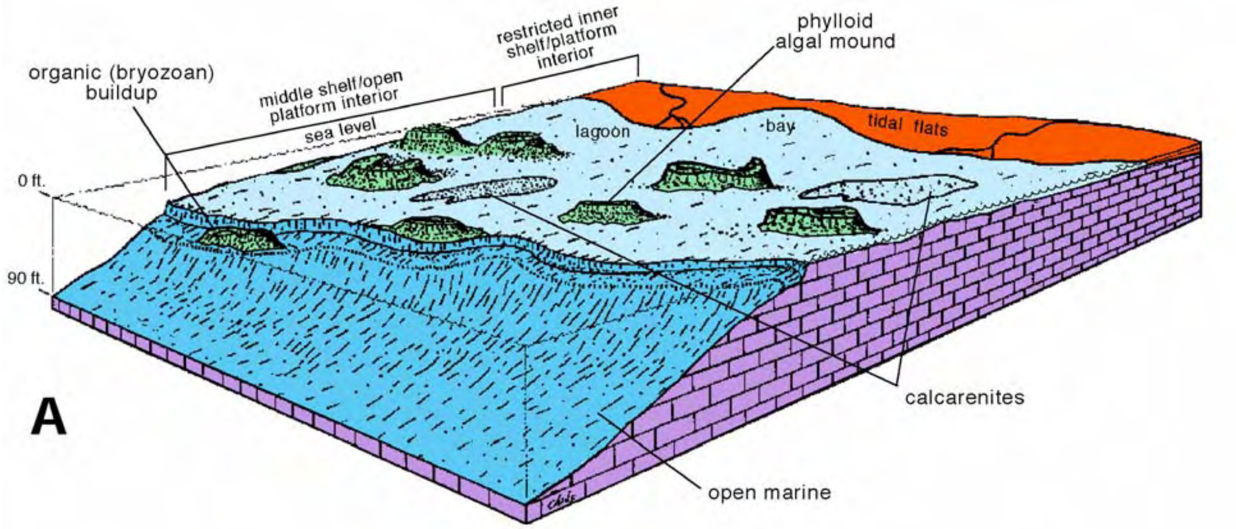


Figure 2. Pennsylvanian stratigraphy of the southern Paradox Basin including informal zones of the Paradox Formation; the upper Ismay and lower Desert Creek zones productive in case-study fields are highlighted. For this study the upper Ismay zone has been further divided into two units – the "upper part" and the "lower part."

REGIONAL CORRELATION SCHEME

Regional structure and isochore maps were constructed using a correlation scheme developed for the project. This correlation scheme ties the core-derived, typical, vertical sequence or cycle of depositional facies from the Cherokee and Bug case-study fields (figure 4) to the corresponding gamma-ray and neutron-density curves from geophysical well logs. The correlation scheme enabled us to identify the major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies (figures 5, 6, and 7, and table 1).

Depositionally, rock units are divided into seals or barriers (anhydrites and shales), mound (carbonate buildup [bafflestones, bindstones, grainstones, and packstones]), and off mound (mudstones and wackestones). Porosity units, and reservoir or potential reservoir layers, are identified within the mound and off-mound intervals. The mound, and some of the off-mound units, are part of the "clean carbonate" packages - intervals containing all of the productive reservoir facies, and where carbonate mudstone and shale are generally absent. The clean carbonate packages abruptly change laterally into thick anhydrite packages, particularly in the upper Ismay zone.



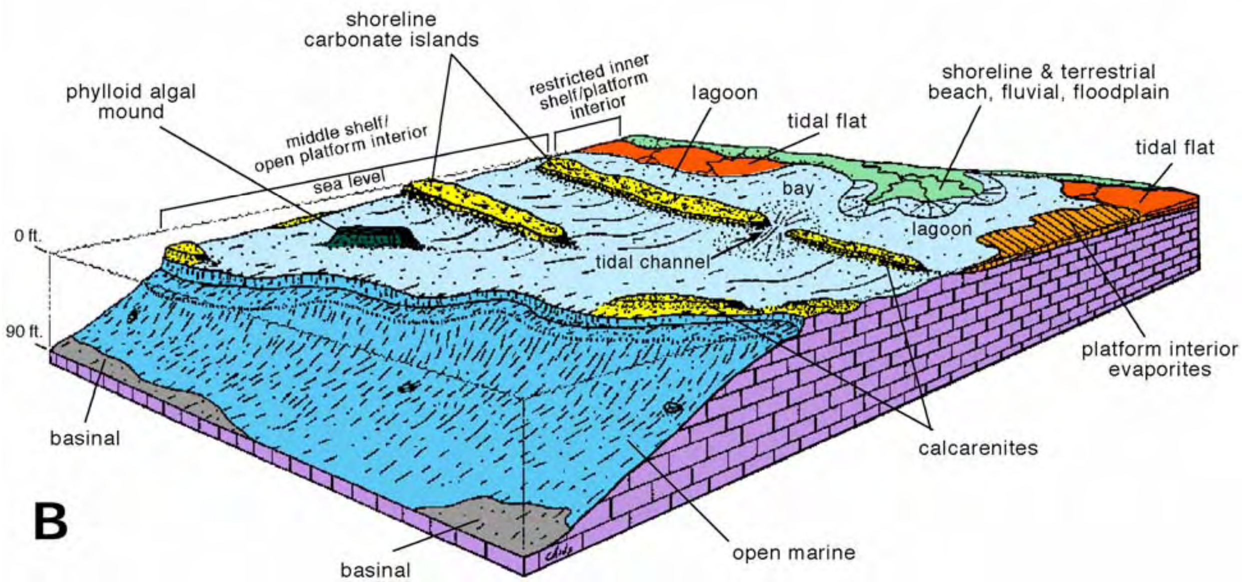


Figure 3. Block diagrams displaying major depositional facies, as determined from core, for the Ismay (A) and Desert Creek (B) zones, Pennsylvanian Paradox Formation, Utah and Colorado.

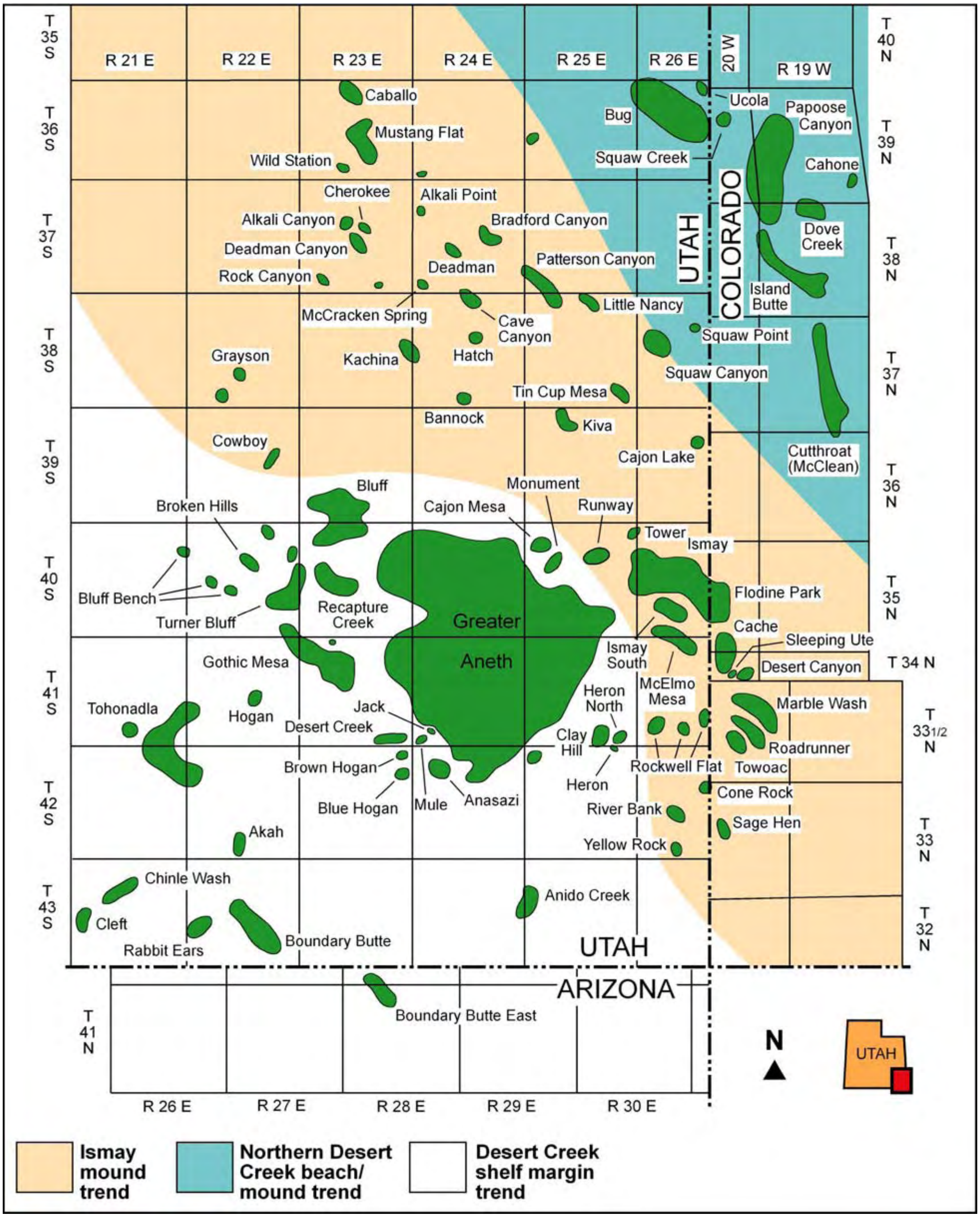


Figure 4. Map showing the project study area and fields within the Ismay and Desert Creek producing trends in the Blanding sub-basin, Utah and Colorado.

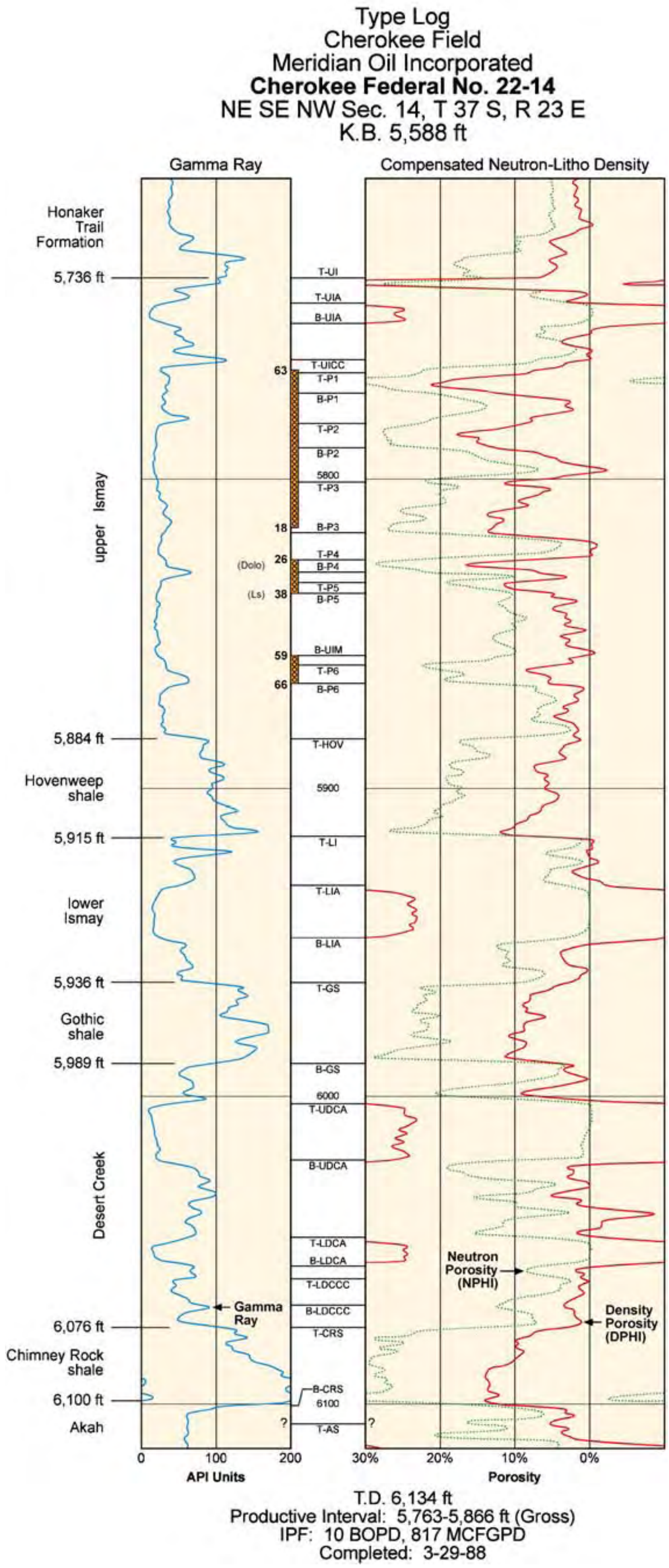


Figure 5. Type log for the Cherokee field (gamma-ray, compensated neutron-litho density) from the Cherokee Federal No. 22-14 well, showing the Ismay and Desert Creek correlation scheme, major units, and productive intervals (refer to table 1 for explanation of unit abbreviations).

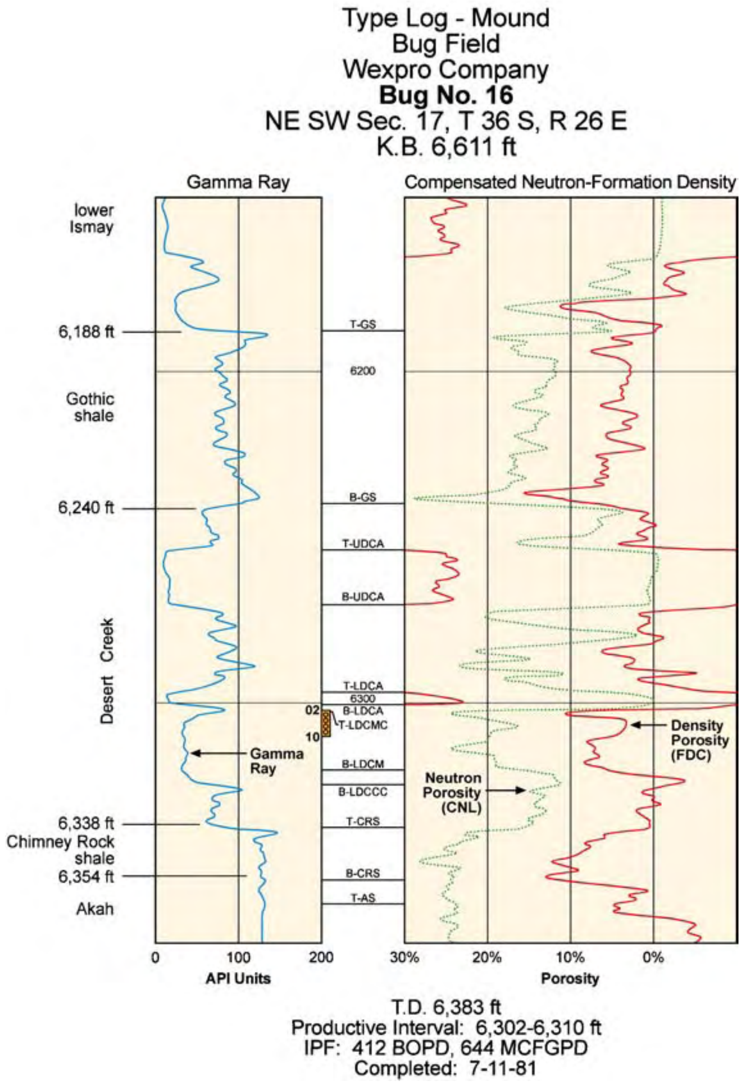


Figure 6. Type log for the Bug field mound (gamma-ray, compensated neutron-formation density) from the Bug No. 16 well, showing the Desert Creek correlation scheme, major units, and productive interval (refer to table 1 for explanation of unit abbreviations).

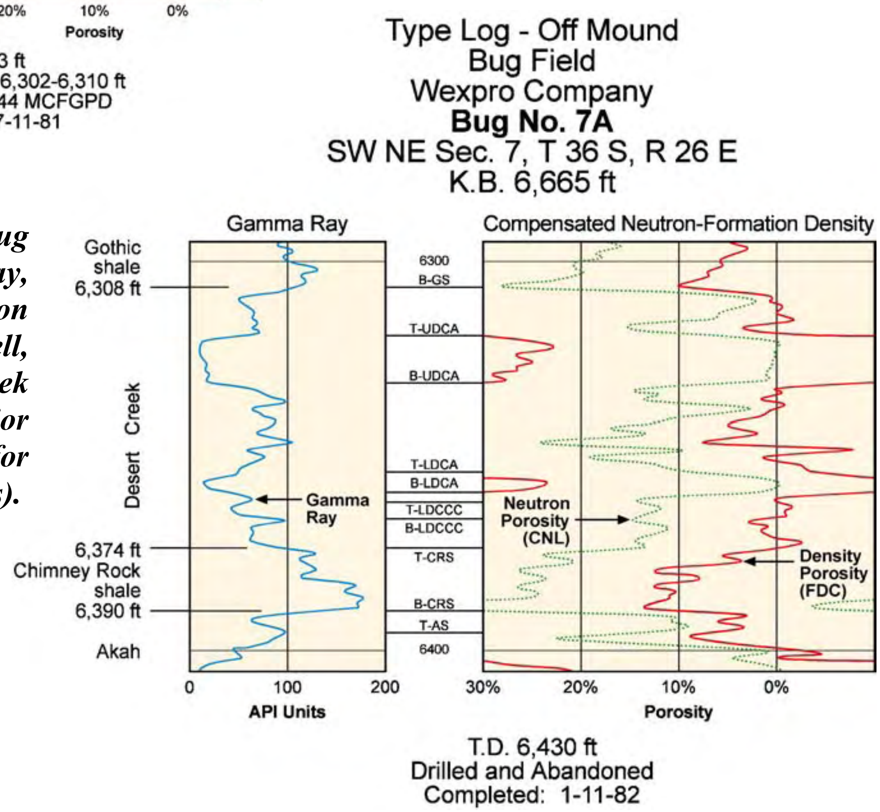


Figure 7. Type log for the Bug field off-mound area (gamma-ray, compensated neutron-formation density) from the Bug No. 7A well, showing the Desert Creek correlation scheme and major units (refer to table 1 for explanation of unit abbreviations).

Table 1. Correlation scheme used for Ismay and Desert Creek zones of the Paradox Formation in Cherokee and Bug fields, Blanding sub-basin, Utah.

Unit Code	Description
T-UI	Top - upper Ismay zone
T-UIA	Top - upper Ismay anhydrite
B-UIA	Base - upper Ismay anhydrite
T-UIA2	Top - upper Ismay anhydrite 2
B-UIA2	Base - upper Ismay anhydrite 2
T-UICC	Top - upper Ismay clean carbonate
T-P1	Top - Porosity Unit #1
B-P1	Base - Porosity Unit #1
T-P2	Top - Porosity Unit #2
B-P2	Base - Porosity Unit #2
T-P3	Top - Porosity Unit #3
B-P3	Base - Porosity Unit #3
T-P4	Top - Porosity Unit #4
B-P4	Base - Porosity Unit #4
T-P5	Top - Porosity Unit #5
B-P5	Base - Porosity Unit #5
B-UIM	Base - upper Ismay mound
B-UICC	Base upper Ismay clean carbonate
T-P6	Top - Porosity Unit #6
B-P6	Base - Porosity Unit #6
T-HOV	Top - Hovenweep shale
T-LI	Top - lower Ismay zone
T-LIA	Top - lower Ismay anhydrite
B-LIA	Base - lower Ismay anhydrite
T-GS	Top - Gothic shale
B-GS	Base - Gothic shale
T-UDCA	Top - upper Desert Creek anhydrite
B-UDCA	Base - upper Desert Creek anhydrite
T-LDCA	Top - lower Desert Creek anhydrite
B-LDCA	Base - lower Desert Creek anhydrite
T-LDCMC	Top - lower Desert Creek mound cap
B-LDCM	Base - lower Desert Creek mound

The top and base of all these intervals (seals, mound, clean carbonate, as well as porosity units) were determined and coded as listed in table 1. The unlisted intervening units represent the baffles or non-reservoir rocks, such as non-porous packestone or wackestone (figures 5 through 7). The mound/mound cap intervals usually have porosity greater than 6 percent, while the clean carbonate intervals are defined by lithology only (such as bafflestone or grainstone), although there may be occasional isolated porosity zones. The top and base of the mound/mound cap intervals are often equivalent to the top and base of the clean carbonate intervals. In addition, the top and base of the mound/mound cap intervals may be equivalent to the top and base of the thinner off-mound clean carbonate intervals.

REGIONAL STRUCTURE AND ISOCHORE MAPPING

The study area covers about 750 square miles (1,900 km^2) within the Blanding sub-basin of the Paradox Basin. The total number of wells drilled to the Paradox Formation within the study area is about 480 wells. We correlated 387 geophysical well logs that penetrated the Ismay or Desert Creek zones of the Paradox Formation. The tops of the units defined in the correlations scheme were entered into a database. Twenty-eight regional maps (figures 8 through 35) were constructed from the unit tops in this database using ArcView® GIS 3.2 software. These maps include isochore and structure maps for the top of the Ismay and Desert Creek zones, major anhydrites and shales, and “clean carbonates.” Adjustments to these computer-generated interpretations were made to the maps where the lack of data points created “bullseyes” and other suspect effects, especially along map edges.

Structure maps were produced for clean carbonates to show the general shape of the buildups (figures 16 and 32). The top of shales (Hovenweep, Gothic, and Chimney Rock shales [figures 18, 24, and 34]) represent the true structure trends of the region. On all structure maps, the structural “highs” are light blue and the “lows” are dark blue.

The isochore maps of the upper Ismay and lower Desert Creek clean carbonate intervals are shown on figures 17 and 33. The “thicks” of clean carbonate are shown in darker green hues while “thins” are very pale shades of green. Note that the thicks of upper Ismay clean carbonate (figure 17) are often connected and nearly surround thins. For both the upper Ismay and lower Desert Creek clean carbonates, thicks are probably the combined effect of platform (middle to inner shelf/tidal flat) deposition and organic (phylloid-algal and bryozoan) buildups. Within the upper Ismay interval, the thins surrounded by thicks are intra-shelf basins filled with thick anhydrites. The remaining thins that are not surrounded by or in close proximity to thicks, are largely open-marine (deep, outer shelf) deposits. The thin areas for the Desert Creek are also largely open-marine deposits.

The isochore maps of the various anhydrites are shown on figures 13, 15, 29, and 31. Thick areas of anhydrite are shown with darker shades of orange and thin areas are shown with lighter shades of orange. Note that the areas of thickest upper Ismay “anhydrite 2” roughly correlate with some of the thins on the upper Ismay clean carbonate isochore map (figure 17). The anhydrite 2 thicks were deposited within semi-isolated, intra-shelf basins.

Figure 8. Top of upper Ismay zone, Blanding sub-basin, Utah

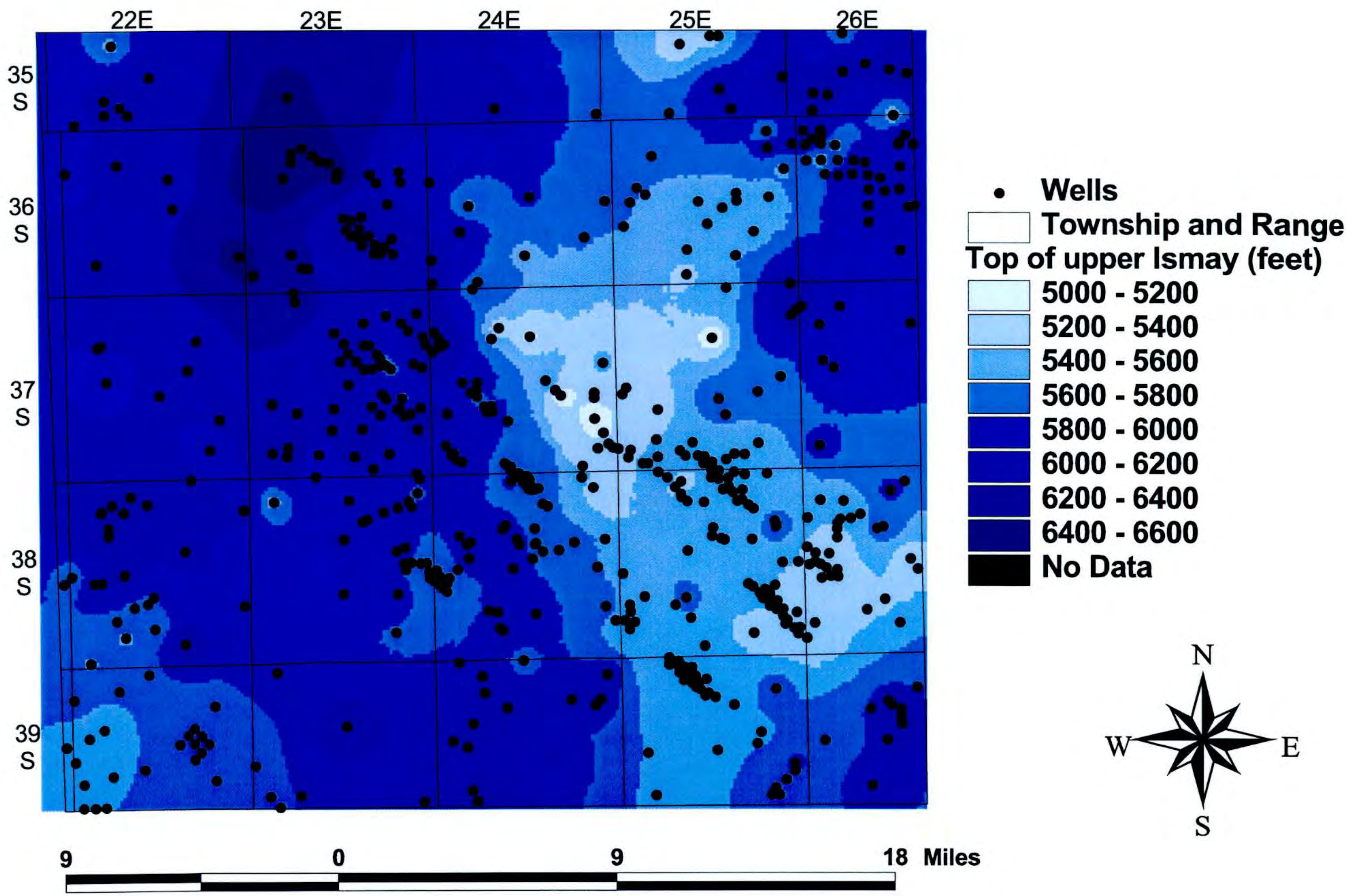


Figure 9. Ismay zone isochore, Blanding sub-basin, Utah

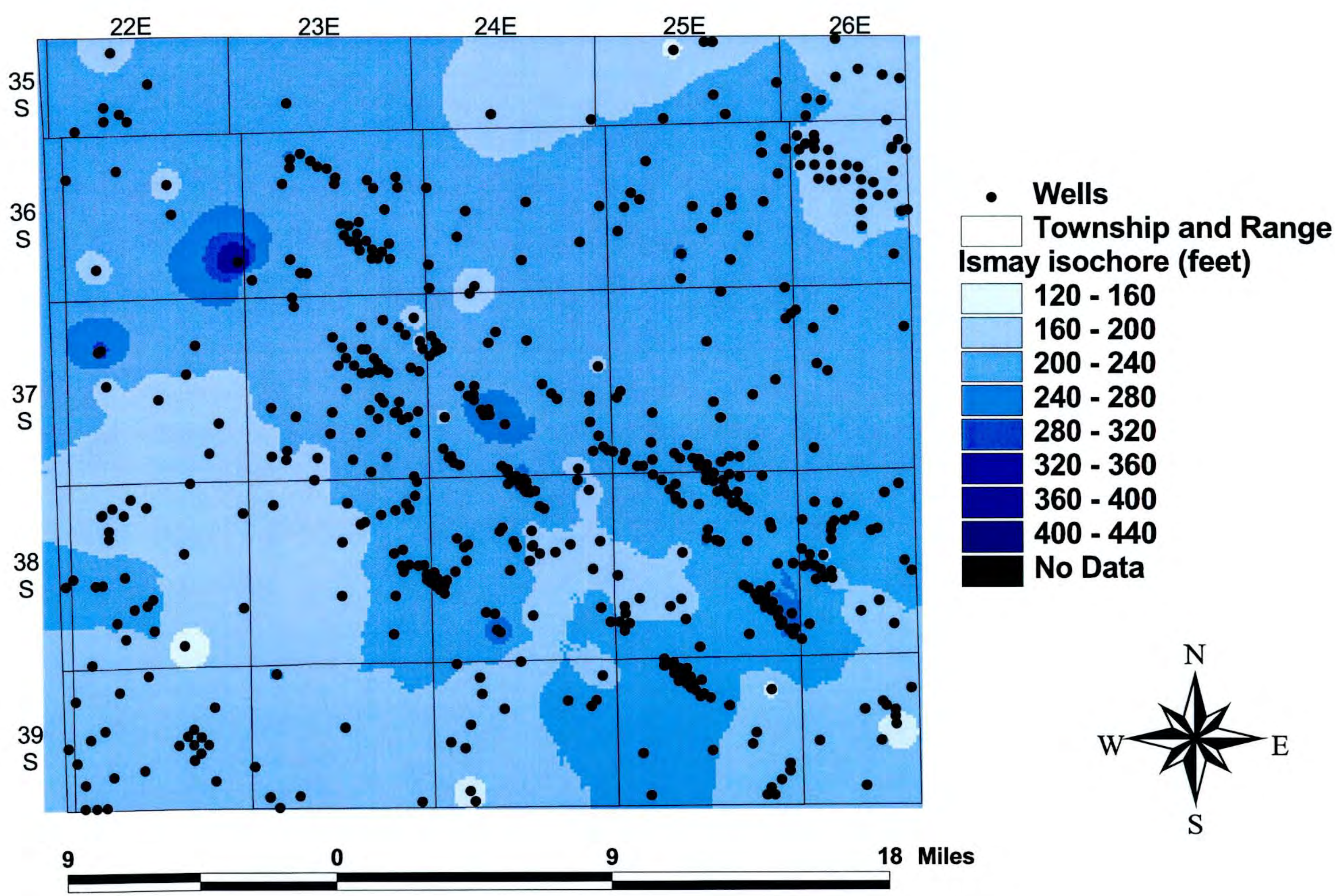


Figure 10. Upper Ismay zone isochore, Blanding sub-basin, Utah

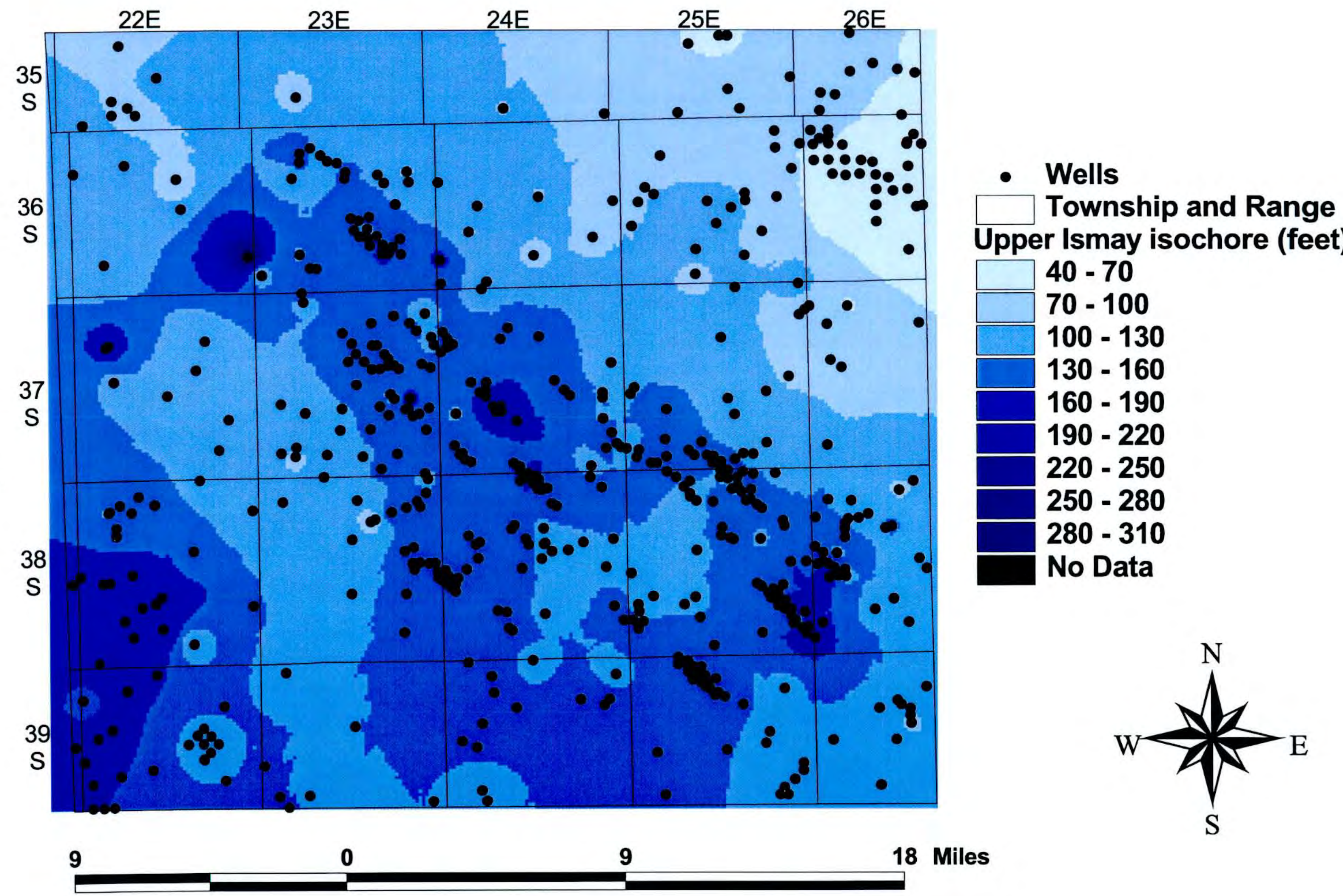


Figure 11. Upper Ismay zone isochore without anhydrite zones, Blanding sub-basin, Utah

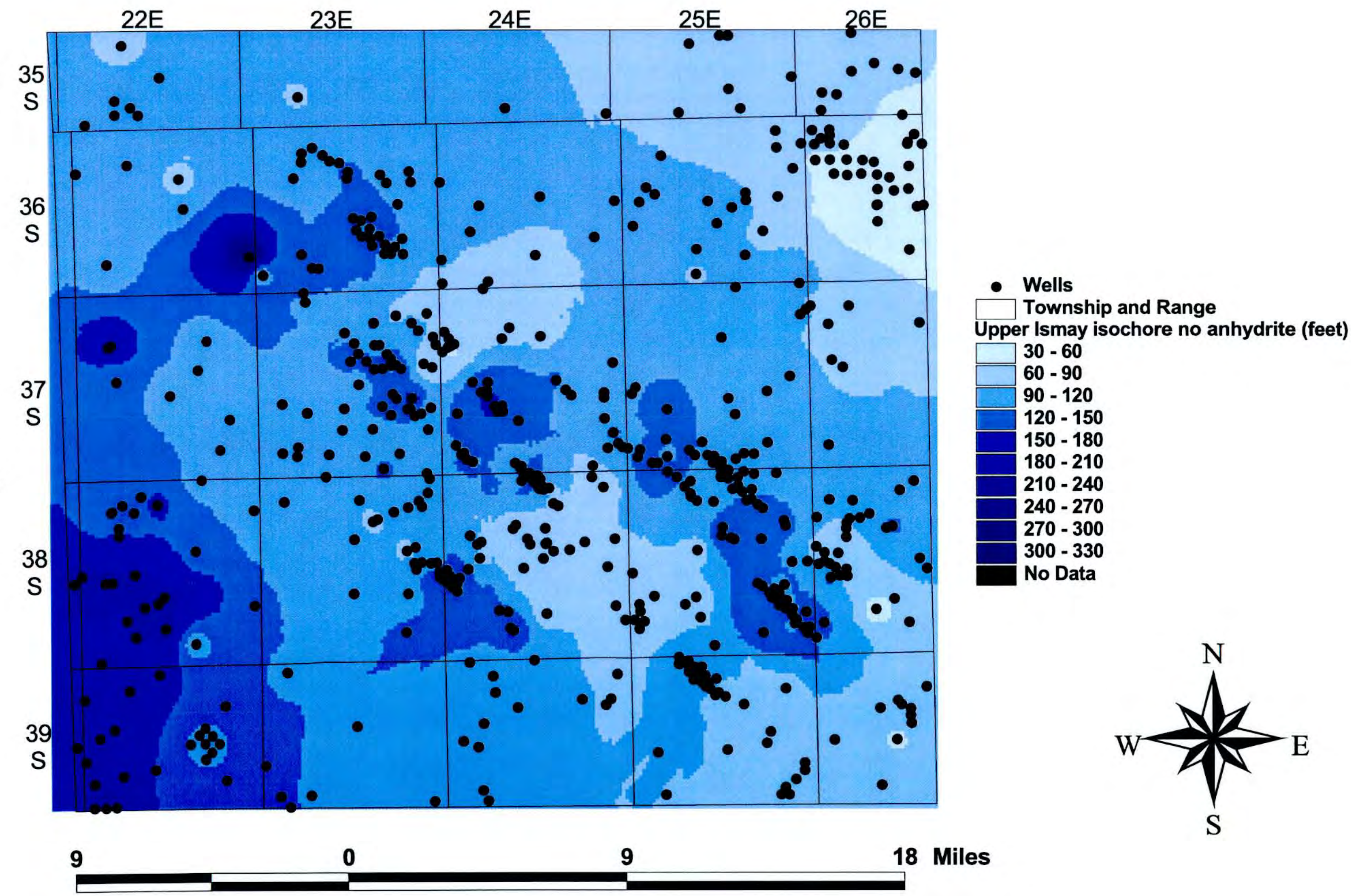


Figure 12. Top of upper Ismay anhydrite, Blanding sub-basin, Utah

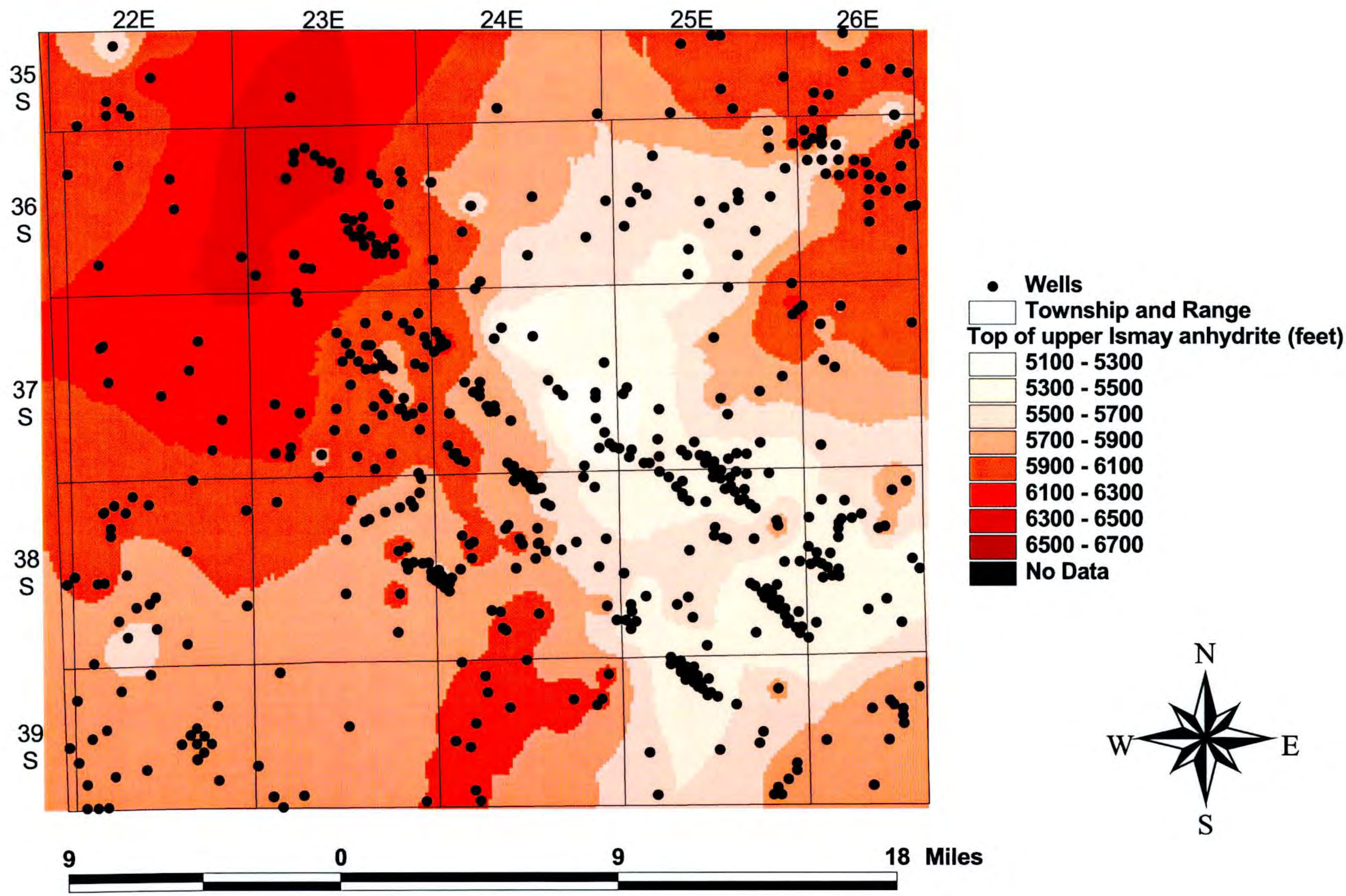


Figure 13. Isochore of upper Ismay anhydrite, Blanding sub-basin, Utah

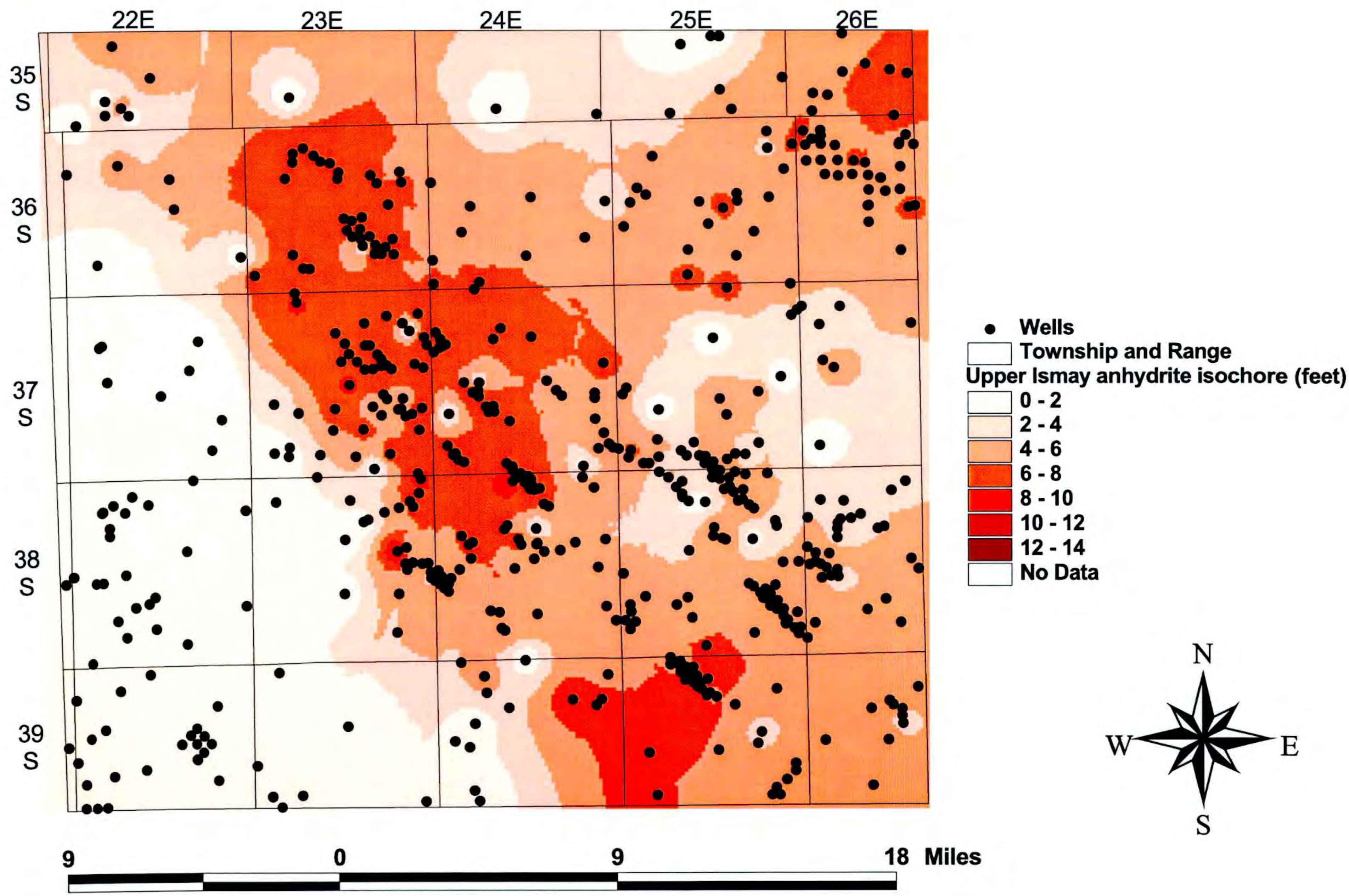


Figure 14. Top of upper Ismay anhydrite 2, Blanding sub-basin, Utah

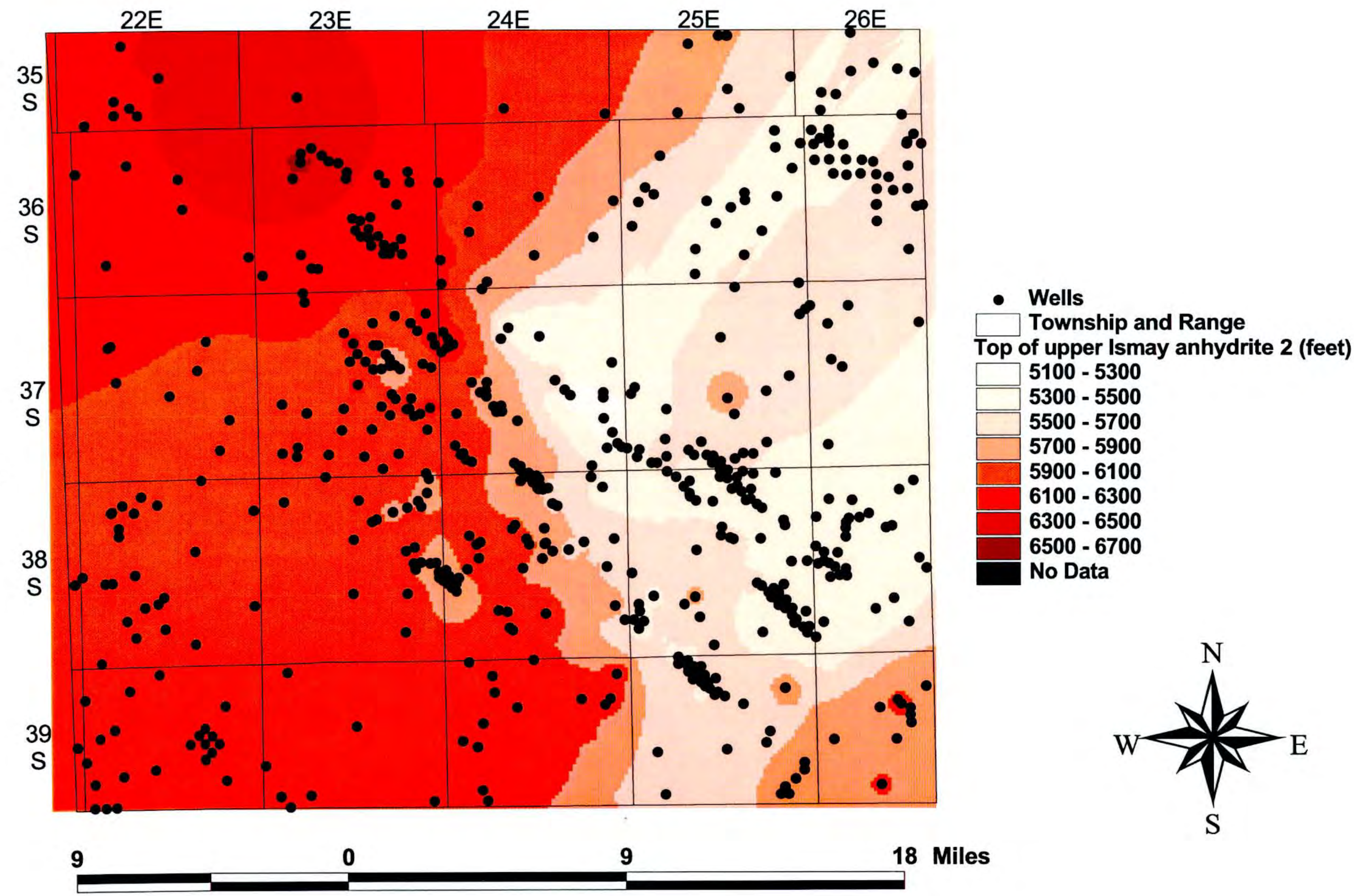


Figure 15. Isochore of upper Ismay anhydrite 2, Blanding sub-basin, Utah

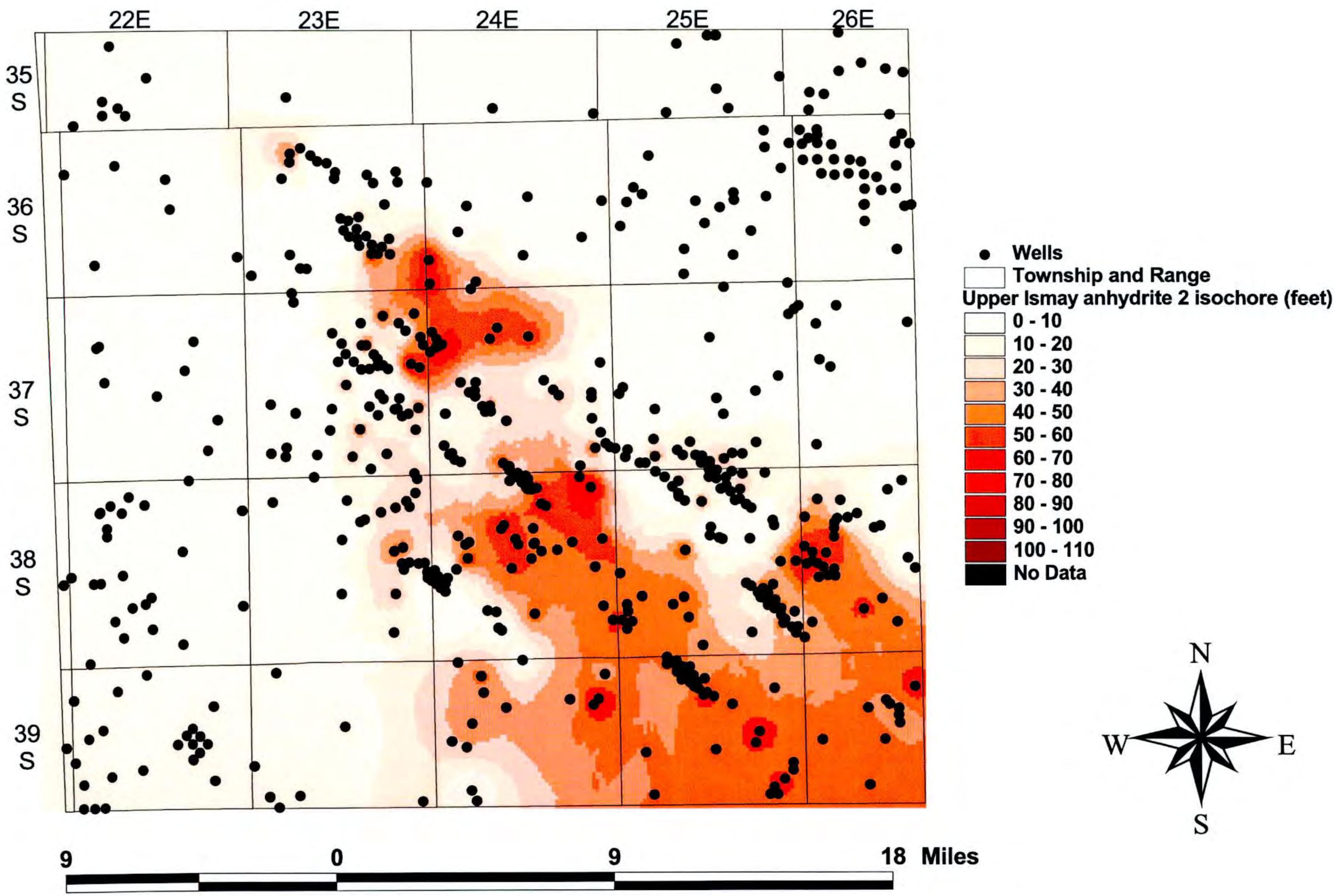


Figure 16. Top of upper Ismay clean carbonate, Blanding sub-basin, Utah

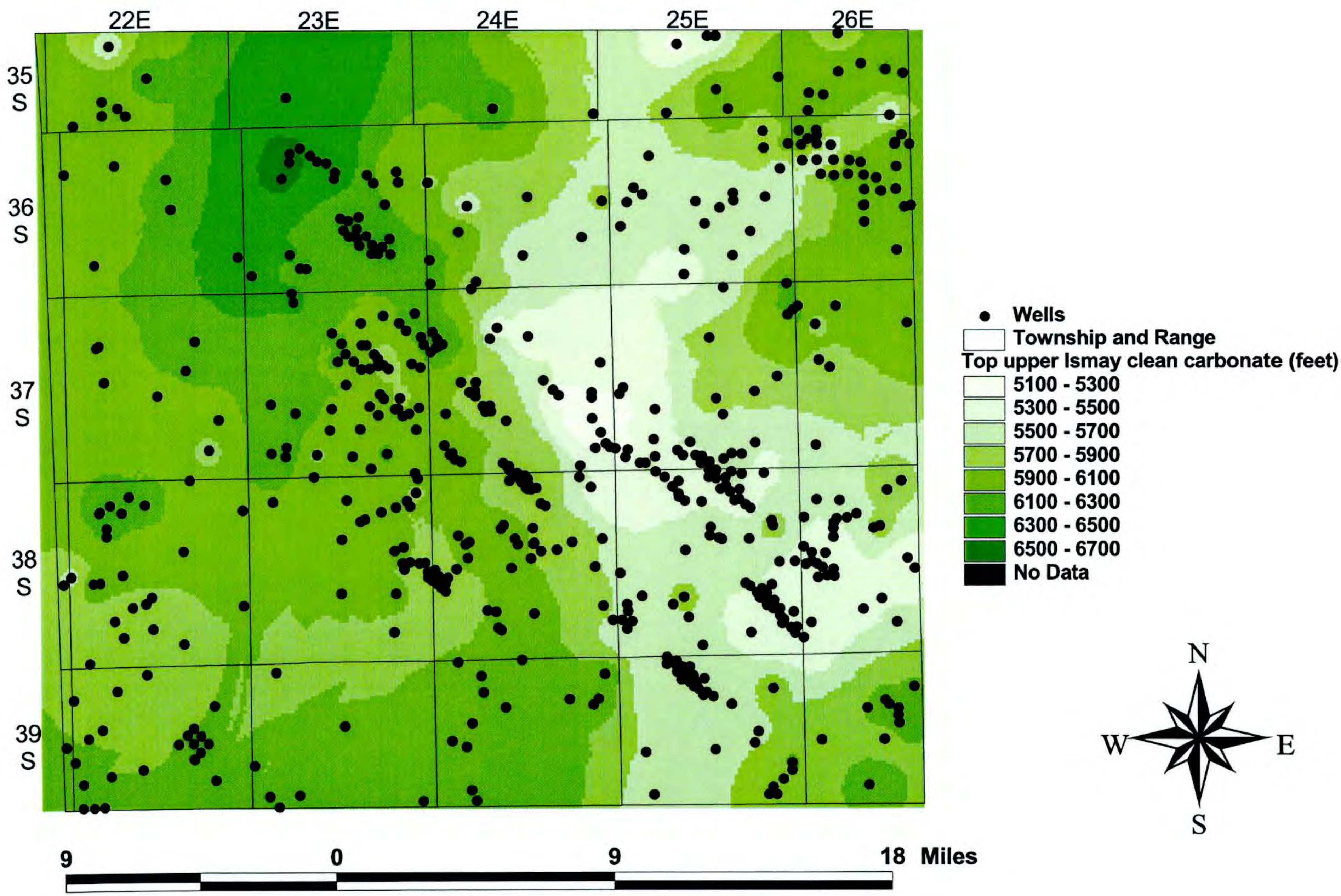


Figure 17. Isochore of upper Ismay clean carbonate, Blanding sub-basin, Utah

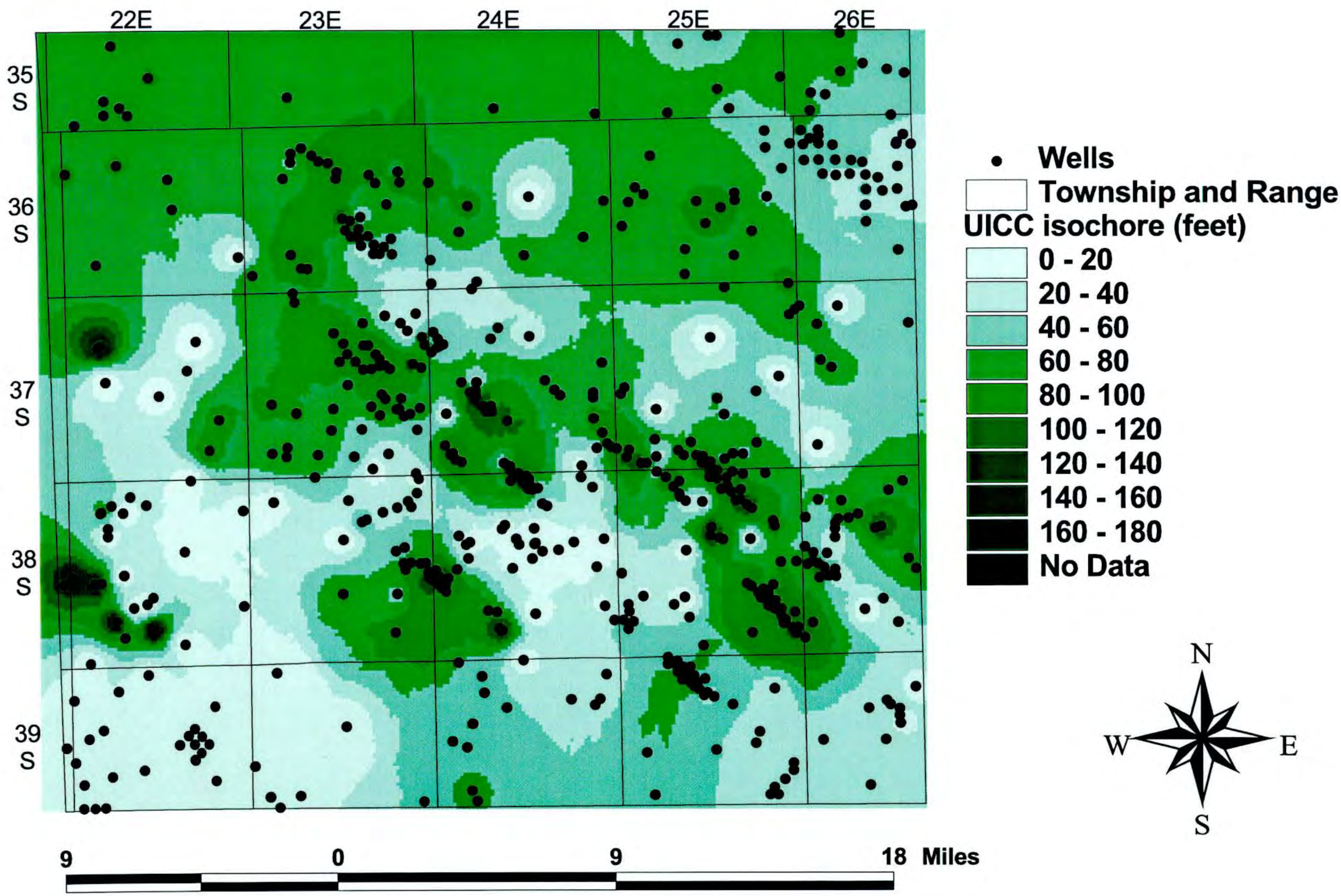


Figure 18. Top of Hovenweep shale, Blanding sub-basin, Utah

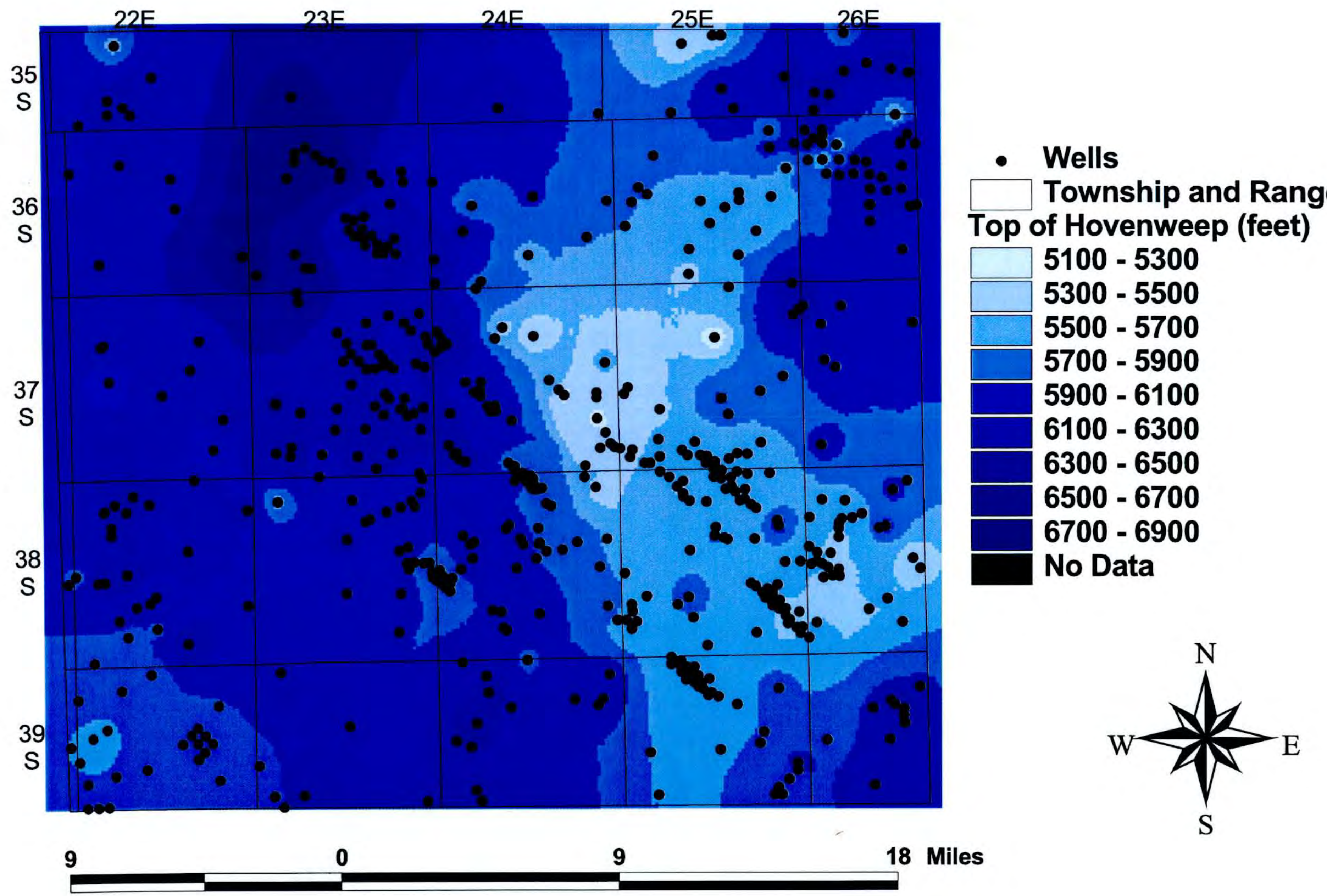


Figure 19. Isochore of Hovenweep shale, Blanding sub-basin, Utah

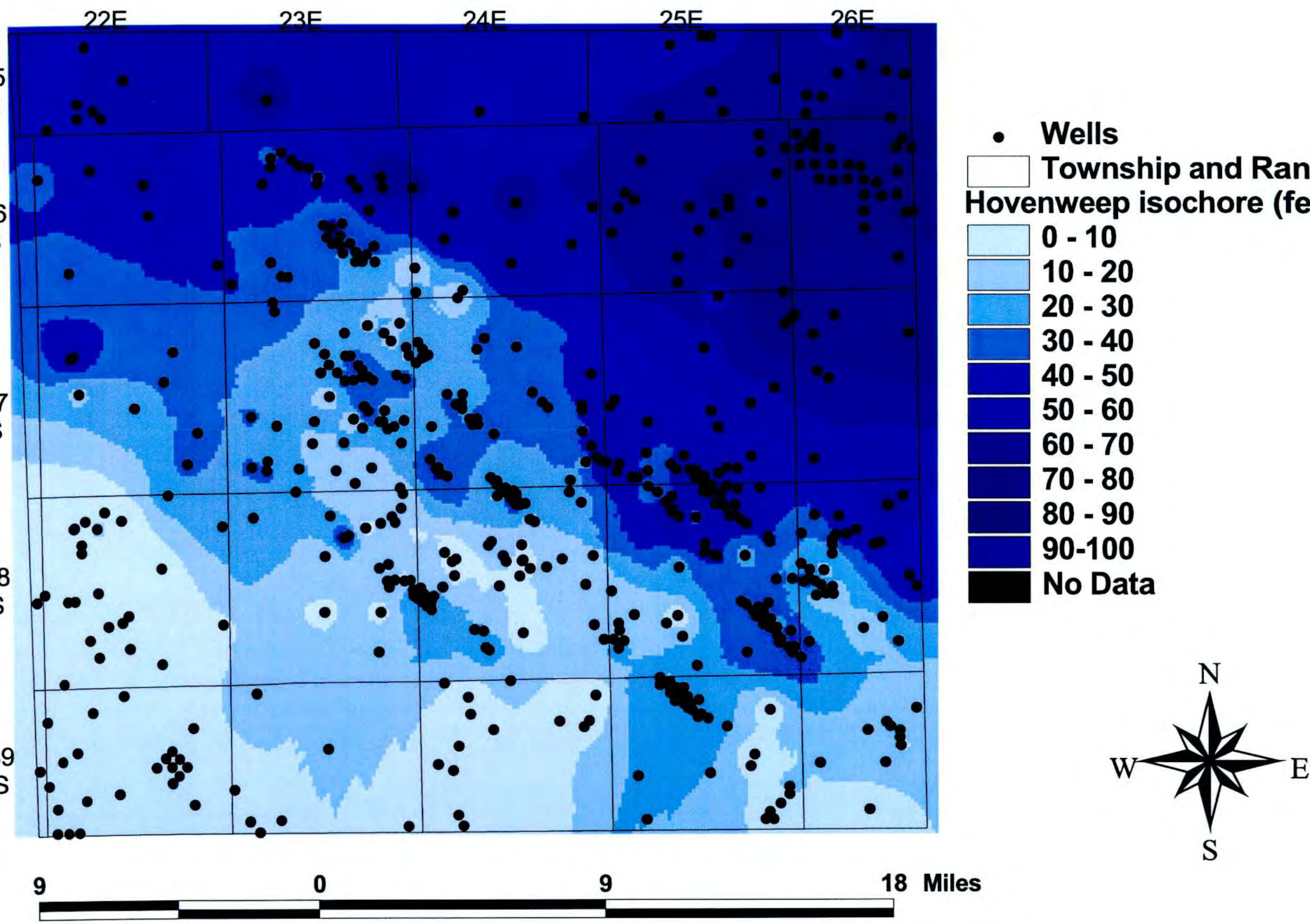


Figure 20. Top of lower Ismay zone, Blanding sub-basin, Utah

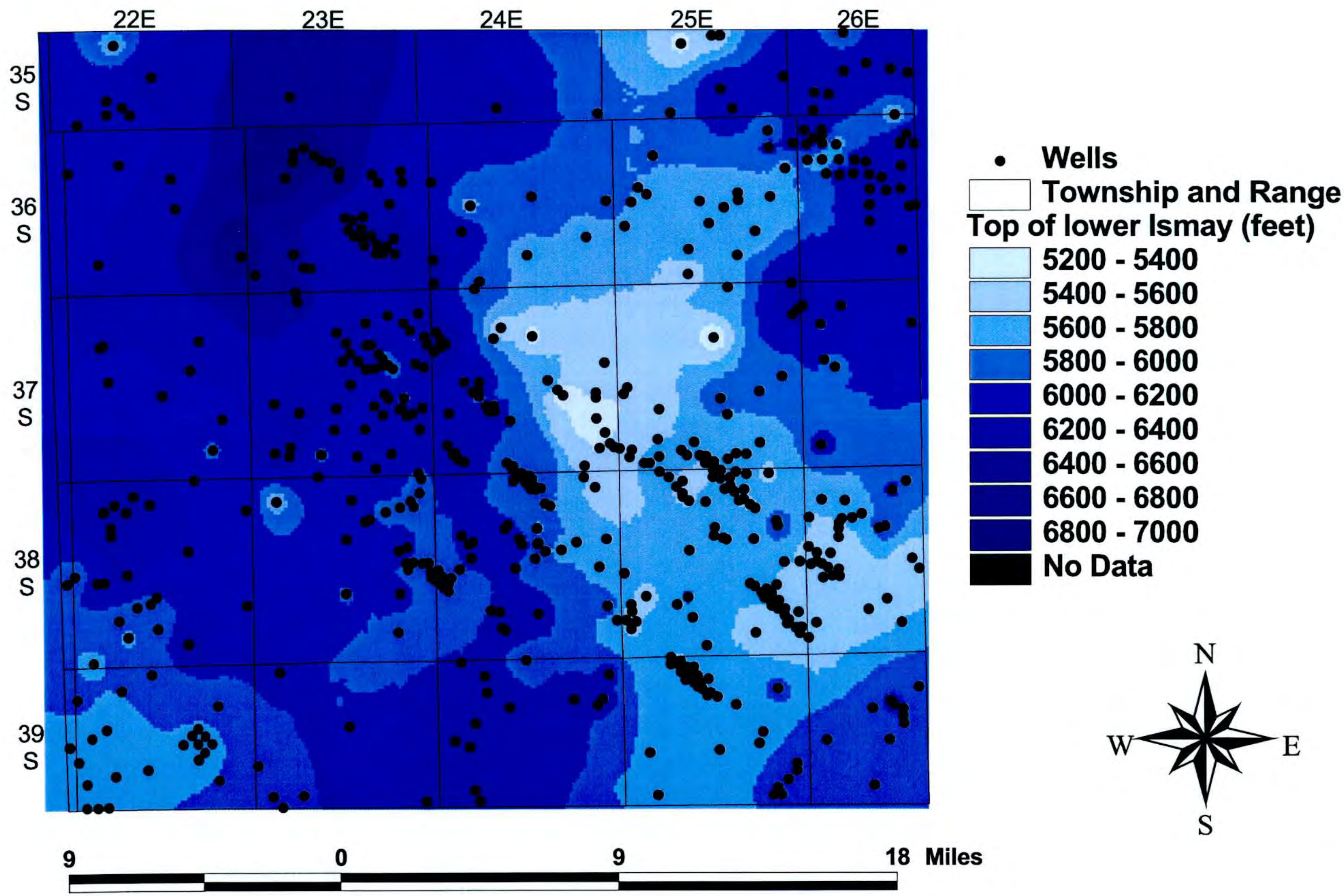


Figure 21. Lower Ismay zone isochore, Blanding sub-basin, Utah

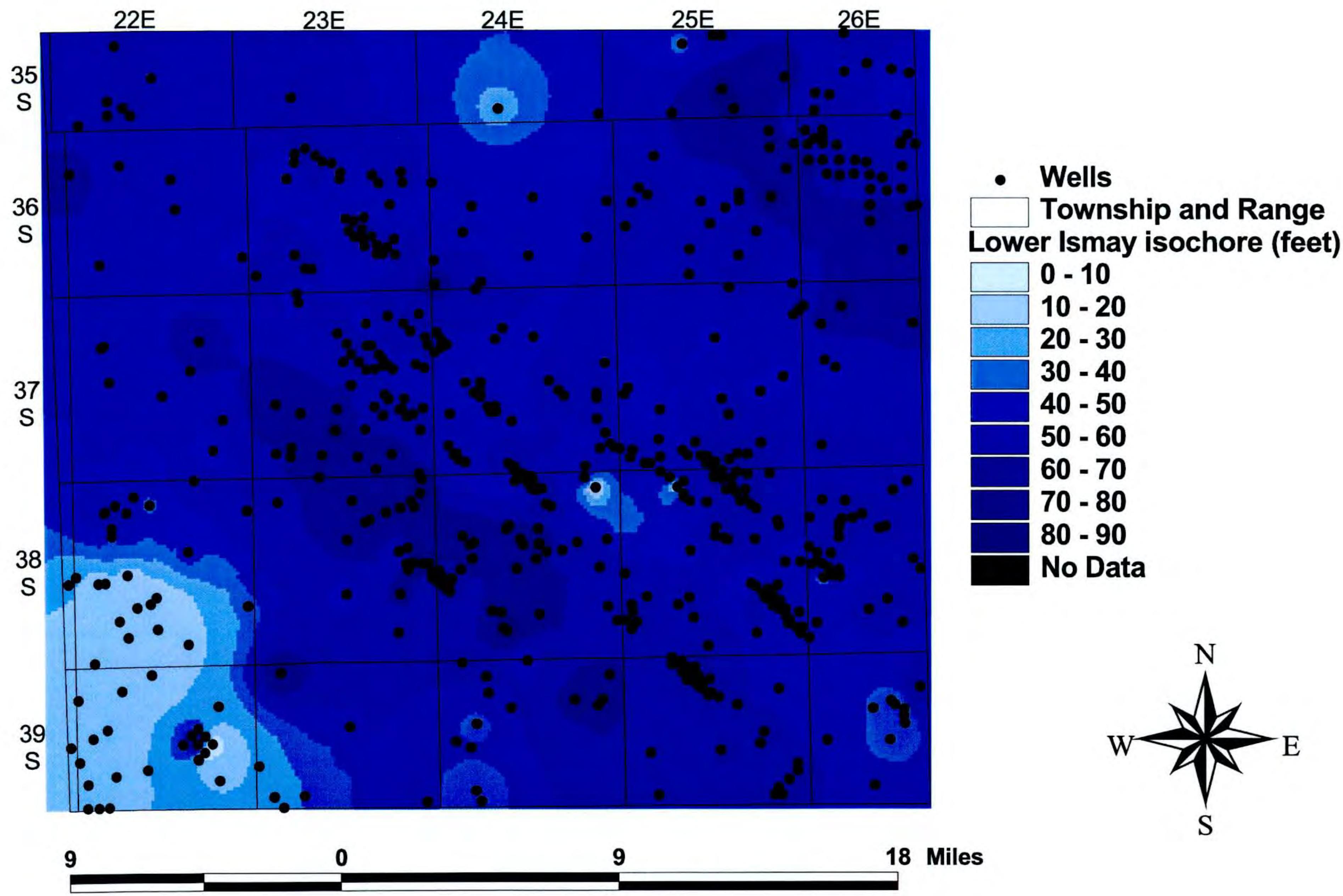


Figure 22. Top of lower Ismay anhydrite, Blanding sub-basin, Utah

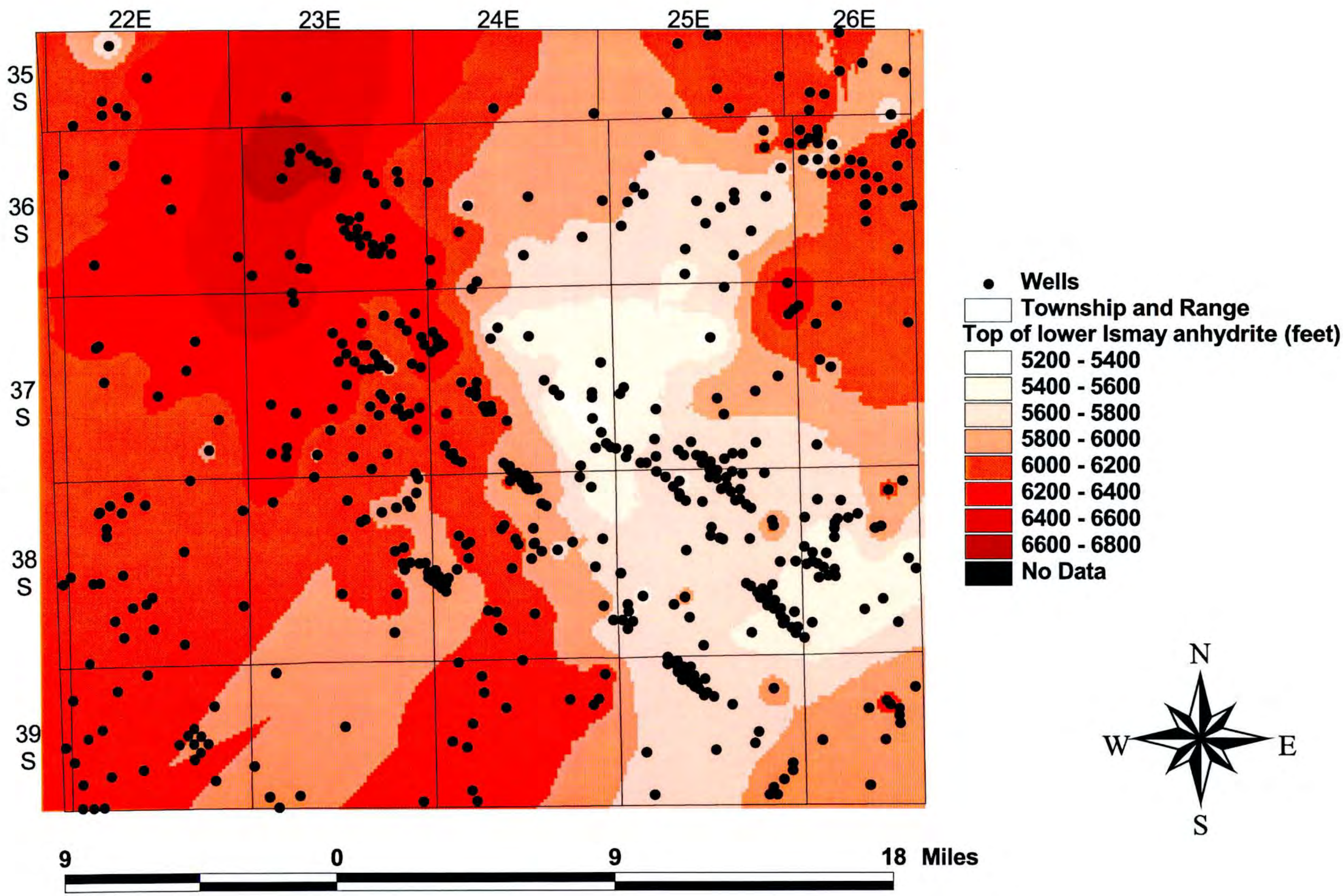


Figure 23. Lower Ismay anhydrite isochore, Blanding sub-basin, Utah

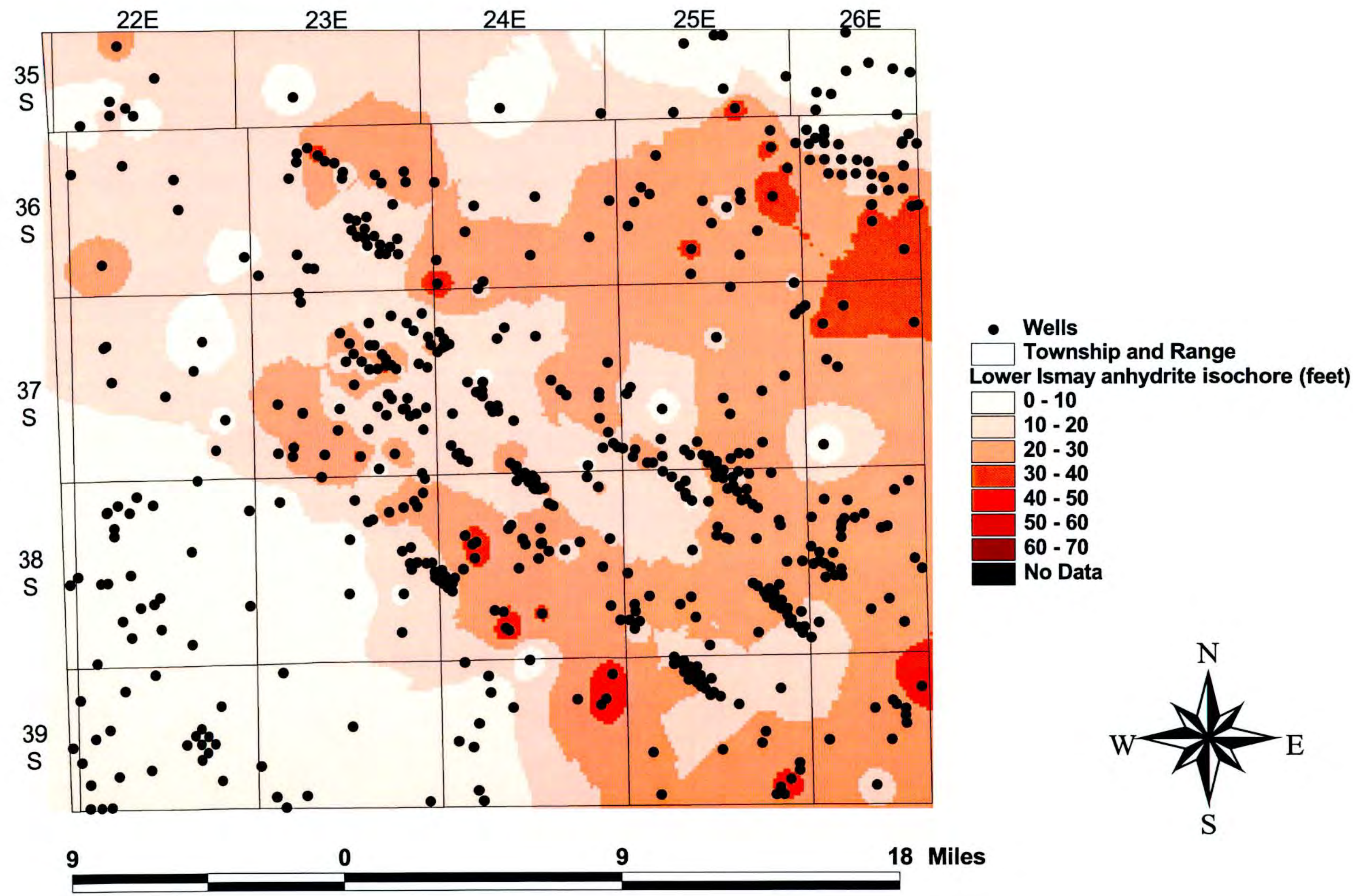


Figure 24. Top of Gothic shale, Blanding sub-basin, Utah

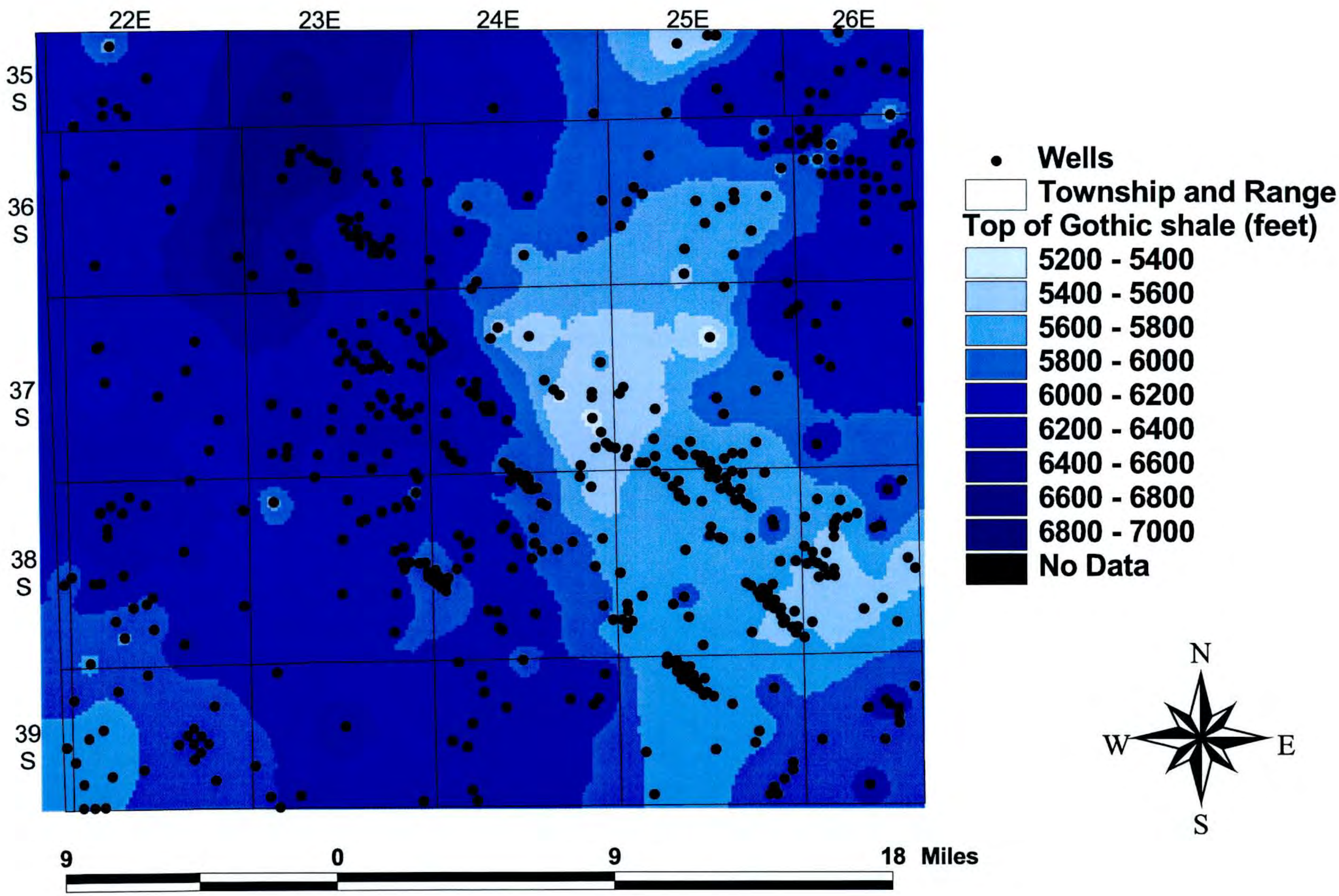


Figure 25. Gothic shale isochore, Blanding sub-basin, Utah

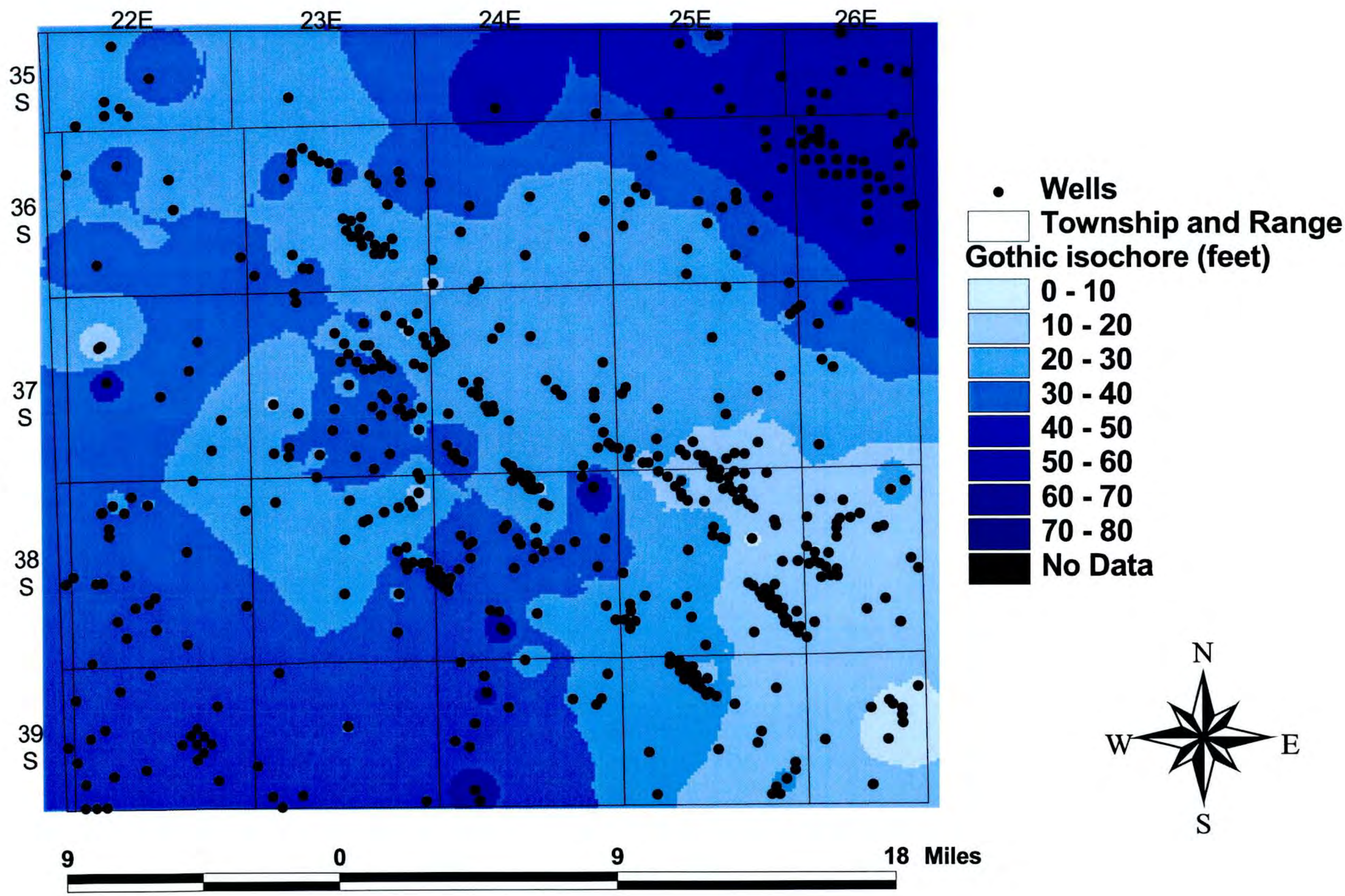


Figure 26. Top of Desert Creek zone, Blanding sub-basin, Utah

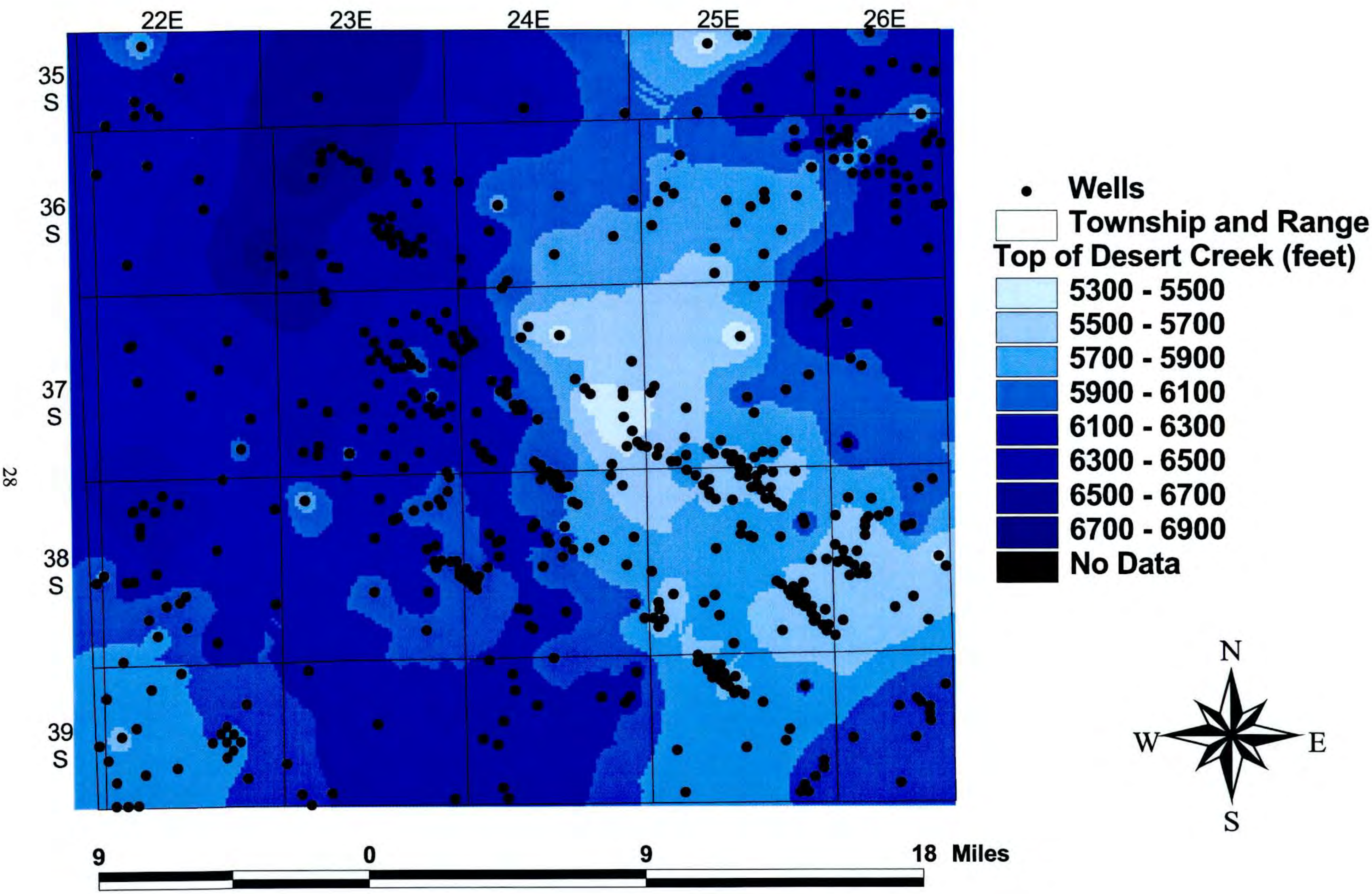


Figure 27. Desert Creek zone isochore, Blanding sub-basin, Utah

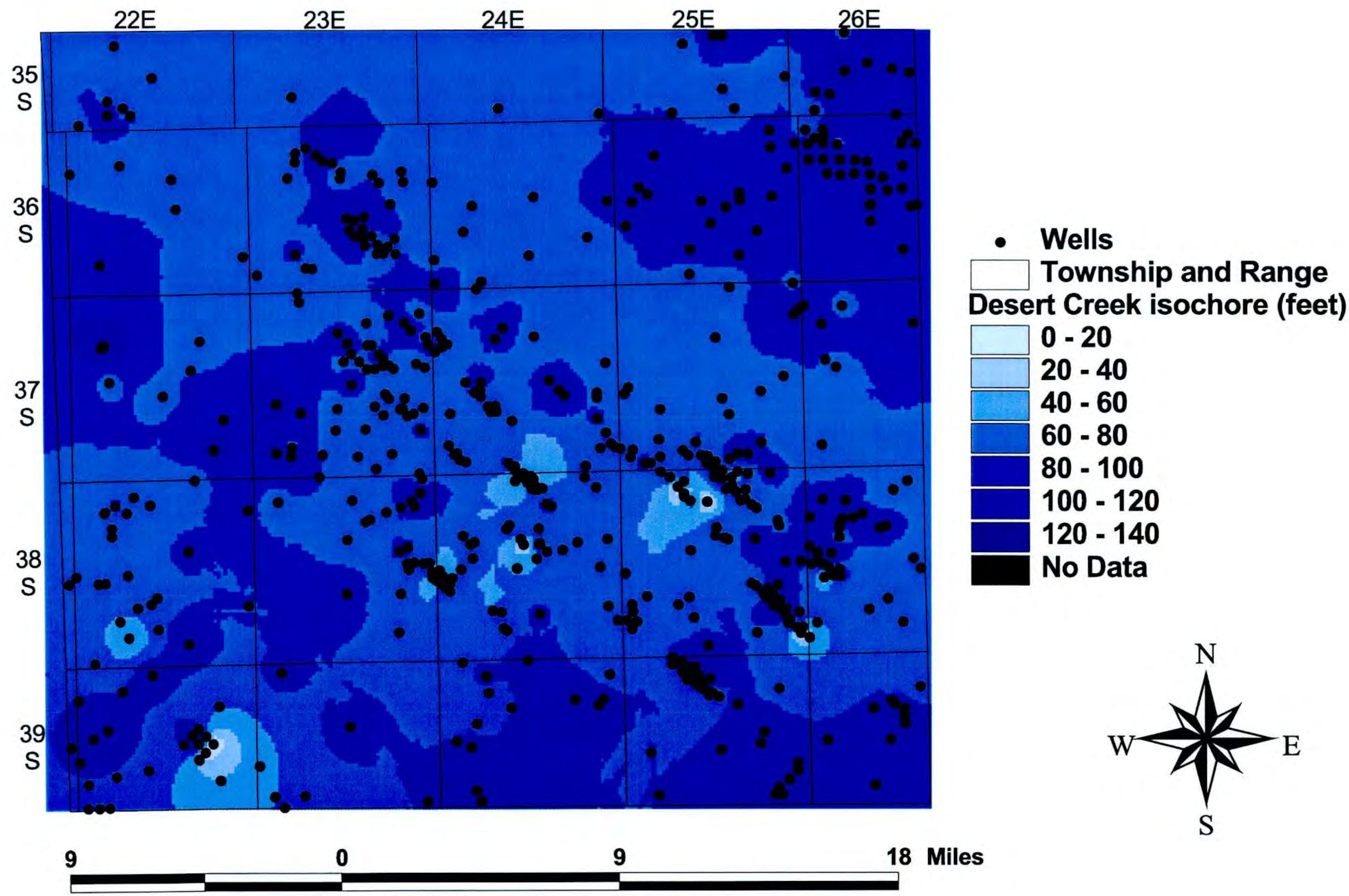


Figure 28. Top of upper Desert Creek anhydrite, Blanding sub-basin, Utah

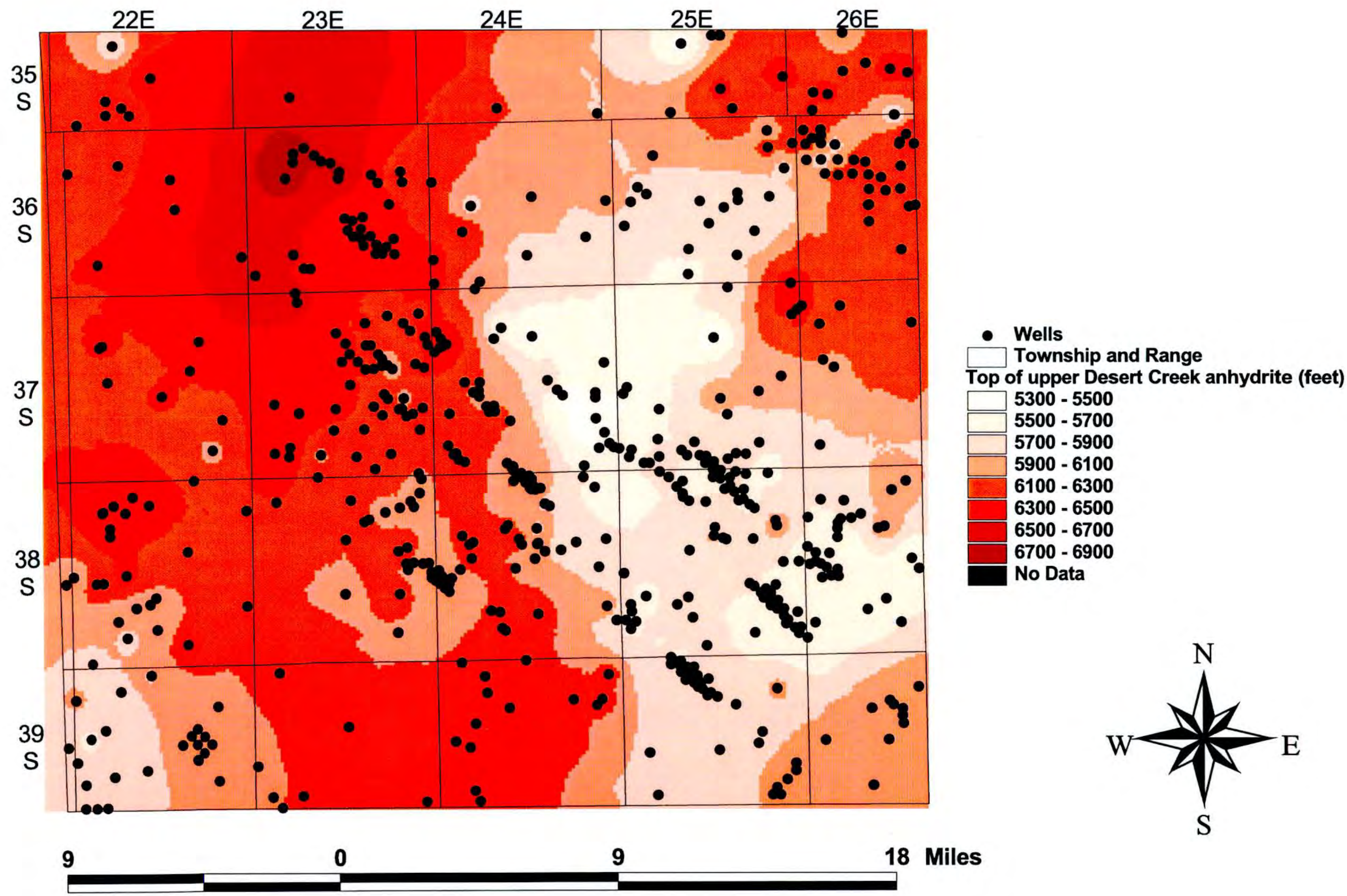


Figure 29. Upper Desert Creek anhydrite isochore, Blanding sub-basin, Utah

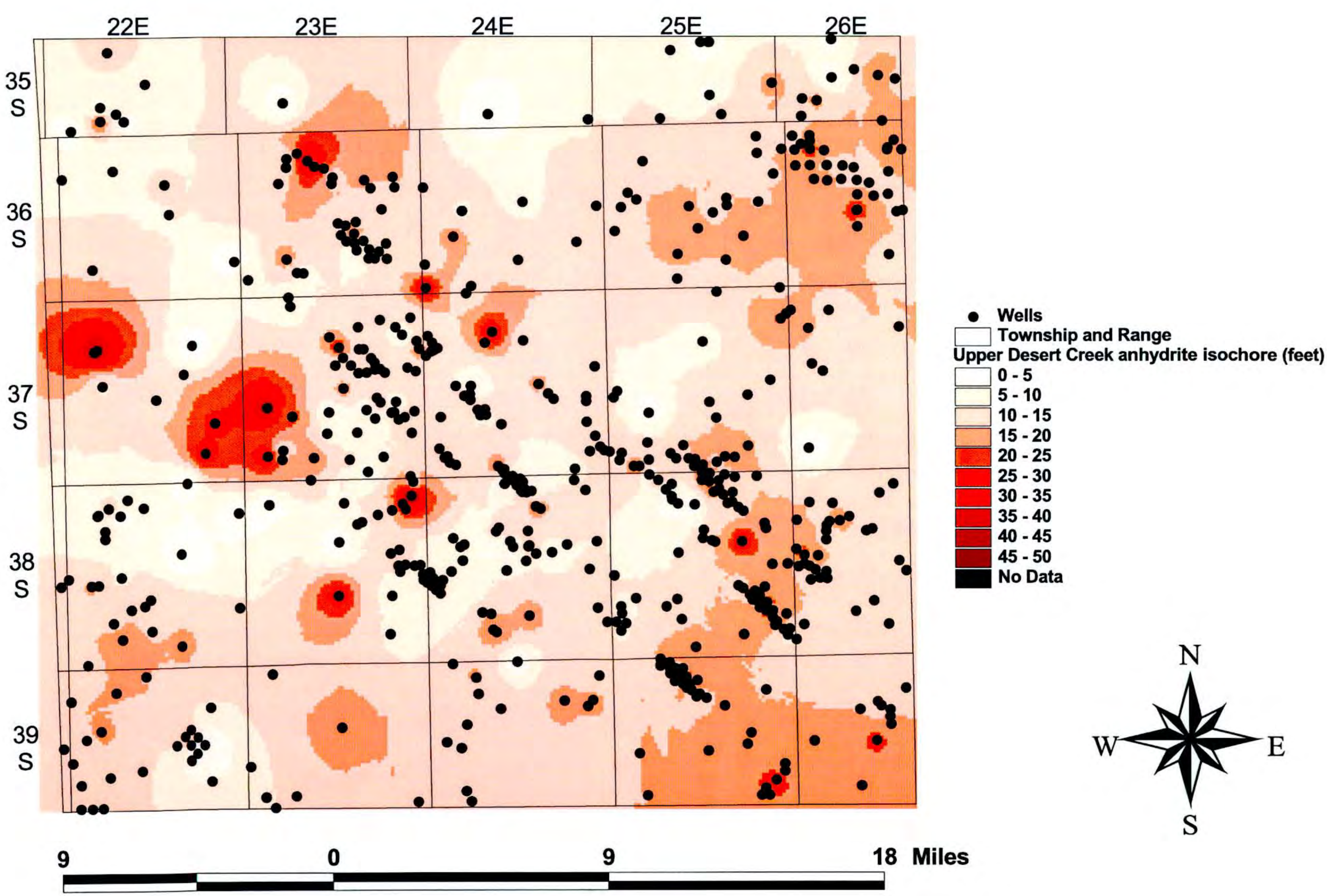


Figure 30. Top of lower Desert Creek anhydrite, Blanding sub-basin, Utah

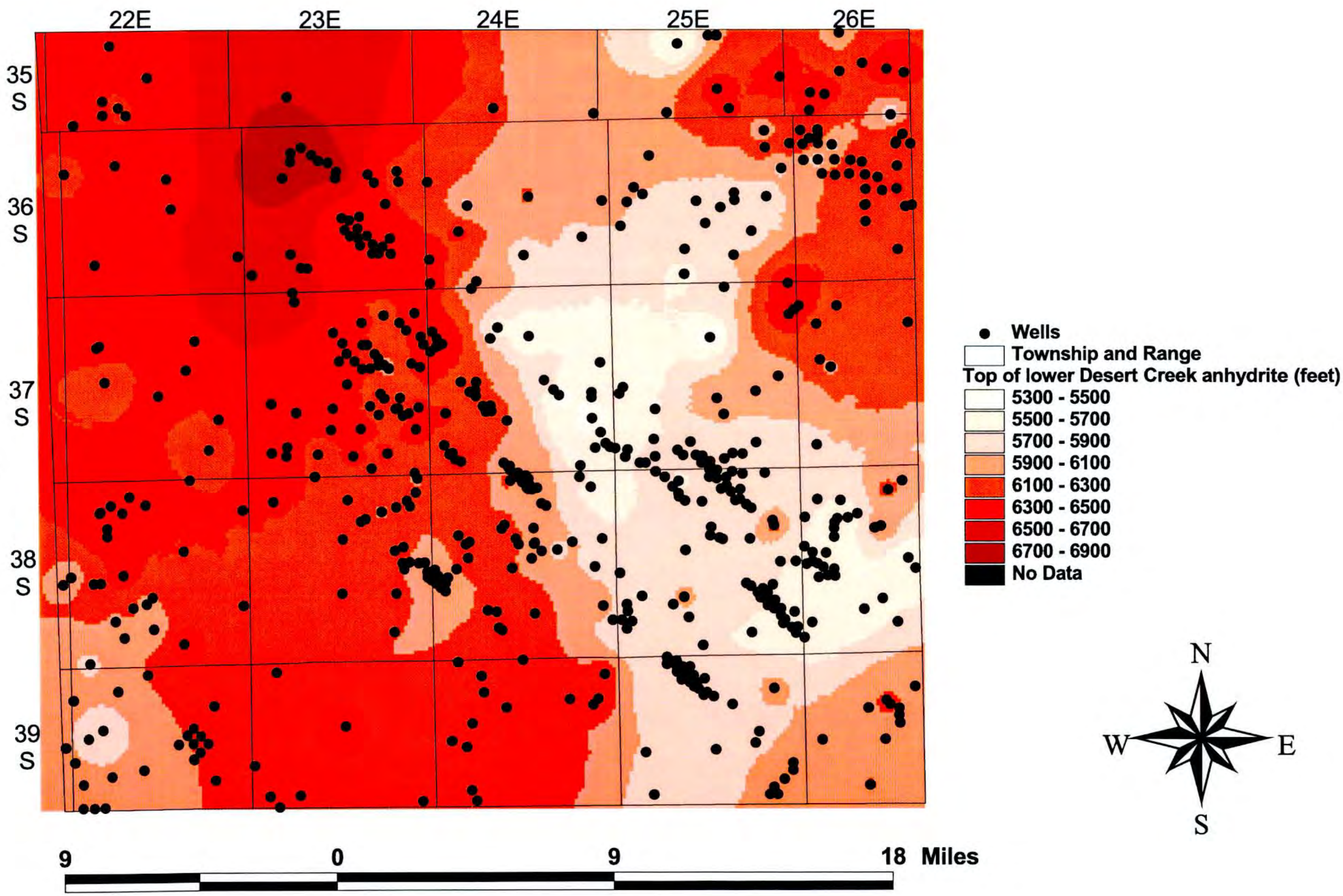


Figure 31. Lower Desert Creek anhydrite isochore, Blanding sub-basin, Utah

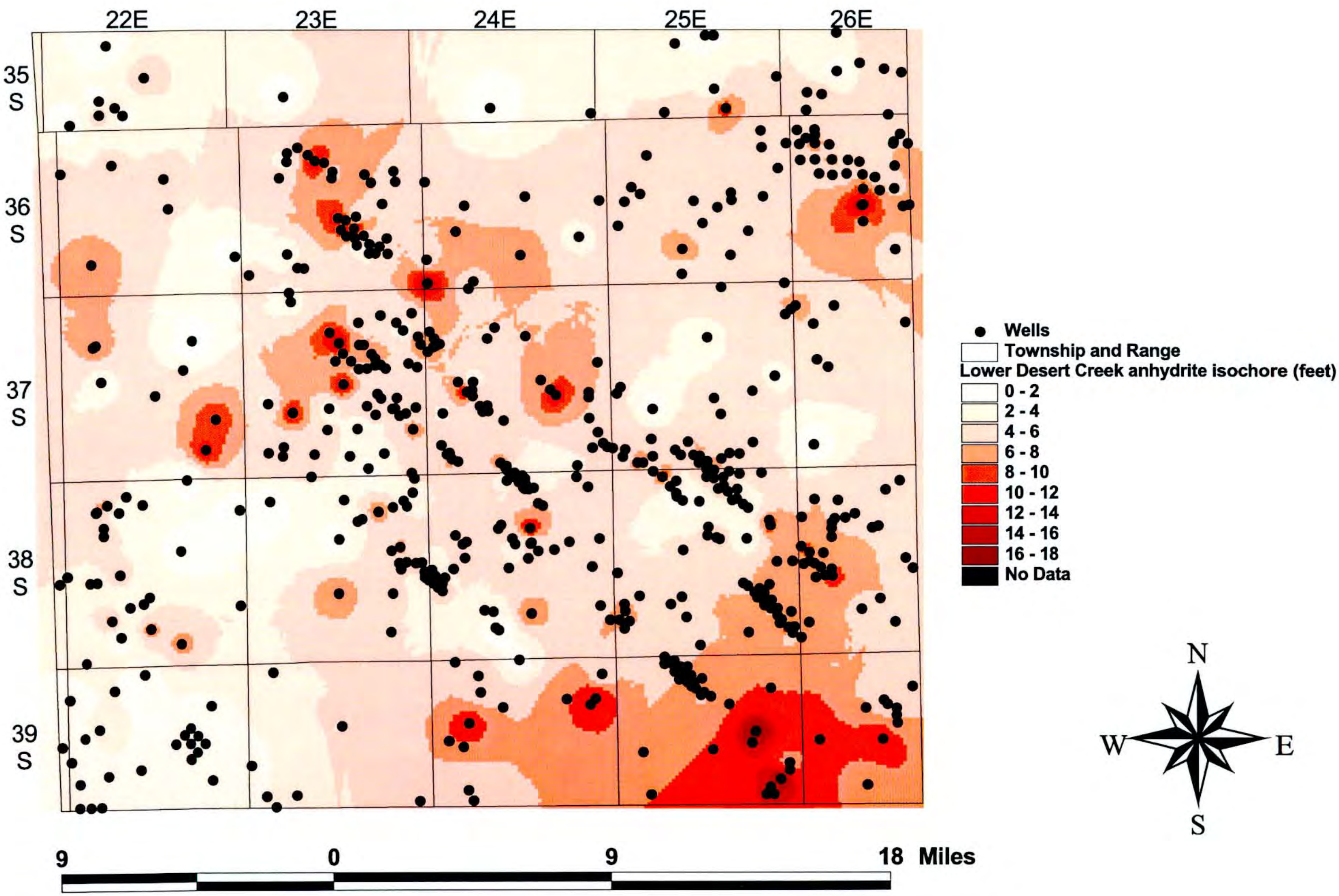


Figure 32. Top of lower Desert Creek clean carbonate, Blanding sub-basin, Utah

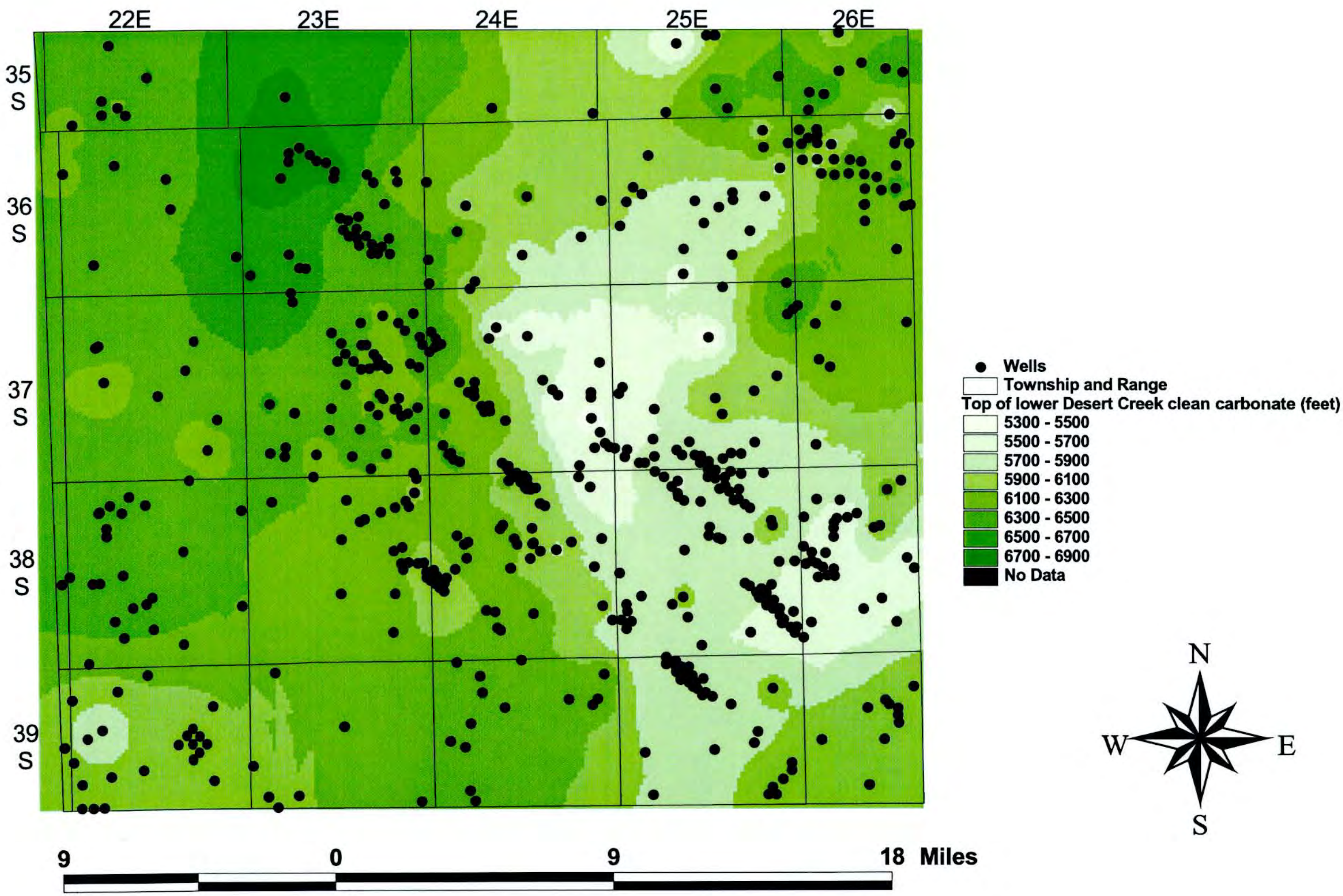


Figure 33. Lower Desert Creek clean carbonate isochore, Blanding sub-basin, Utah

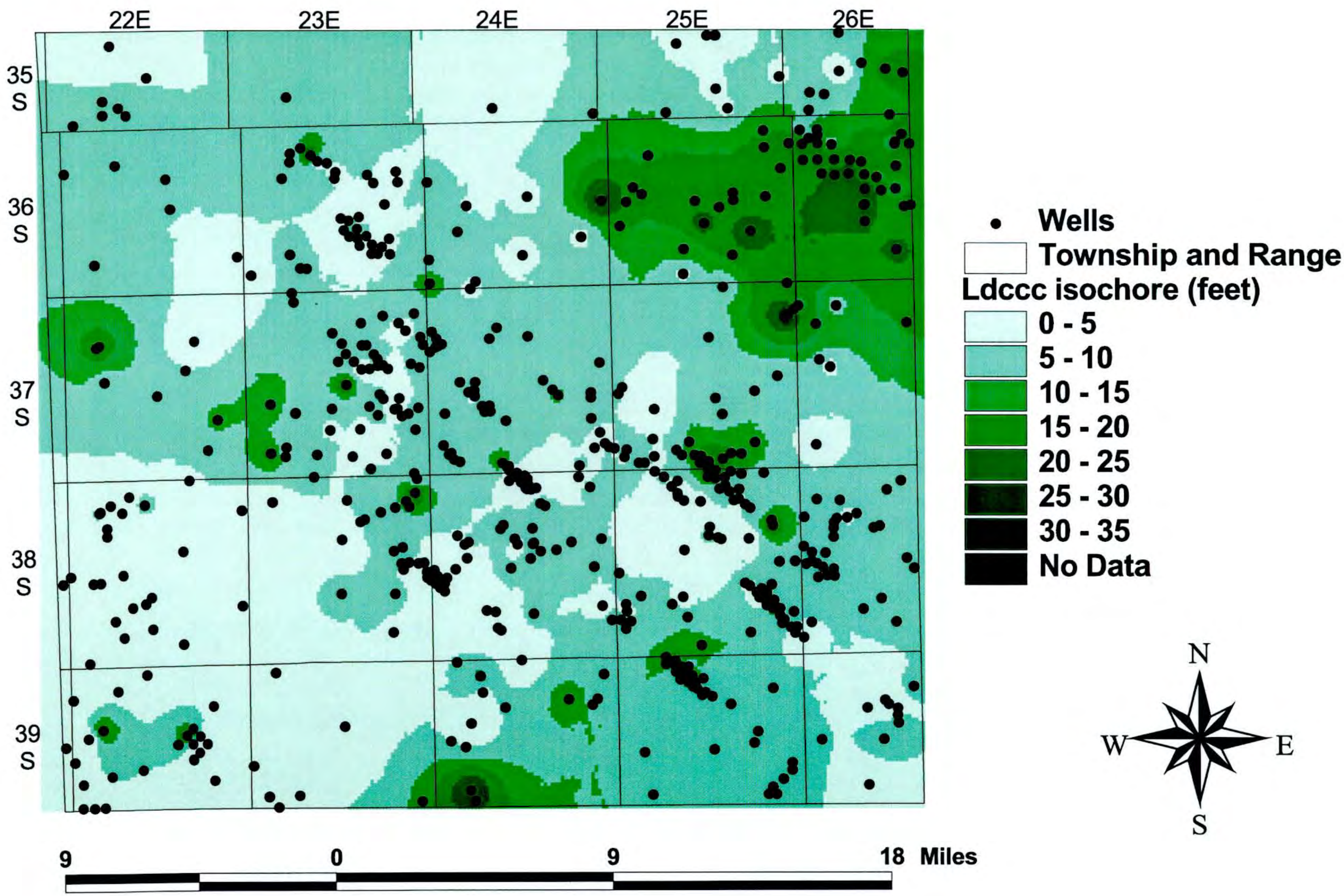


Figure 34. Top of Chimney Rock shale, Blanding sub-basin, Utah

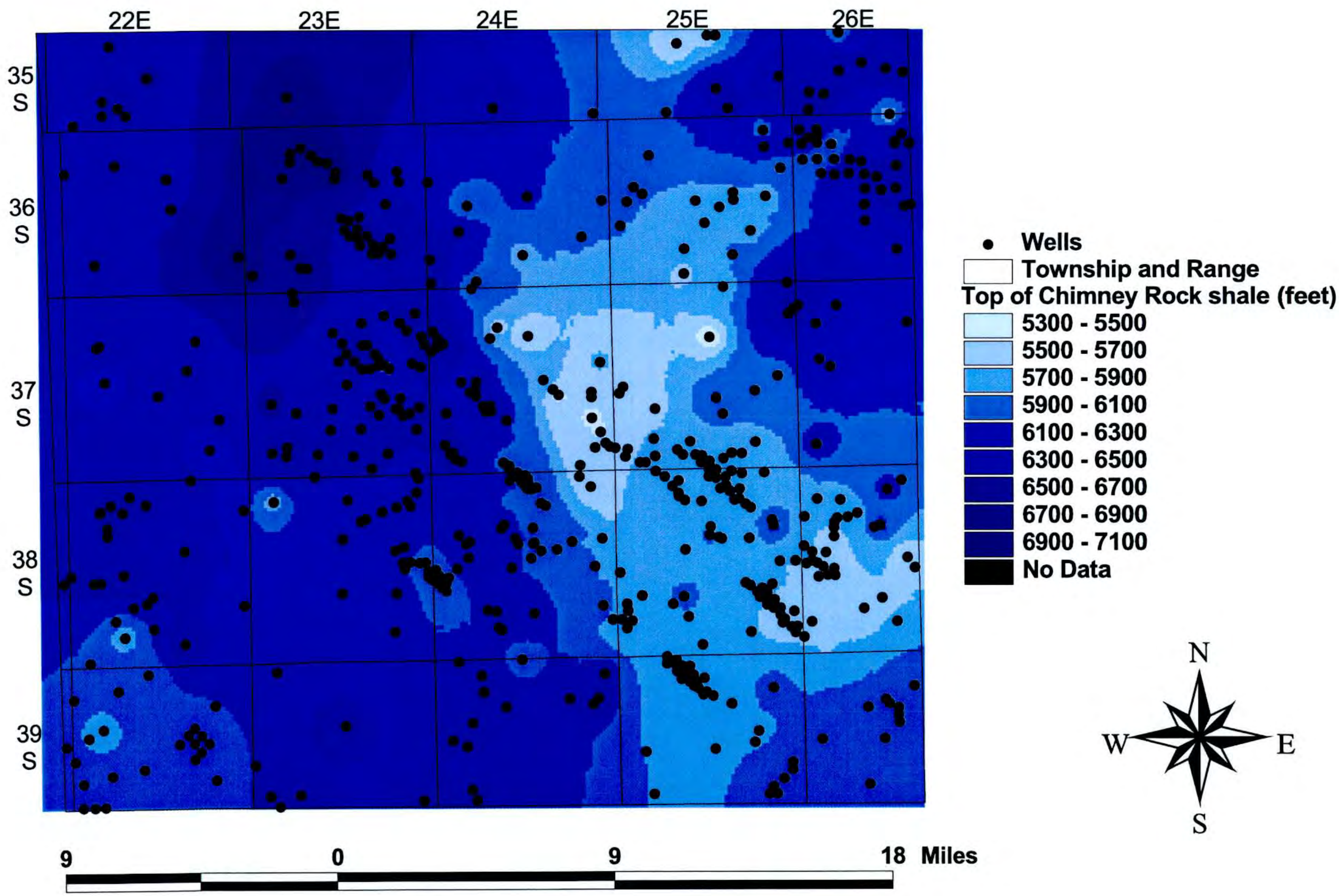
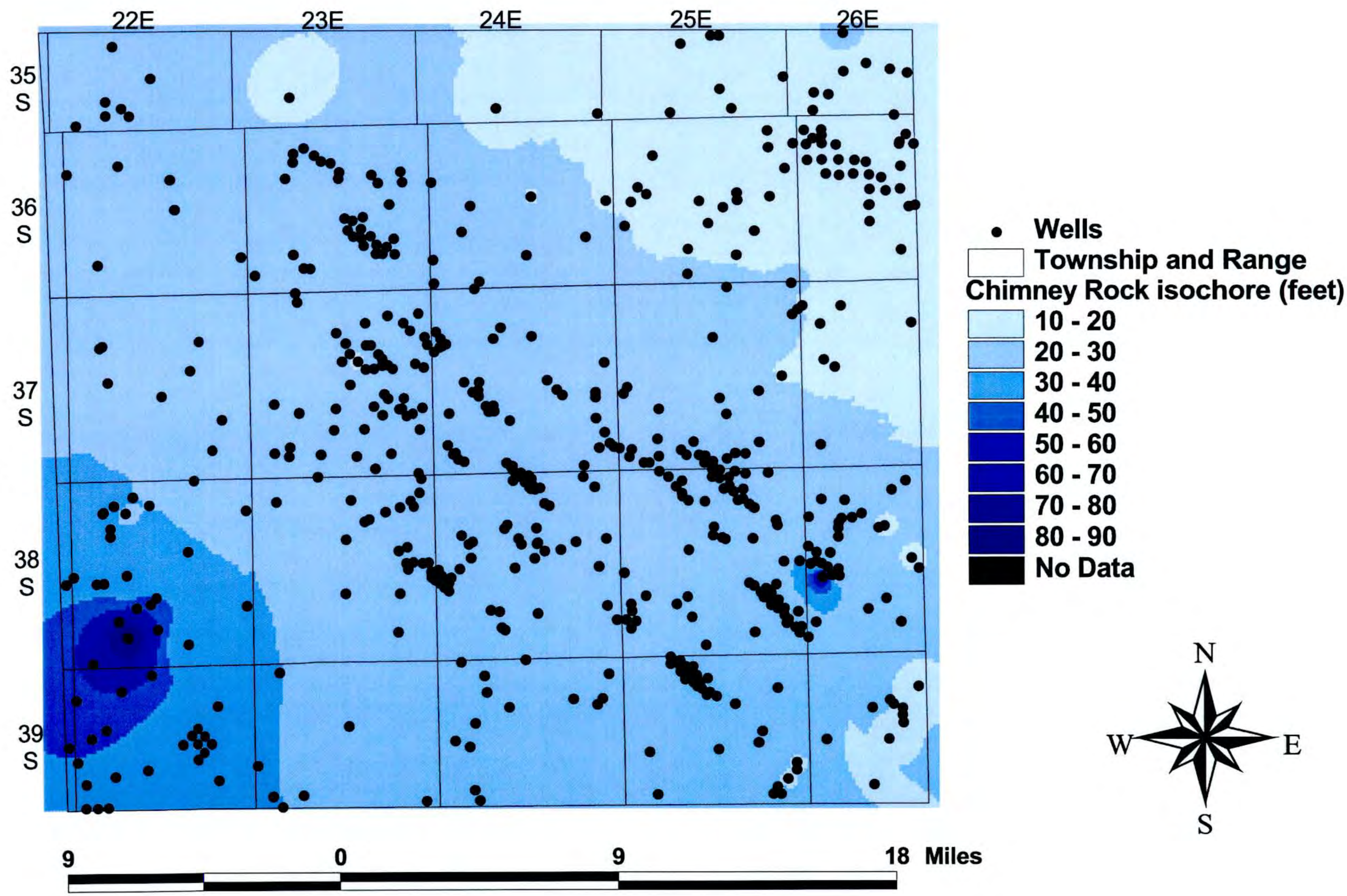


Figure 35. Chimney Rock shale isochore, Blanding sub-basin, Utah



Isochore maps of the shales (figures 19, 25, and 35) indicate possible paleotopographic highs (thins) and lows (thicks) in parts of the region. Thins are shown by light blue shades and thicks are darker shades of blue. The maps display both regional thickness trends and local variations. Topographic highs could be the sites of potential carbonate buildups or phylloid-algal mounds in the Ismay and Desert Creek zones.

Thickness relationships of important stratigraphic intervals and facies types were combined with examination of cores throughout the Blanding sub-basin to provide a significant database for identifying potential targets for horizontal drilling within the small, heterogeneous, phylloid-algal buildups and associated facies in the upper Ismay and lower Desert Creek zones.

Regional subsurface mapping of depositional facies for the two productive intervals of the upper Ismay and lower Desert Creek zones shows considerable spatial heterogeneity of the reservoir and non-reservoir rock types. In the Ismay, the location and shape of several anhydrite-rich, intra-shelf basins play major roles in the deposition and orientation of productive phylloid-algal buildups, as well as the shoreline facies that wrap around these evaporite basins. Facies distal from the anhydrite-filled basins generally contain less favorable reservoir rocks, whereas most phylloid-algal buildups and porous inner-shelf facies are very close to the intra-shelf basins. The Desert Creek zone in the Blanding sub-basin contains several of the same facies as the Ismay zone, the most notable exception being the intra-shelf evaporite basins.

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