Assessing the Technology Needs of Sub-economic Resources

Phase I: Greater Green River and Wind River Basins

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1.0 Introduction

In 2000, NETL conducted a review of the adequacy of the resource characterization databases used in its Gas Systems Analysis Model (GSAM). This review indicated that the most striking deficiency in GSAM's databases was the poor representation of the vast resource believed to exist in low-permeability sandstone accumulations in western U.S. basins. The model's databases, which are built primarily around the United States Geological Survey (USGS) 1995 National Assessment (for undiscovered resources), reflected an estimate of the original-gas-in-place (OGIP) only in accumulations designated "technically-recoverable" by the USGS – roughly 3% to 4% of the total estimated OGIP of the region. As these vast remaining resources are a prime target of NETL programs, NETL immediately launched an effort to upgrade its resource characterizations.

In preparation for this effort, NETL contractors EG&G and Advanced Resources International conducted a review of existing low-permeability assessments to assist NETL in determining the nature of low-permeability resource data available and to evaluate the types of additional data and information needed to properly support NETL gas program R&D planning.

NETL set three primary requirements for its new resource characterization data sources. First, the data must include as much of the existing resource as possible. Instead of datasets that are restricted to resources deemed recoverable with either current technologies, or incremental improvement on existing technology, our models require as much of the gas-in-place as possible. This gives the modeling activity the potential of identifying those R&D approaches that may produce the technology leaps that will render large volumes of "unrecoverable" gas recoverable. Second, the resource must be described in significant detail. Assessments that characterize large volumes of gas using regional averages to not allow the model to sensitively discern the potential impact of various alternative R&D approaches. For example, finely segmenting the resource based on depth alone provides significantly improved modeling of technologies that affect drilling costs. Finally, the resource assessments needed to include information on the reservoir properties that control gas recovery. Assessments that deal with extrapolations of past production rates are to closely tie to past technologies and practices. In the case of low-permeability sandstones, this requirement necessitated estimates of the likely contribution of natural fracturing to bulk permeability.

Upon review of existing data, NETL concluded that no existing data were appropriate sources for its modeling needs, and a decision was made to conduct new, detailed log-based, gas-in-place assessments.

1.1 Summary of Key Prior Resource Assessments

NETL's review focused on the work of the National Petroleum Council (NPC), the United States Geological Survey (USGS: both the national assessments and the in-place studies conducted in cooperation with NETL), and The Scotia Group. The general findings were as follows – subsequent sections outline these studies in greater detail

USGS gas-in-place studies: USGS gas-in-place studies for key western, tight gas basins, provide an invaluable base of information, and form the basis for ongoing efforts. These reports highlighted the concept and importance of basin-center gas formations, providing rationale for off-structure exploration and development of overpressured, low-permeability reservoirs. They also increased the awareness that a truly massive volume of natural gas exists in these basins, providing the impetus for accelerated and targeted technology development. Finally, these studies reaffirmed that a combination of sweet-spot/natural fracture detection and advanced drilling/completion would be required. However, much of the USGS's in-place assessment work is now dated (in particular the 1987 Piceance basin and 1989 Greater Green River basin studies) and the information gained over the past decade needs to be incorporated. Also, the USGS studies, particularly the earlier two, do not provide the detailed disaggregation of the resource that would be needed to support the types of technology modeling envisioned in this effort.

The Scotia Group appraisals: The studies by The Scotia Group provide valuable insight into the USGS's in-place resource estimates. However, Scotia's work to quantify current recoverable volumes does not relate well to the type of information needed by NETL. In many basins, Scotia's work discards 80% or more of the resource as "technically non-viable" without discussion as to the specific conditions and barriers that make these resources presently too costly to produce. Furthermore, as with all assessments that are tied to the specific technology of a given time, the studies will quickly became obsolete and not amenable to renewed assessment with different technology assumptions.

The National Petroleum Council Reports: The NPC assessments, being based on a particular set of technology assumptions, are similarly not amenable to modeling of alternative future technology/policy scenarios. In addition, these studies do not appear regularly, and are not always based on the latest data (the NPC's 1999 report was based primarily from assessments taken from the 1992 study, which was, in turn, based largely on the 1980 study).

The USGS National Assessments: The USGS National Assessments have limited utility for NETL's technology planners and modelers. Although the USGS did not recognize tight gas as part of the national resource base for their 1989 national assessment, these resources were included for the 1995 assessment. However, tight gas resources in several major emerging basins (such as Wind River, Anadarko, and Fort Worth) were not appraised. The appraisal methodology relies on the extrapolation of historical data on well performance and development practices and therefore does not incorporate the role of future technologies in any detail.

1.2 Other Significant Contributions

The following provides brief descriptions of additional resource studies that have contributed to our present understanding of the nation's tight gas resources.

- *1973 Federal Power Commission*: The FPC assembled an industry panel to provide an initial review of the tight gas resources of the Green River, Piceance, and Uinta basins.

The study estimated a resource base of 600 Tcf gas-in-place.

- *1978 Federal Energy Regulatory Commission:* FERC's report relied heavily on the FPC study, and added assessments of the tight gas-in-place for the Northern Great Plains (130 Tcf) and San Juan basin (63 Tcf).

- *1978 Lewin and Associates:* Lewin and Associates provided the initial comprehensive appraisal of tight gas resources. Thirteen high-potential basins were studied. The work was conducted at a play level, allowing for substantial improvement in the estimation of missing data. Lewin used type-well productivities and mapping of prospective areas to estimate 423 Tcf gas-in-place in tight formations. The study excluded formations below 13,000 feet.

Table 1 provides selected results from these early efforts. This work provided the foundation for the 1988 Study for the Secretary of Energy by the Bureau of Economic Geology (BEG) and ICF-Lewin as well as the 1992 study by the NPC. It was these latter two landmark studies that helped to establish industry and public acceptance of the potential of low-permeability reservoirs as major contributors to domestic gas supply.

Table 1: Selected findings of early tight-gas resource assessments (Tcf gas-in-place)

	FPC '73 – FERC '78	**LEWIN 1978**
Northern Great Plains	130	74
Greater Green River	240	91
Uinta	210	50
Piceance	150	36
Wind River		3
Big Horn		24
Douglas Creek Arch		3
Denver		19
San Juan	63	15
Permian/Val Verde		24
Edwards Lime		14
E.Texas/Cotton Valley		67

- *1990-1991 ICF Resources*: Under sponsorship from DOE/METC, ICF conducted detailed field-level studies to determine remaining gas-in-place and expected recoverable volumes for tight gas formations in East Texas (31 Tcf in-place, 6.2 Tcf recoverable) and the San Juan basin (17 Tcf in-place, 2.3 Tcf recoverable).
- *1991-1992 DOE/METC:* METC conducted the initial, and to-date only, extensive well log analysis and mapping to assess the resource potential of the primary low-permeability sandstone formations in the Appalachian basin. The study estimated that 28 Tcf of gas remained in Silurian Clinton sandstones and 25 Tcf remained in the various Devonian and Mississippian sandstones.

- *Reports of the Potential Gas Committee*: Similar to the NPC, the PGC assesses gas volumes that can be expected to be produceable in the future under reasonable future prices and foreseeable technology advances. Resource volumes are divided into probable (roughly equivalent to the concept of reserve growth, i.e., extensions and new pools in established areas), possible (not associated with known fields, but in favorable areas), and speculative (in formations/areas not now productive) categories. PGC's methodology is based on expert estimates of the volume of potential reservoir rock, multiplying that volume by an expected yield, and then discounting the resulting volume for geologic risk. Unfortunately (for NETL's purposes), PGC lumps tight-gas resources with the "conventional" reservoirs into a large category of "traditional resources".

2.0 USGS GAS-IN-PLACE ASSESSMENTS

The resource studies of the late 1970s and early 1980s outlined in Section 1.2 clearly established that the Rocky Mountain basins contained significant volumes of gas in low-permeability formations. Estimates of the resource potential of the Greater Green River basin, for instance, had shown from 90 to 240 Tcf gas-in-place. This gas was marginally- to sub-economic at best given prevailing E&P technologies and economics, and therefore became a prime target for federal R&D efforts. Suspecting that the resource was being significantly under-estimated, the USGS and DOE-METC began work to comprehensively assess the resources present in the major basins. This work was conducted independently from the USGS's regular national assessments (see section 5.0) and employed a drastically different methodology.

For this work, the USGS method was to evaluate the total tight-gas resource-in-place of specific basins through exhaustive volumetric study of vast rock sequences. Only two sacrifices to practicality are noted. First, gas in sandstones less than 10 ft. thick are discarded. Second, gas in normally-pressured sandstones or in units in the transition zone between overpressured and normally-pressure units are not counted in all studies (the GGRB study was limited to the overpressured units). Gas-in-place volumes were determined in the conventional way, with most parameters being based on a sampling of well data or assigned by regional experts. Recoverable volumes were then estimated from in-place numbers by application of estimated recovery factors. A key methodological aspect of these studies is that many of the variables (thickness, porosity, recovery factor, etc.) are expressed as probability functions and processed through a probability model, ultimately yielding a range of possible resource sizes, each with an assigned likelihood of occurrence.

2.1 1987 USGS Piceance basin study *(R.C.Johnson and others; USGS open-file #87-357)*

This initial report utilized the ongoing DOE work at the MWX site to provide a resource assessment of the low-permeability sandstones of the Mesaverde Group in the Piceance basin. The Mesaverde was divided into three stratigraphic plays, a lower (dominantly-marine) Iles play, a thin, intermediate Rollins sandstone play, and an upper (dominantly-fluvial) Williams Fork play. Being marine/shoreline in origin, the Iles includes numerous relatively-continuous sandstones (including the Morapos, Castlegate, Sego, Corcoran, and Cozette). The Rollins (or Trout Creek) sandstone, a particularly widespread blanket sand at the top of the Iles sequence, was regarded as separate play because it is persistently water-bearing. The primarily non-marine sandstones in the overlying Williams Fork play are highly-lenticular and channelized. Each of these three units are divided into basin-center ($R_o > 1.1\%$) and transition (R_o from 0.73% to 1.1%) plays, resulting in six assessed plays.

Total sandstone volumes for each were calculated from isopach maps based on 60 well logs/outcrop sections. All the sandstone in each play was assumed to occur at the play's average depth (with an average overburden) with temperature and pressure based on assumed gradients. Porosity and gas saturations were based primarily on data from the MWX wells. These data were used to create initial in-place resource estimates for each play.

To provide for a probabilistic presentation of these data, each parameter (with the exception of porosity, which is assumed to be perfectly positively correlated with gas saturation) is assigned values at 0%, 50%, and 100% probability levels. The USGS further tweaked the distributions until the two answers matched. These volumes were then aggregated assuming a 75% degree of dependency between the six plays.

In order to calculate the volumes likely to be recovered under specific cost/technology conditions, recovery factors were estimated. These values were also defined probabilistically. Two scenarios were conducted; 1) current technology with \$5.00/Mcf price and 2) advanced technology with unspecified (but high) price. Technology in this case basically means the technical limits on recovery factor.

Table 2: 1987 USGS Piceance basin study results (values in Tcf).

PLAY	**Resources**			**Recovery Factor**		**Reserves**	
	Mean	F05	F95	Cur.	Adv.	Cur.	Adv.
Williams Fk.- b/c	205.6	286.9	133.0	3%	15%	6.0	30.1
Williams Fk. - tran.	116.9	189.5	37.7	3%	18%	3.6	21.6
Rollins - b/c	3.4	6.1	1.6	5%	20%	0.2	0.6
Rollins - tran.	0.6	0.9	0.2	10%	22%	0.05	0.1
Iles - b/c	72.0	107.3	20.0	3%	15%	2.1	10.6
Iles – tran.	24.1	39.4	8.0	6%	20%	1.5	4.9
6-play aggregate	419.6	605.3	274.4			13.4	67.9

2.2 1989 Greater Green River basin *(B.E.Law and others; Wyoming Geological Association; 40th field conference guidebook, pg. 3 - 25)*

This report describes the GGRB Cretaceous and Lower Tertiary overpressured, tight sequence. The assessment encompasses up to 14,000 ft. of stratigraphic section over an area more than 50,000 km^2 in size. The subject rocks range from alluvial plain to marine basin and include marine shales, marginal-marine sandstones with overall blanket geometries, and highly-lenticular fluvial sandstones encased in non-marine shales with associated coals.

The *Cloverly-Frontier Play* includes the sandstones formed during the initial Cretaceous shoreline regression (extension eastward) in the region. It is the deepest play and extends throughout the basin with the exception of the Moxa Arch, which was excluded due to the presence of conventional reservoirs. The overlying *Mesaverde Play* includes the major Upper Cretaceous clastic wedge in which the Rock Springs, Blair, Ericson, Almond, and other sandstone-bearing units prograded eastward over Hilliard-Baxter-Steele-Mancos marine shales. This play occurs mainly in the eastern and northern parts of the basin. The *Lewis Play* consists of isolated sandstones formed within the Lewis Shale during the transgression that drowned Mesaverde environments. Lewis reservoirs occur in the eastern half of the basin. The *Fox Hills/Lance Play* includes marginal marine and fluvial sandstones that prograded eastward across the Lewis Sea at the close of the Cretaceous. These sandstones are included in the assessment only where overpressured in the deeper parts of the basin. The Tertiary *Fort Union* play is the shallowest unit and is only overpressured in a relatively small area of the southeastern (Washakie) basin center.

Table 3: 1989 USGS Greater Green River basin study results

	Cloverly-Frontier	**Mesaverde**	**Lewis**	**Fox Hills Lance**	**Fort Union**
Play Area (ac.)	7,783,000	5,200,000	2,500,000.	2,600,000	331,000
Avg. Thickness	110 ft.	1,350 ft.	400 ft.	675 ft.	600 ft.
Avg. Porosity	5.0%	6.5%	8.0%	7.5%	8.0%
Avg. Depth	17,500 ft.	15,500 ft.	12,000 ft.	10,000 ft.	10,200 ft.
Avg. Gas Sat.	45%	45%	50%	40%	40%
OGIP	304 Tcf	3,347 Tcf	610 Tcf	707 Tcf	96 Tcf
Fut. RF (50^{th}%)	5%	7%	12%	8%	8%
Future RGIP	16.4 Tcf	265.2 Tcf	81.8 Tcf	61.5 Tcf	8.3 Tcf
Curr. RF (50^{th}%)	1%	1%	2.5%	1%	1%
Current RGIP	3.7 Tcf	41.4 Tcf	18.0 Tcf	8.4 Tcf	1.1 Tcf

Play area was determined by identifying the vertical and horizontal distribution of overpressuring and determining how much of the play s sandstone distribution fell within these limits. The authors used whatever data they could gather do to this; often this was mud weight and temperature data, although some DST and pressure-test data were available. Rock thickness was based on sandstone isopach mapping. Porosity distributions by play were generally based on expert opinion informed by assumed porosity-depth relationships. One key assumption of the work is that *the sandstones are assumed to be uniformly gas-charged*. Water saturation is allowed to vary only in relation to estimated porosity and water is assumed to be present only at irreducible levels. Pressure, temperature and Z-factors are estimated in a standard way. Recovery factors (1% to 5%) were assumed for each play, also as a distribution, for two cases consistent with those used in the Piceance study.

Of course, what makes this study notable, is the magnitude of the total gas-in-place estimate; 5,075 Tcf, more than five times that of the earlier Piceance basin study. Two-thirds of this volume was found to be contained within the various sub-units of the Mesaverde Play. The key parameter estimates and results by play are given in Table 3.

2.3 1996 Wind River basin study *(R.C. Johnson and others, Open-file #96-264)*

As with other USGS assessments, the study area is divided into geologic plays that are separately analyzed. Eight stratigraphic units are considered, most with overpressured (equated to areas with temperature of 300 ^{o}F or higher), moderately-pressured (present vitrinite reflectance exceeds 1.1%), and transitional (Ro between 0.73% and 1.1%) plays. Each of the 22 assessed plays is partitioned into numerous sub-plays (analogous to large, irregular, grid cells) to allow for some regional variation in volumetric properties.

The sub-plays are generally areas of relatively consistent drilling depth. For each sub-play, depth, area (closure), pay thickness, porosity, saturation, temperature, pressure, and trap fill (which seems to be analogous to expected dry hole percentages) are estimated. A degree of variance around the estimated mean is also estimated (for example, thickness varies to values plus and minus 50% from the mean at the 5th and 95th percentiles). A single set of variances, as well as temperature, pressure and Z-factor gradients (all linear functions of depth) were used for all sub-plays within each play. Sub-play resources are calculated, then aggregated to provide mean estimates at the play level. Play-level results are then aggregated for the study area. Although the specific report doesn't use the name, this study is the first to use GRASS (the Gas Resource Assessment Spreadsheet System), an Excel application of the USGS probabilistic methodology. It is also the first to use a large number of grid-cell/sub-plays to allow for regional differentiation of input parameters.

Table 4: 1996 USGS Wind River basin study results

	Area	**Por**	**Sg**	**Fill**	**F50**	**F95**	**F05**
Frontier - overpressured	2,093	6	50	100	118	76.5	170
Frontier - mod. pressured	695	7	50	100	29.2	18.8	42.6
Frontier - transitional	269	7	50	50	3.6	1.7	7.6
Cody Sh. - overpressured	413	6	50	100	30.6	19.9	44.2
Cody Sh. - m. pressured	413	7	50	70	19.2	12.4	28
Cody Sh. - transitional	233	7	50	30	2	0.8	3.8
Fales SS - overpressured	41	6	50	100	1.2	0.8	1.7
Fales SS - m. pressured	285	7	50	100	7.3	4.7	10.7
Fales SS - transitional	82	7	50	30	0.5	0.2	1.3
Mv-shoreline - o/p	636	6	50	100	34.7	22.6	50.2
Mv-shoreline - m/p	960	7	50	50	17.2	11.1	25.2
Mv-shoreline – trans.	533	7	50	20	3.8	1.6	7.4
Mv-fluvial - o/p	489	6	50	100	48.9	31.9	70.8
Mv-fluvial - m. pressured	1,067				71.8	46.3	105
Mv-fluvial – transitional	582	7	50	50	17.4	7.3	33.5
Meeteetse - o/p	498	6	50	100	51.3	33.4	74.2
Meeteetse - m. pressured	886	7	50	100	59.7	38.4	87.1
Meeteetse – transitional	470	7	50	50	12.5	5.2	24
Lance - mod. Pressured	1,206	7	50	100	316	203	461
Lance – transitional	927	7	50	50	48.9	20.5	94.1
L. Ft. Union – Sealed	1,348	7	50	0-70	83	37.4	153
L. Ft. Union – Unsealed	420	8	50	0-30	18.2	7.7	35.1
Aggregated TOTAL					995	603	1,530

2.4 1999 Bighorn basin study *(R.C. Johnson and others; USGS open-file #99-315-A)*

The authors used the scant drilling information available for the central Bighorn basin to guide the USGS fourth Rocky Mountain region volumetric assessment of the in-place resources in a likely basin-centered, low-permeability gas accumulation. Methodological alternations were necessary to accommodate the near lack of real data for this basin.

The resource occurs within the Upper Cretaceous formations ranging from the Frontier (deepest) to the Lance. Much of the accumulation is believed to be normally pressured or underpressured.

A moderately-sized area of overpressuring has been identified below 14,000' in the basin center from mudlog and drillstem test data. As with the Wind River study, sub-thrust areas along the western margin of the basin were not assessed.

Eight plays were identified as follows: 1) Muddy sandstone overpressured, 2) Muddy sandstone transitional, 3) Frontier Formation overpressured, 4) Frontier Formation transitional, 5) Mesaverde Formation overpressured, 6) Mesaverde Formation transitional, 7) Meeteetse Formation, and 8) Lance Formation. The USGS used the GRASS methodology to produce the volume results.

Table 5: 1999 USGS Bighorn basin study results

	Area	**Por**	**Sg**	**Fill%**	**F50**	**F95**	**F05**
Muddy - overpressured	889	7	50	100	13.4	8.7	19.6
Muddy - transitional	1,357	7	50	50-70	5.5	2.3	10.0
Frontier – o/p	1,047	7	50	100	41.9	27	61.1
Frontier – transitional	1,937	7	50	50-70	24.6	10.3	47.4
Mesaverde – o/p	301	7	50	100	38.5	24.8	56.2
Mesaverde – trans.	1,781	7	50	20-70	75.8	31.8	146
Meeteetse – trans.	1,805	7	50	50-70	44.9	18.4	86.5
Lance – transitional	1,444	7	50	50-70	89.8	37.6	173
Aggregated TOTAL					334	161	600

The authors speculate that the Bighorn basin contains lower resource volumes, in comparison to the similarly-sized accumulation in the Wind River basin, because of 1) a generally-lower thermal maturity and 2) a lack of widespread overpressuring (only 28% of the appraised resource is from the overpressured plays).

3.0 SCOTIA GROUP RESOURCE/RESERVE ASSESSMENTS (1993-1998)

Beginning in 1993, NETL commissioned the Scotia Group to re-assess the various USGS estimates of total tight gas-in-place in selected western basins and to estimate how much of that gas should be recoverable under current cost and technology conditions. Re-assessment was probably deemed necessary given perceived skepticism over the large volumes presented by the USGS (particularly the 5,000 Tcf GGRB figure). The USGS numbers were indeed revised downward by Scotia, *primarily by showing that the USGS methodology possibly over-estimated typical porosities and water-saturations* in all the basins. The Scotia methodology changed very little with each study, as a result, all four reports are described together.

3.1 Scotia Methodology

The Scotia reports used a volumetric approach to determine in-place resources, then applied various cost and performance criteria to partition the resource among different resource and reserve categories. The reports give a single estimate for each resource category, then applies a distribution of recovery factors to obtain different potential-additions-to-reserve numbers, each with a given probability of occurrence.

Like the volumetric USGS studies, subsurface well log correlation and mapping were used to obtain play area estimates. Scotia also used gamma-ray-based (50% cut-off) sand counts to get first approximations of pay thicknesses, and like the USGS, only sands over 10 ft. in thickness were included. Whereas the USGS relied on a panel of experienced geologists to assign porosities and water saturations to each play, Scotia used log (some core) analyses, tailored for tight sandstone applications, to determine porosities and saturations for various depth ranges within each play. Scotia s data indicated much lower typical porosities and higher water saturations than the USGS had assigned, resulting in significantly lower GIP estimates. Specifically, Scotia found that porosities were not normally-distributed around a mean (as assumed by the USGS), but skewed to the lower values. Also, Scotia determined that the lower-porosity units tended to have higher than expected water saturations.

To high-grade the resource into categories that were likely to contribute to reserves (i.e., contain economically-recoverable gas at current technologies), cut-offs of porosity (varying from 4-10.5% depending on play and depth), Sw (60-65%), and Vsh (35%) were established for separate 500’-thick depth slices. These cut-offs generally attempt to limit the rock volume to that with expected permeability greater than 0.001 md. (Note: for the GGRB study, 1,000’ depth slices were used). Porosity and Sw values/distributions were generated for both the base resource and technically-viable volumes from digitized well logs. Pressures and temperatures are calculated from gradients to derive Formation Volume Factors. Base resource gas-in-place (in rocks with Vsh<50%) and gas-in-place expected to contribute to reserves (Vsh<35% and porosities and Sw above the depth/play dependant cut-offs) were calculated. Table 6 compares the various Scotia estimates with those prepared by the USGS.

Reserves are typically the subset of economically-recoverable volumes that have already been proved by the wellbore. This definition is typically slightly modified for application to the low-permeability, basin-centered resources (the subject of this memo) to account for the vast volumes that have not actually yet been discovered, but are nonetheless, widely accepted to exist.

Table 6: Comparison of USGS and Scotia gas-in-place assessments

Basin	USGS GIP estimate	Scotia GIP estimate
Greater Green River	5,064 Tcf	1,974 Tcf
Uinta		396 Tcf
Piceance	420 Tcf	307 Tcf
Wind River	995 Tcf	488 Tcf
Bighorn	334 Tcf	

Scotia further analyzed these resources to determine volumes likely to contribute to reserves. As a first cut, large portions of the resource are excluded as *technically-nonviable* (Table 7). Porosity (and associated calculated permeability), saturation, and volume-of-shale cutoffs that varied with depth were used to identify this fraction. It appears that these values are determined based on estimates of how much porosity is necessary in a given depth range to make locations economically-feasible (the assumption is that they must have permeability (estimated from porosity) greater than 0.001 md to be producible at commercial rates given 1993 costs and 1993 capabilities in hydraulic fracturing). Therefore, some of the resource labeled technically-nonviable may in fact be technically possible, but only *economically*-unviable (and only economically-nonviable at the time of the writing).

Table 7: Scotia studies **-** distinction of technically viable and non-viable portions of OGIP

	Gas-in-place	Technically-viable	Tech. Non-viable
Greater Green River	1,974 Tcf	848 Tcf (43%)	1,126 Tcf (57%)
Uinta	396 Tcf	71 Tcf (18%)	325 Tcf (82%)
Piceance	307 Tcf	53 Tcf (17%)	254 Tcf (83%)
Wind River	488 Tcf	62 Tcf (13%)	426 Tcf (87%)

Scotia further divided the technically-viable resources into those that occur in reservoirs with demonstrated production and those that, thus far, have not responded to typical completion and stimulation efforts (Table 8). The *non-demonstrated resources* are those that *should* be economically-productive based on available data, but have thus far not been economically recoverable in practice. Unexpected highly-lenticular geometries of reservoirs is one of the prime suspects for making apparently viable resources non-demonstrated.

Table 8: Scotia studies **-** distinction of demonstrated and non-demonstrated portions of the technically-viable resource

	Technically-viable	Demonstrated	Non-demonstrated
Greater Green River	848 Tcf	615 Tcf (73%)	233 Tcf (27%)
Uinta	71 Tcf	18 Tcf (25%)	53 Tcf (75%)
Piceance	53 Tcf	45 Tcf (85%)	8 Tcf (15%)
Wind River	62 Tcf	16 Tcf (26%)	45 Tcf (74%)

A further subdivision (Table 9) of the demonstrated resource category is based on the position of the resource relative to a conceptual economic basement . This basement is the depth below which increased drilling costs and technical/geologic risks tend to make average-sized prospects in a particular play *uneconomic.* This depth varies by play, and will change with time as costs and technologies change. *Established resources* occur above the economic basement, *non-established resources* are located below economic basement and above the deepest commercial production. Note that for non-established resources, it is the commerciality that is not firmly established (generally due to depth); the presence and produceability of the gas is generally accepted. *Speculative resources* occur below the deepest commercial production at the date of the report (commerciality is doubtful and gas presence is unestablished). The speculative category was devised after the GGRB study was completed.

Table 9: Scotia studies - distinction of established, non-established, and speculative portions of the demonstrated resource.

	Demonstrated	Established	Non-established	Speculative
Greater Green River	253 Tcf	68 Tcf (27%)	185 Tcf (73%)	
Uinta	18 Tcf	4 Tcf (22%)	9 Tcf (50%)	5 Tcf (28%)
Piceance	45 Tcf	9 Tcf (20%)	15 Tcf (33%)	21 Tcf (47%)
Wind River	16 Tcf	8 Tcf (50%)	0 Tcf	8 Tcf (50%)

Calculation of economic basement was done separately for each play. Current EUR distributions were used to estimate the expected revenue. Dry hole risks were assigned to each play (for the GGRB study, all wells in the play were included - the two later studies excluded wells located in non-demonstrated areas). The expected monetary value of production is then plotted versus drilling cost (a proxy for depth) - the point where increasing cost reduces EMV to zero is the economic basement.

Reserves (Table 10) are subsets of both the established and non-established resource fractions. These are the maximum volumes that can be profitably recovered assuming a fully efficient drilling pattern and excluding existing wells. Scotia describes that the key factor in estimating reserves in tight sands is the determination of drainage area (and shape) as it relates to the prevailing spacing. The relative recovery of different wells within the drainage area is thought to be consistent (approximately 85%) and a function of the abandonment pressure set by current economics. Decline curves were used to estimate EUR from producing wells, although seasonal curtailment and other external factors complicated this. Average production profiles by play were created and analyzed to determine maximum drainage radius.

The Scotia work in the Rocky Mountain areas has provided a solid review of the USGS in-place resource estimates. However, Scotia's work clearly does not provide the type of information required by NETL for two reasons. First, in many basins, Scotia qualifies 70% or more of the resource as technically-non-viable. What is missing is an assessment of the specific conditions of the resource that currently makes it non-viable, and what work could be done that could make more of the resource viable. An appraisal that indicated a basin's potential for improving its technically-recoverable resource base would be very valuable to R&D planners. This thinking also applies to the non-demonstrated and non-established portions of the viable resource. What conditions are making the resource too costly to produce, and what degrees/types of technology advancement are needed. The second issue derives from the fact that the Scotia reports imposed current conditions (cost, technology). Because these parameters change with time, the studies can quickly become obsolete.

Table 10: Scotia studies - recoverable reserve (current technology) fractions of the established and non-established resources

	Reserves - established resources	Reserves – non-established resources
Greater Green River	23 Tcf	12.0 Tcf
Uinta	0.9 Tcf	2.3 Tcf
Piceance	2.6 Tcf	3.0 Tcf
Wind River	2.1 Tcf	0.0 Tcf

Table 11: Scotia Studies **-** results by play

	Resources			Reserves	
Play	**Base (Tcf)**	**Viable (Tcf)**	**Establ. (Tcf)**	**Estab. (mean)**	**Non-estab. (mean)**
UINTA: Wasatch	59.9	7.1	3.8	1.33	0.55
UINTA: Mesaverde	335.6	63.6	None	None	1.70
PICEANCE: Marine	85.6	26.6	2.8	0.78	2.16
PICEANCE: Paludal	52.3	8.2	None	None	None
PICEANCE: Fluvial	141.2	13.3	5.7	1.58	None
PICEANCE: Multi-pay	28.2	5.2	0.9	0.20	0.78
WIND RIVER: Frontier	61.1	23.5	1.1	0.53	
WIND RIVER: Cody	61.0	7.4	1.7	0.50	
WIND RIVER: Mesaverde	92.6	5.7	0.3	0.14	
WIND RIVER: Meeteetse	89.7	12.5	None	None	
WIND RIVER: Lance	176.4	11.4	4.3		
WIND RIVER: Ft. Union	6.9	1.0	1.0	0.51	
GGRB: Cloverly/Frontier	285	252	None	None	3.07
GGRB: Mesaverde/Almond	228.2	71.7	40.1	14.2	3.2
GGRB: Mesaverde/Ericson	636.2	231.1	None	None	3.5
GGRB: Mesaverde/Rock S.	102.0	58.0	None	None	None
GGRB: Mesaverde/Blair	7.3	5.0	None	None	None
GGRB: Mesaverde/Undiff.	83.5	26.0	None	None	None
GGRB: Lewis	229	60.0	27.0	8.4	3.6
GGRB: Lance/Fox Hills	349	125	None	None	None
GGRB: Fort Union	54	20	None	None	None

4.0 NATIONAL PETROLEUM COUNCIL STUDIES

As part of its continuing support of DOE and the Secretary of Energy, the National Petroleum Council (NPC) has prepared three landmark natural gas studies over the past 20 years that address low-permeability resources and reserves. The initial study, completed in 1980, was devoted specifically to the size and recoverability of low-permeability resources. It included data on ten appraised basins plus information on other non-conventional sources. The second study, completed in 1992 (titled "The Potential for Natural Gas in the United States"), re-examined low-permeability resources as part of a larger review of domestic natural gas supplies. This study updated the information on the ten basins appraised in 1980, and added new resource information on the Appalachian, East Texas, Arkansas-Louisiana, Texas Gulf Coast, Anadarko, and Permian basins tight gas formations. The most recent, completed in 1999, ("Meeting the Challenges of the Nation's Growing Natural Gas Demand"), addresses the key issues surrounding the development of domestic natural gas, including low-permeability resources. The latest study provided only minor updates to the resource numbers given in the 1992 report, making adjustments only for basins and plays where actual drilling and development results have deviated widely from the 1992 projections. A new study by the NPC is now in the initial stages.

4.1 1999 NPC Study

The 1999 NPC study devoted considerable attention to addressing various conditions that may restrict future gas supply. The NPC found many reasons to be optimistic about the future of gas, as the resource base appears to be sufficient to support high demands, at least through 2015; however, the following issues and concerns related to low-permeability resources were raised:

- Future supplies will clearly be dependent on continuing technology advance. NPC notes a concern that it may be difficult to maintain the current pace of technology advancement given ongoing trends in industry and federal R&D spending.

- A large proportion of the nation's tight gas resource is located on federal lands, especially in western onshore basins. NPC provided an initial review of the impact of federal land access and suggested that further analyses is necessary to allow informed discussion as to the appropriateness of various federal policies.

- As the nation turns to unconventional sources of supply, the average productivity of wells will decline, resulting in an ever-increasing number of wells to supply a given volume. NPC notes a concern that the domestic industry may not be capable of such activity given capital and infrastructure limits (including the availability of rigs and skilled personnel).

The NPC remained confident that these challenges will be met, and projected an increase in domestic natural gas production from 19 Tcf per year to 27 Tcf per year in 2015. Tight gas sandstones are expected to contributed significantly to this production increase - annual tight gas production is expected to roughly double from 3 to 5.7 Tcf per year. NPCs predictions are based on a technically-recoverable unconventional natural gas resource base of 290 Tcf (current technology) to 372 Tcf, with nearly two-thirds of that resource held in tight sands (Table 12).

Table 12: Technically-recoverable low-permeability resources included in the 1999 NPC study – by resource type (Tcfg).

Resource	Current Technology	Advanced Technology
Tight Gas	177.6	230.6
Gas Shales	38.8	52.6
Coalbed Methane	58.4	74.0
Other	14.7	14.7
TOTAL	289.5	371.9

Table 13: Technically-recoverable low-permeability sandstone resources included in the 1999 NPC study – by region (Tcfg).

Region	Current Technology	Advanced Technology
Appalachia	13.4	18.3
Arkla – E. Texas	23.6	29.8
Texas Gulf Onshore	8.3	9.1
Rocky Mountains	104.8	137.0
Mid-Continent	12.8	16.9
Permian Basin	14.7	19.5
Lower 48 TOTAL	177.6	230.6

The 1999 NPC study relies heavily on the low-permeability resource volumes developed in the older 1980 study. A few modest adjustments were made when current activity and expectations differed significantly from the 1980 assumptions. For tight gas, the changes were modest, primarily reflecting reduced tight gas estimates for the San Juan basin. Small upwards adjustments were made for tight gas resources in East Texas and Appalachia.

4.2 1992 NPC Study

The second NPC study incorporated much of the data from the 1980 assessment, gathered industry input for missing tight gas plays, and utilized the 1990-91 ICF data for formations in East Texas and the San Juan basin. The study included only those formations that NPC felt would be likely industry targets through 2010. To determine likely production levels at various price and technology scenarios, NPC utilized GRI/EEA s Hydrocarbon Model. The NPC concluded that 232 Tcf can be extracted from tight gas sands using 1991 technologies. Assuming that technology improvements continued to 2010 at historical rates, NPC estimated that 349 Tcf could be recoverable by 2010 (see Table 14).

The NPC estimated that technology advancements over the preceding two decades had resulted in annual reduction in drilling costs of approximately 3 to 4% per year and expansion of the resource base by approximately 0.7% per year. Both of these historical trends were anticipated to continue, or accelerate, through 2010. Model results indicated that these continued advances would result in a reduction in gas prices of nearly $1/Mcf and an increase in supply of nearly 3 Tcf per year by 2010. As a result of this technology, the NPC estimated that 349 Tcf of gas could be extracted with 2010 technology. Additional tight gas, bringing the total recoverable to 437 Tcf, could be realized with a “second generation” of advanced technology that were postulated to appear by year 2030.

Table 14: 1992 NPC study results (technically-recoverable tight gas at current technology)

	New fields	Old fields	New plays	TOTAL
Appalachia	3.4	0.0	10.5	13.9
Ark.-La.-Tex.	4.2	4.2	19.0	27.4
S. Tex. Onshore	7.1	5.5	5.8	18.4
Williston	0.4	0.3	0.0	0.7
Rockies Forelands	26.4	7.3	89.9	123.6
San Juan basin	1.3	6.5	0.0	7.8
Mid-continent	8.4	2.7	10.8	21.9
Permian	2.3	4.0	12.4	18.7
TOTAL	53.6	30.4	148.4	232.4

4.3 1980 NPC Study

For their initial work on non-conventional resources, the NPC provided estimates of the tight gas resource potential of 10 high-potential basins (primarily in the Rockies and Texas). These estimates were made for the near-term, single most productive formations that industry would most likely target. The NPC then used these data to guide the assessment to the remaining known tight gas regions in the U.S. The NPC provided estimates for total gas-in-place, maximum recoverable volume, and likely recoverable gas for different cost and technology scenarios. NPC estimated 444 Tcf in-place in the priority basins with an additional 480 Tcf potential in speculative areas. This study excluded resources below 15,000 feet.

Table 15: 1980 NPC tight gas resource assessment (values in Tcf gas)

	OGIP	**Technically-Recoverable**	**Base tech. & $2.50 price**	**Adv. Tech & $2.50 price**
Great Plains-Williston	147.7	100.1	54.7	74.0
Greater Green River	136.1	86.5	3.1	12.4
Wind River	33.7	23.3	7.0	8.8
Uinta	10.5	15.3	12.2	14.8
Piceance	49.1	33.0	12.9	12.9
Denver	13.2	7.9	0	0
San Juan	3.3	2.2	0	1.5
Val Verde (Ozona/Sonora)	4.5	2.8	0	1.7
Edwards Lime (trend)	14.3	8.7	2.1	8.1
Cotton Valley (trend)	21.9	12.8	5.4	8.4
Sub-total: Appraised	**444**	**292.6**	**97.4**	**142.6**
Extrapolated				
Other Western	69.5	48.9	15.0	17.3
Other Southwestern	183.5	113.4	37.6	87.6
Mid-Continent	8.1	5.4	1.3	4.0
Eastern	227.5	139.9	45.2	107.2
Sub-total: Extrapolated	**480**	**307.6**	**99.1**	**216.1**
TOTAL	**924**	**600**	**197**	**359**

5.0 USGS NATIONAL ASSESSMENTS

The USGS included tight gas sandstones for the first time in its 1995 assessment. The USGS included tight sandstones within a new category called "continuous accumulations". To assess these accumulations, the USGS devised a new methodology that differed significantly from that typically employed in the national assessment. The method was also much different from the volumetric approach used in the ongoing USGS gas-in-place studies described earlier. Although the play-based approach was retained, a USGS model called UNCLE was used to calculate the probable future additions to reserves from estimates of geologic risk, play area, success rates, and expected EURs. The success ratio and EUR estimates were based on data from existing wells.

Table 16: 1995 USGS National Assessment – technically-recoverable resources estimated for continuous-type plays in sandstones

	Technically-recoverable gas (Tcf)		
	95% chance	**5% chance**	**Mean**
Region 2 – Pacific Coast			
05 Oregon and Washington	2.8	30.9	12.2
Region 3 – Colorado Plateau and Range			
20 Uinta and Piceance basins	11.6	23.4	16.7
21 Paradox basin	0.05	0.5	0.2
22 San Juan basin	10.7	36.9	21.2
Region 4 – Rocky Mountains			
28 Central Montana	19.9	79.0	43.2
31 Williston basin	0.1	0.2	0.2
37 Southwestern Wyoming	56.0	213.5	119.3
39 Denver basin	1.5	5.7	3.2
Region 6 – Gulf Coast			
47 Western Gulf	1.8	3.7	2.6
49 East Texas basin	3.6	9.4	6.0
Region 8 – Eastern			
67 Appalachian basin			46.0
TOTAL			**229.3**

Specific findings of the USGS relative to low-permeability formations are as follows:

- An unlikely extraction effort would be required to obtain all the gas deemed as recoverable – amounting to 960,000 productive wells and 570,000 dry holes.

- Most low-permeability sandstone gas would be extracted from a relatively small subset of the productive wells: 50 % of the recoverable resource would be produced from 100,000 wells averaging about 1.5 Bcf per well; or 75% would be produced from 250,000 wells that would average about 0.5 Bcf per well.

- A subsequent economic analysis of the low-permeability resources (USGS Circular 1145) judged that only 21 Tcf of the technically-recoverable resource was economically-recoverable at a $2.00/Mcf gas price. A rise in price to $3.34/Mcf was expected to add only 7.5 Tcf additional gas to the economically-recoverable category. Of this 28.5 Tcf recoverable at $3.34/Mcf price, 11.7 Tcf occurred in the San Juan basin, 5.5 Tcf in the Louisiana-Mississippi Salt basins, and 5.2 Tcf from Central Montana. The Rocky Mountain region contributed only 5.5 Tcf with 3.3 Tcf from southwestern Wyoming and 2.2 Tcf from Uinta-Piceance.

Table 17: 1995 USGS national assessment – details on additional areas

Play (cell size in acres)	**Play Prob.**	**Success Ratio**	**Mean Number open cells**	**Est. EUR per cell (mean)**	**Adds to reserves (mean)**
GGRB: Cloverly/Frontier	100%	60%	29,000	1.43 bcf	37.3 Tcf
GGRB: Mesaverde	100%	70%	24,102	1.80 bcf	51.7 Tcf
GGRB: Lewis	100%	70%	13,739	1.31 bcf	19.0 Tcf
GGRB: Fox Hills/Lance	100%	70%	9,500	0.90 bcf	10.2 Tcf
GGRB: Ft. Union	100%	70%	1,180	0.80 bcf	1.0 Tcf
Piceance: Williams Fork	100%	55%	10,304	0.92 bcf	4.9 Tcf
Piceance: Isles	100%	55%	10,508	0.90 bcf	4.8 Tcf
Uinta: Wasatch East	100%	88%	1,240	1.40 bcf	2.1 Tcf
Uinta: Wasatch West	100%	30%	1,132	1.35 bcf	0.5 Tcf
Uinta: Mesaverde/basin flanks	100%	60%	6,132	1.06 bcf	3.8 Tcf
Uinta: Mesaverde/deep syncline	100%	20%	3,200	1.06 bcf	0.6 Tcf
Columbia River: sub-basalt (160)	100%	70%	7,037	1.42 Bcf	12.2 Tcf
San Juan: Dakota (160)	100%	60%	9,266	1.48 Bcf	8.2 Tcf
San Juan: Mesaverde (160)	100%	55%	7,396	2.36 Bcf	9.6 Tcf
San Juan: Pictured cliffs (160)	100%	50%	7,294	0.90 Bcf	3.3 Tcf
Montana: Bio. gas - hi (160)	100%	80%	7,520	0.90 Bcf	5.4 Tcf
Montana: Bio. gas - med (160)	100%	70%	67,354	0.43 Bcf	2.0 Tcf
Montana: Bio. gas - lo (160)	100%	50%	119,832	0.26 Bcf	1.5 Tcf
Williston: Niobrara (320)	80%	33%	68,752	0.11 Bcf	1.9 Tcf
Denver: J-sand. deep (320)	100%	60%	2,315	0.60 Bcf	0.8 Tcf
LA-Miss: Cotton Valley (640)	100%	100%	1,740	3.47 Bcf	6.0 Tcf
Michigan: Antrim - dev. (40)	100%	99%	15,703	0.32 Bcf	4.9 Tcf
Michigan: Antrim - undev. (80)	100%	80%	54,976	0.32 Bcf	13.9 Tcf
Illinois: New Albany Sh (160)	100%	50%	30,727	0.12 Bcf	1.9 Tcf
Cinc. Arch: Dev. Sh. (160)	50%	50%	45,046	0.12 Bcf	1.4 Tcf
Appalachia: Clinton - hi (40)	100%	90%	224,287	0.12 Bcf	24.6 Tcf
Appalachia: Clinton - med (40)	100%	70%	108,939	0.08 Bcf	5.7 Tcf
Appalachia: Clinton - lo (40)	50%	30%	124,550	0.05 Bcf	0.9 Tcf
Appalachia: U. Dev. - hi (40)	100%	80%	147,758	0.08 Bcf	10.0 Tcf
Appalachia: U. Dev. - med (40)	100%	50%	91,046	0.08 Bcf	3.8 Tcf
Appalachia: U. Dev. - lo (40)	50%	30%	124,061	0.05 Bcf	0.9 Tcf
Appalachia: Big Sandy (150)	100%	90%	13,429	0.60 Bcf	9.1 Tcf
Appalachia: Silt/Sh. (60)	100%	85%	35,454	0.09 Bcf	2.8 Tcf
Appalachia: Lo-T.M. Sh. (150)	100%	70%	39,500	0.12 Bcf	3.5 Tcf

6.0 Advanced Resources International (ARI) Study of the Greater Green River Basin

ARI's analysis of the Greater Green River Basin had three objectives:

- Update the gas-in-place estimates for two of the major formations – the Mesaverde and the Frontier – focusing only on the overpressured zones.
- Assemble information of the key reservoir parameters governing recovery from these formations
- Provide estimates of recoverable resources using current and advanced E&P technology characterizations.

The partitioning study divided the GGRB into 20 geologically-consistent areas based on structural features, deposition, depth, reservoir pressure, and other information. A series of base maps were prepared to calculate gas volumes in-place in each partition. A structural overprint of the basin was completed using satellite imagery, aeromagnetic and gravity data and was used to rank each partition according to its estimated potential for natural fracturing. Historical drilling and production data were then used to estimate expected well performance in each area. The study reported 1,005 Tcf gas-in-place in the Mesaverde and 213 Tcf gas-in-place in the Frontier (Table 18).

Table 18: ARI partitioning study results (values in Tcf gas)

Partition	Mesaverde			Frontier		
	Gas-in-place	Tech-rec. CurrTech	Tech-rec. adv. tech.	Gas-in-place	Tech-rec. CurrTech	Tech-rec. adv. tech.
Pinedale	238	19.2	27.1	17	0.8	4.7
Sand Wash deep	89	13.1	18.2	8	1.3	2.2
Hoback	197	11.1	15.8	29	2.4	4.2
Wamsutter Arch	63	7.1	9.4	7	3.2	1.9
Farson deep	80	6.0	18.1	23	1.0	4.6
Red Desert	181	12.7	8.5	43	2.4	7.0
Cherokee Arch	13	2.5	12.0	2	0.7	0.6
East Sand Wash	37	3.3	4.7	7	0.7	1.3
Washakie deep	84	8.4	3.5	12	0.2	2.4
East Washakie	23	2.1	3.0	4	0.4	0.6
Red Desert deep	10	0.8	1.1	9	1.3	1.0
Green River deep				24	0.9	5.5
Vermillion				11	4.0	1.8
West Washakie				4	1.1	1.4
West of Moxa Arch				12	2.7	1.7
Dad dix				2	0.4	0.6
TOTALS	**1,005**	**86.4**	**121.4**	**213**	**23.4**	**41.2**

The key findings and conclusions of the ARI partitioning study are as follows:

- A structural interpretation of the basin is essential for estimating the key parameter controlling well performance – natural fracture enhanced reservoir permeability.

- The following are the three most essential technology advances; 1) identification of naturally-fractured areas prior to drilling; 2) utilization of horizontal drilling technologies; and 3) cost reduction for multiply-completed vertical wells in which thick vertical columns of stacked sandstones exist.

PROJECT facts

U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Gas Exploration, Production, and Storage

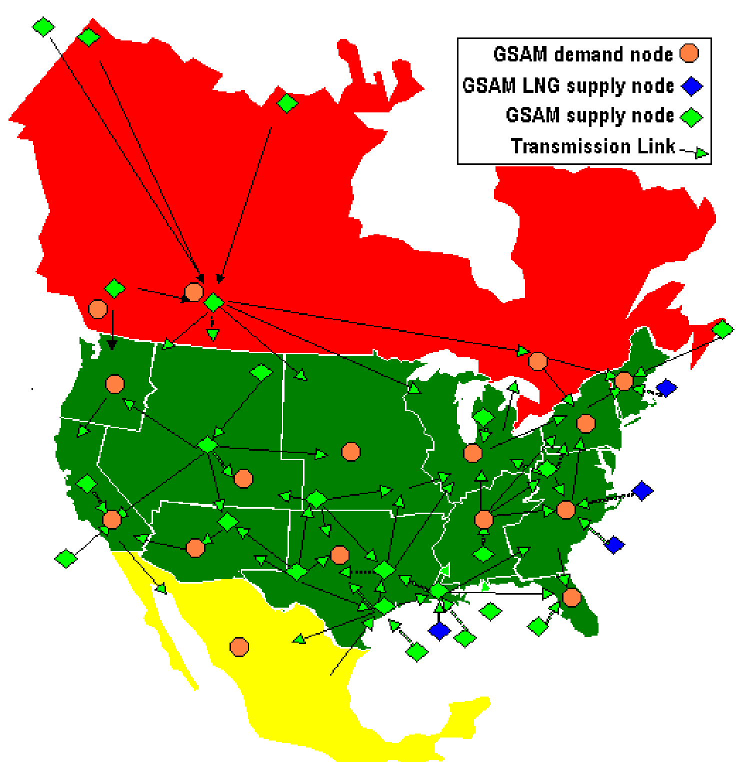
04/2002

GSAM
THE GAS SYSTEMS ANALYSIS MODEL

Measuring Natural Gas R&D Value

Overview

The Department of Energy (DOE) is charged with ensuring the nation's energy security, economic health, and environmental protection by promoting the most efficient and responsible utilization of the nation's energy resources. To support this goal, DOE planners in the Strategic Center for Natural Gas at the National Energy Technology Laboratory conduct detailed analyses of alternative R&D and policy scenarios using the Gas Systems Analysis Model (GSAM). GSAM's complex suite of resource databases, market characterizations, and computer programs allows decision-makers to assess and compare the potential impact of alternative R&D/Policy scenarios on future national gas supply, price, and use, as they craft the nation's natural gas R&D portfolio.



GSAM estimates the potential impact of alternative technology/policy scenarios on the production and use of natural gas in North America.

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Model Capabilities

The primary use of GSAM is to provide insight into the role of technology and policy in impacting future natural gas use. Specifically, GSAM can assess the impact of the following:

- Technological advances that alter the productive capacity of natural gas reservoirs.
- Technological advances that alter the costs and risks of finding and producing natural gas.
- Changes in industry's capacity to explore for and produce natural gas.
- Changes in regulation, taxation, and royalty structures that impact the natural gas industry.
- Changes in the rate at which natural gas technologies are utilized in the marketplace.
- Changes in the size and efficiency of the national gas storage system.
- Changes in the capacity, cost, and efficiency of the overall national gas pipeline system.
- Alternative scenarios for the future markets for natural gas.

What Sets GSAM Apart?

GSAM has been specifically designed to model natural-gas supply technologies. Whereas other models are limited to broadly defined "high" and "low" technology cases, GSAM provides means to evaluate the potential impacts of specific technologies and policy actions. There are four main aspects of the model that allow this to occur.

- **GSAM is based on estimates of remaining gas-in-place.** GSAM is unique in that it uses a resource characterization that goes beyond current estimates of what is "technically recoverable". By including large volumes of gas currently viewed as uneconomical and unrecoverable (a category that once included both tight gas and coalbed methane), the model can help us determine what paradigm-altering technologies will be needed to allow the next dramatic expansion in the nation's natural-gas resource base.

- **GSAM uses production type curves to estimate future supply:** As compared to complex and time-intensive reservoir simulation or overly-simplistic decline curve projections, GSAM's type-curve approach provides a superior means to quickly and scientifically estimate how technology advances will impact future production rates on large volumes of reservoirs.

- **GSAM contains detailed reservoir-specific characterizations:** Instead of idealized abstractions that reflect general reservoir behavior, GSAM's resource database contains real field-derived data for more than 5,000 existing reservoirs that represent more than 90 percent of the natural gas production in the United States and Canada. In addition, more than 10,000 as-yet undiscovered gas accumulations are characterized using the latest estimates from the United States Geological Survey. This extraordinary level of detail allows GSAM estimates to be highly responsive to the natural geologic variation present within the nation's natural- gas resource pool.

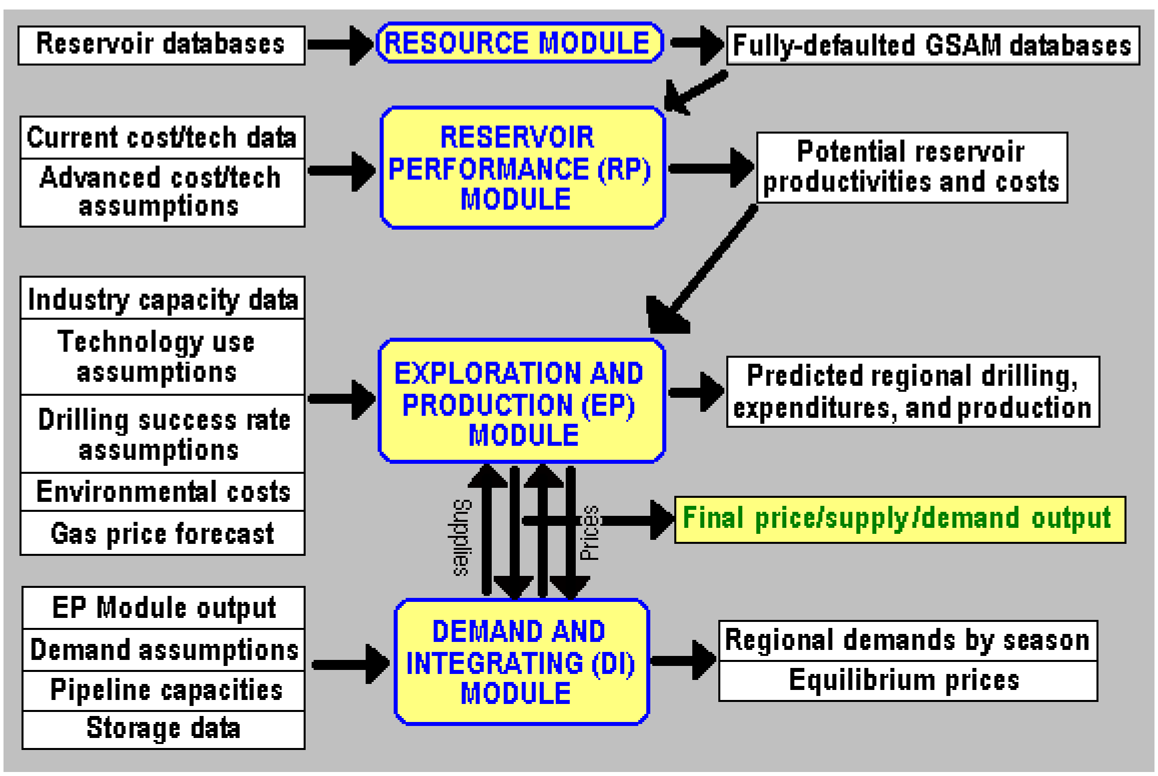
- **GSAM is a fully integrated model of the entire North American gas system:** GSAM incorporates a variety of market constraints including: (1) measures of industry supply capacity, (2) expected future prices for gas, (3) the rates at which technologies can be expected to penetrate the market, (4) a representation of natural gas transmission capacity, (5)the national gas storage system, and (6) expectations for demand in various end-use markets for gas. These constraints allow the model to determine if the additional supplies enabled by advanced exploration and production technologies can be realistically produced and delivered where and when needed.

How GSAM works

GSAM works through sequential modules to estimate the impact a hypothetical change in some aspect of the natural gas system might have on the operation of the system as a whole. Greatly simplified, GSAM's upstream modules estimate the potential productivity of individual reservoirs for two (current and advanced) cost/technology cases. The downstream modules then evaluate which reservoirs will be produced in each year, and under which technology/cost case, given market constraints, prices, and assumed industry utilization rates.

- **Upstream Modules:** The Resource and Reservoir Performance Modules of GSAM answer the question, "How could a change in technology and/or costs affect production potential of the nation's gas reservoirs?" These modules accomplish this by running each of 15,000+ resource segments through simple, 3-second simulations based on production type curves. Yearly gas volumes, costs, and an estimate of the minimum acceptable supply price required to make the production economic, are output.

- **Downstream Modules:** GSAM's downstream modules can be run in two separate modes to determine how the upstream module's estimates of production potential will be realized. One mode uses a standard gas-price forecast such as provided by the Energy Information Administration's Annual Energy Outlook (AEO). GSAM's Exploration and Production Module then selects which reservoirs will be produced, based primarily on the availability of advanced technology and expected industry drilling capacity. Alternatively, the user can allow GSAM's Demand and Integrating Modules to determine if markets exist for these volumes, and if the gas can be economically delivered to those markets, by invoking characterizations of the pipeline network, gas storage system, and expected future demand. In this mode, GSAM's internal linear solver works to calculate a balance of supply and demand by region and season, and provides its own estimate of likely future gas prices.



GSAM consists of a complex suite of state-of-the-art computer modules and databases.

GSAM
The Gas Systems Analysis Model

Measuring Natural Gas R&D Value

Outputs

Some of the outputs of a full GSAM run include:

- Natural-gas production by region, resource type, geologic play, and location on federal or private lands.
- Costs incurred in producing the gas.
- Royalties and taxes paid.
- Estimates of industry activity, including wells drilled, success rates, pipeline utilization, and more.
- Natural-gas prices at the wellhead and end user.
- Natural-gas consumption by region, season, and sector (industrial, commercial, residential, and electric generation).

How DOE uses GSAM

Development of GSAM began in 1991. Peer reviews in 1994 and 1997 guided enhancements to the model. Although several key components are still in development, including integration with the DOE oil-system model, TORIS, GSAM has already contributed through the following applications:

- **Gas R&D Program Metrics**—DOE periodically runs GSAM analyses to estimate the future impact of its ongoing R&D programs. A calibrated base case (the most likely future scenario) is compared to alternative cases that do not include the expected R&D outcomes of various program elements. The difference between these cases is an estimate of the realized impact of that R&D. These impacts are then analyzed with respect to timing, program costs, and conformance to program mission, to determine program benefit. Metrics analyses using GSAM were conducted in 1995, 1999, and 2001.

- **Gas R&D Program Planning**—DOE also runs GSAM to test the potential impact of various contemplated activities. In this mode, a large number of possible impacts are run iteratively in an attempt to identify those aspects of the national gas system that may provide the most leverage in achieving the program's goal of increased supply at reasonable prices. The insight from such analyses supports the setting of program goals and prioritizing program portfolios.

- **Gas Policy Analyses**—GSAM is used by DOE to investigate the impacts of various policy initiatives. Examples of policy analyses supported by GSAM include studies to estimate the economic impact of changes in taxation and royalty on (1) low-volume "stripper" wells and other marginal, high-cost resources; (2) land-use regulation that restricts access to vast gas resources, both offshore and in key western basins, and; (3) environmental regulations that add incremental costs to gas production.

Assessing Technology Needs of "Sub-Economic" Gas Resources in Rocky Mountain Basins

By Ray M. Boswell, Ashley S.B. Douds
H. Raymond "Skip" Pratt
Kathy R. Bruner, Kelly K. Rose
and James A. Pancake
EG&G Services
Vello A. Kuuskraa
and Randal L. Billingsley
Advanced Resources International

The Department of Energy has undertaken a new program of detailed, gas-in-place resource assessments to support the identification of the most promising R&D opportunities.

The goal of the Department of Energy's (DOE's) natural gas program is to assure the long-term sustainability of affordable domestic natural gas supply through steady expansion of the nation's economically-recoverable gas resource base. To do this, the National Energy Technology Laboratory's Strategic Center for Natural Gas (NETL-SCNG) implements a portfolio of R&D projects designed to enable and accelerate the transition of sub-economic resources into recoverable resources and, ultimately, into reserves. To support this effort, NETL has undertaken a coordinated program combining technology modeling, industry tracking, and resource assessment (Figure 1).

This article describes the work undertaken to supply this effort with specially-tailored assessments of the marginally-economic and sub-economic resources that are a prime target of DOE-supported technologies. Phase I, now nearing completion, has focused on vast low-permeability and deep gas resources of the Greater Green River (GGRB) and Wind River (WRB) basins of Wyoming. This report provides an overview of the ongoing effort. A more detailed report will be posted on NETL's website (www.netl.doe.gov) in the Fall of 2002.

Broad Resource Base is Disaggregated

This work differs from previous studies in that it conducts detailed log-based regional resource assessment within a gas-in-place framework. Detail is provided through the analysis of hundreds of well log suites to produce datasets that capture the natural variety in key geologic and engineering parameters such as depth, pay thickness, porosity, pressure, and water saturation. This disaggregation of the resource into numerous, uniquely-described segments is vital to allowing NETL computer models to sensitively probe the "response" of the resource to individual R&D cases. In addition, the detailed geographic dissaggregation of the resource will provide an improved means to assess the impact of various federal land access and environmental policies on future supplies.

The effort uses a gas-in-place approach that attempts to describe resources without reference to economic or technical viability. Other, less inclusive characterizations, such as the

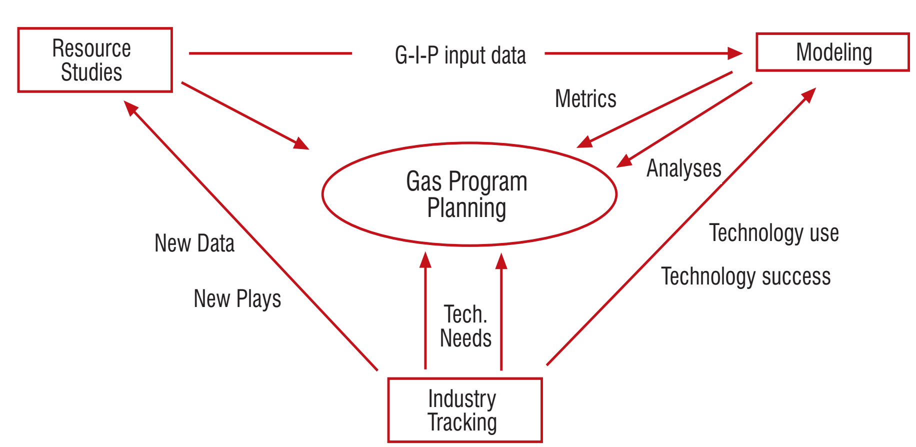


Figure 1: Schematic of SCNG's Integrated Approach for Planning R&D

Table 1: United States Geological Survey Assessments of Resources for GGRB and WRB

Greater Green River Basin			Wind River Basin		
Play	**GIP ('89)**	**Tech. Rec. ('95)**	**Play**	**GIP ('96)**	**Tech. Rec. ('95)**
Ft. Union	96	1	Ft. Union	101	Not Assessed
Fox Hills/Lance	707	10	Lance	365	Not Assessed
Lewis	610	19	Meeteetsee	124	Not Assessed
Mesaverde	3,347	52	Mesaverde	194	Not Assessed
Frontier-Cloverly	304	37	Frontier	151	Not Assessed
Total	**5,064**	**119**	**TOTAL**	**935**	**Not Assessed**

United States Geological Survey's National Assessment of technically-recoverable resources, are not suitable for technology modeling as they presuppose what might be recoverable in the future. Because history has shown that it is very easy to underestimate what technology can accomplish (see sidebar on the topic of "Resource Growth" at end of article), we have attempted to characterize as much of the remaining gas-in-place as possible. This will allow DOE's Gas Exploration and Production Team to probe the full resource base, looking for opportunities to continue past successes where dramatic technology advance has allowed vast resources previously viewed as "unrecoverable" (such as coalbed methane and gas shales) to be added to the nation's resource base.

Initial Study Areas: The Greater Green River (GGRB) and Wind River (WRB) Basins

It is well established that the basins of the Rocky Mountain region hold large quantities of natural gas in low-permeability formations. From 1987 to the present, the United States Geological Survey (USGS) has worked with NETL to raise industry awareness of the vast resources of the Piceance-Uinta (420 tcf), Greater Green River (5,064 tcf), Wind River (935 tcf), and Big Horn (334 tcf) basins. Yet, despite the enormous potential, many took the view that the vast majority of these resources were too widely disseminated and tightly held to ever be recoverable. This viewpoint was supported in 1995, when the USGS reported as part of its National Assessment that the technically-recoverable resource in the low-permeability plays of the Greater Green River basin was roughly 119 tcf (Table 1). Resources in the Wind River basin were similarly assessed to hold 935 tcf of gas in-place but were not included in the USGS 1995 National Assessment. In effect, roughly 98 percent of the 6000 tcf of gas believed to exist within the Greater Green and Wind River basins was deemed "not technically recoverable." To better constrain the potential of this resource, and to assist in identifying those technologies that may unlock this potential, these two basins were selected as the targets for Phase I of this effort.

Units of Analysis

For both basins, well log information was collected with the goal of obtaining quality log suites from one or more of the deepest wells in each township. To ensure the dataset was not biased to higher quality reservoirs, well productivity was not considered. Based on the USGS's previous work, the team began with the section from the Cretaceous Lance/Fox Hills formations through the Mississippian Madison Limestone in the GGRB, and the interval from the Lower Fort Union Formation to the Tensleep Sandstone in the WRB. The team then considered regional geology, industry completion practice, the needs of NETL's analytical models, and time and resource constraints, to finalize the selection of "units of analysis" or UOAs. (Figure 2).

Determination of Volumetric Parameters

Each UOA was correlated in loop fashion to establish the occurrence and distribution of lithofacies (Figure 3). Correlations and sandstone thickness mapping were generally accomplished

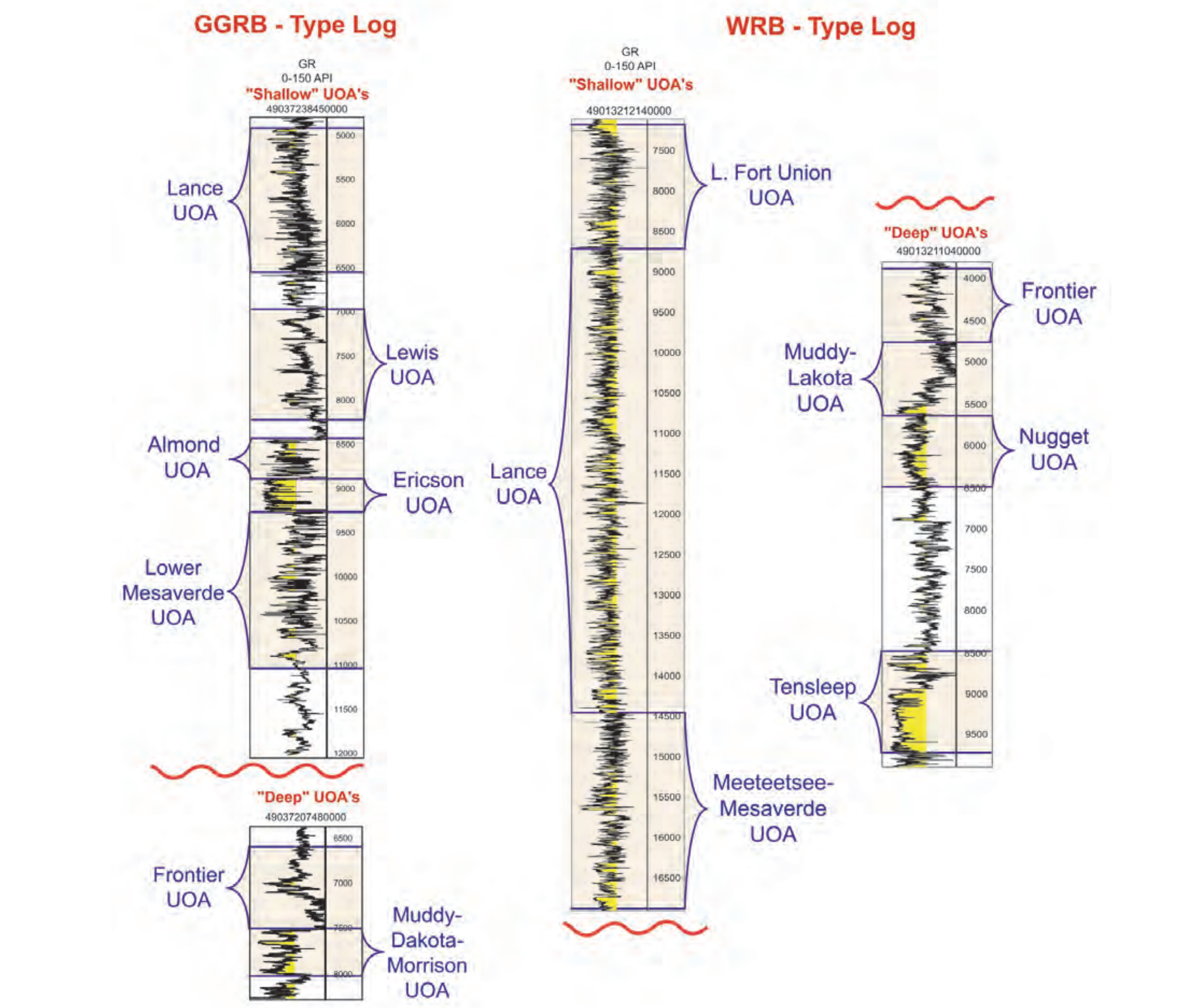


Figure 2: Type Logs Indicating 14 Units of Analysis (UOAs) in the GGRB and WRB

on a UOA-level (Figure 4); however, where appropriate and possible (primarily in marine and marginal-marine intervals), correlations were accomplished on a sand-body level (see Figures 3 and 5).

Well log suites were analyzed to provide drilling depth to unit mid-point (Figure 6) and average volumetric parameters across the UOA. Volumetric parameters include average porosity, water saturation, pressure, temperature, and thickness of potential pay. Average porosities were determined almost exclusively from recent vintage compensated density-neutron logs. Saturations were calculated using shaley-sand corrections (Simondoux) based on log-based determinations of shale volume (V_{sh}) and shale resistivity (R_{sh}), and regional estimates of formation water resistivity (R_w). These characterizations will be revisited once ongoing NETL studies to sample and analyze Rocky Mountain region formation waters provide better R_w data. Pressure and temperature at the play mid-point were determined from drilling depth and township average gradients based on information obtained from logs and from commercial databases (e.g., *IHS Energy Data*).

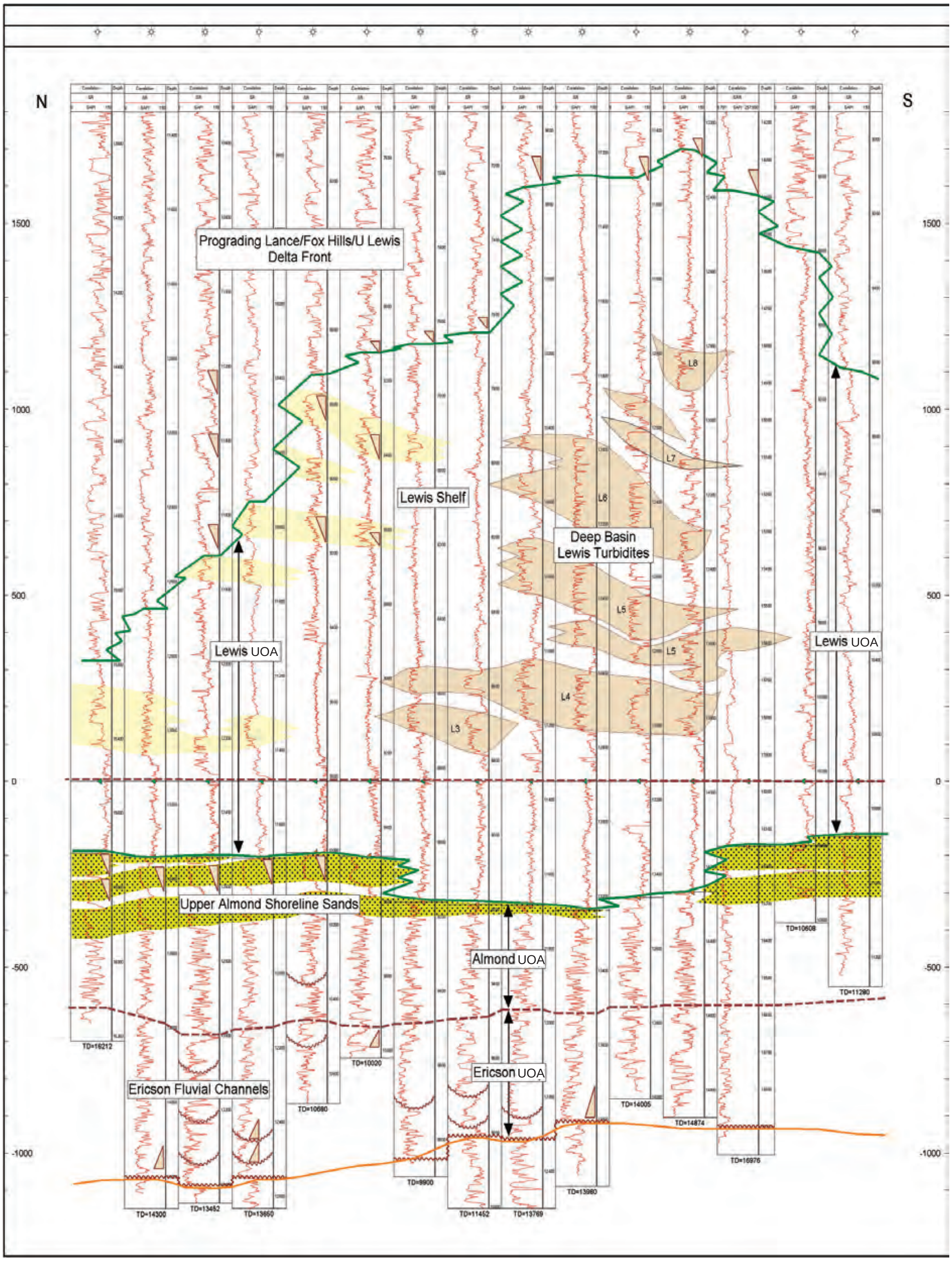


Figure 3: North-South Stratigraphic Cross-Section of the Lewis, Almond, and Ericson UOAs in the Eastern Greater Green River Basin.

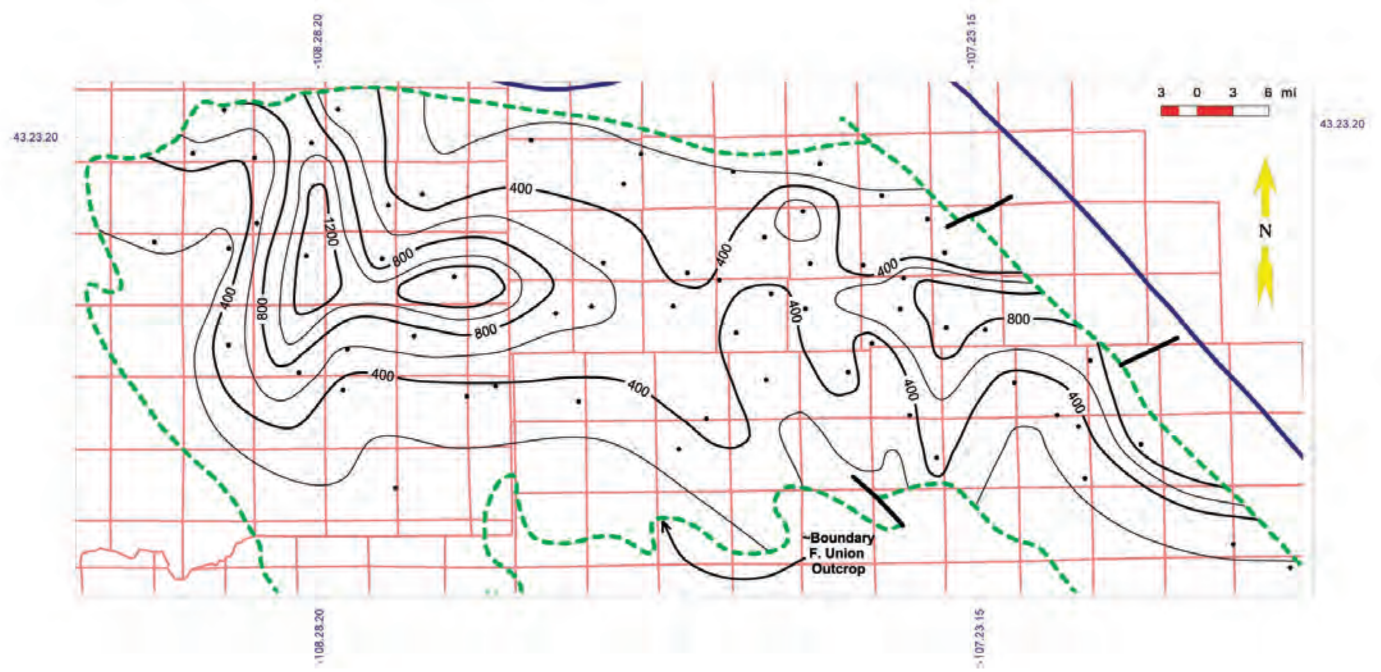


Figure 4: Isolith Map of Sandstone Within the Fort Union UOA, Wind River Basin

The volumetric parameter called "potential pay" thickness bears further discussion. The term "pay" is usually equated with the thickness of an interval that is expected to produce under current circumstances. Geologists are accustomed to establishing practical reservoir or field-specific porosity (for example 6 or 8 percent) and water saturation (commonly 60 percent) cut-offs in determining pay. However, the goal to create resource descriptions that allow the models to determine what segment of the total resource might be pay as much as 20 years into the future under cost/ technology scenarios that are very different from what currently exists. Therefore, aggressive cut-offs of 4 percent porosity and 70 percent S_w were used in defining "potential pay" with the understanding that under most technology/cost conditions, the models may not consider much of this low-quality resource to be viable.

Despite efforts to create detailed and disaggregated datasets, it remained necessary to average variable parameters across large vertical sections. For many units of analysis, this averaging did not create any major difficulties, as parameters such as porosity and saturation were often fairly consistent within a unit. However, for the upper Mesaverde "Almond" unit, the presence of the high-quality marginal-marine "Upper Almond" sandstones within the same unit with numerous lower-quality "Main Almond" units presented a problem. The solution was to prepare separate characterizations of the "best" and "rest" within that unit. Included within the "best" category are zones that, in the team's judgment, would be most likely to be completed (commonly those marked by density-neutron cross-over). Although the models do not currently have the capacity to utilize this distinction, modifications are being planned that will allow more accurate modeling of the standard industry practice of high-grading zones within a play for completion.

Permeability Analyses

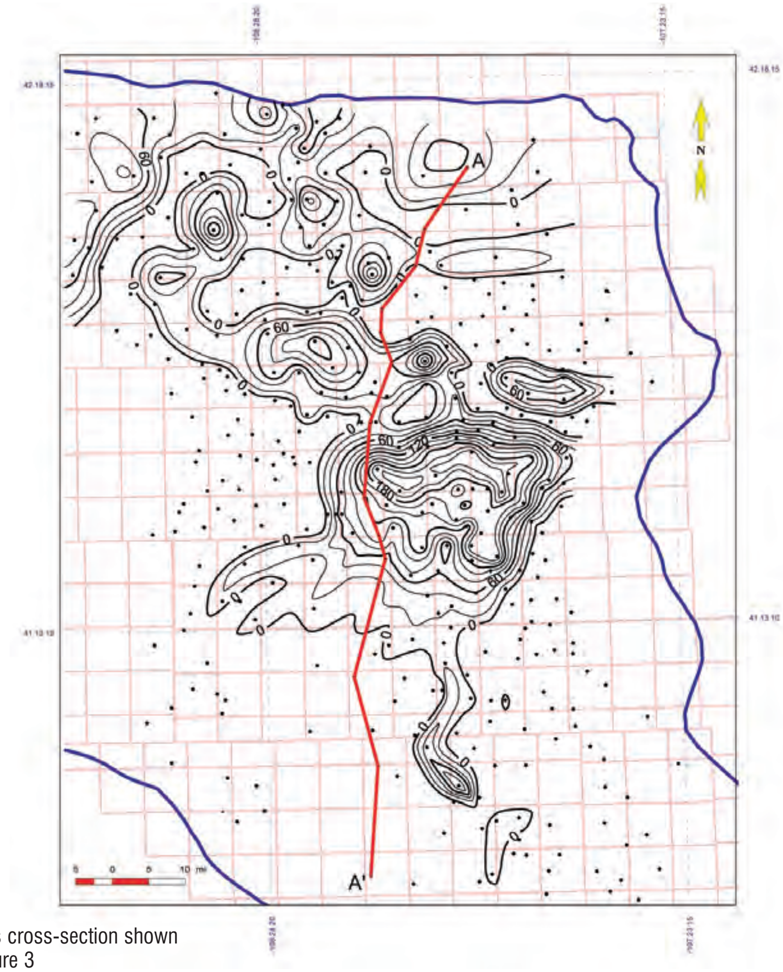
The final element in providing datasets to model the future economics and productivity of these resources is an estimation of permeability. First, an estimate of total permeability was generated through the detailed analysis of the productivity and log character for 10-20 calibration fields per unit of analysis. A statistically representative "type" well was chosen for each calibration field. Log based porosity, thickness and saturation for each "type" well was used to constrain gas-in-place for a decline curve analysis. Production data were analyzed using a Fetkovich-style type curve approach to define the bulk producing permeability around the wellbore. Existing porosity-permeability relationships were used to constrain the expected matrix contribution to the bulk system. The difference between expected matrix permeability and the bulk system permeability was ascribed to the presence or absence of a fracture permeability overprint in the reservoir (calibration field). The estimates for incremental fracture-related permeability in each calibration field were then correlated to the corresponding structural complexity as determined through analysis of aeromagnetic, gravity, and other satellite imagery data (Figure 7). From these correlations, estimates of areally variable matrix and fracture permeability contributions were generated, as appropriate, for each cell of each UOA.

Geographic Dissaggregation

To provide the needed geographic disaggregation of the resource, each unit of analysis is divided into cells on the scale of townships (deeper units) or quarter townships (shallower units). Well-log-based estimates for each volumetric parameter were gridded to provide interpolations for each grid cell. For example, for a deep unit of analysis that covers 80 townships, the datasets will consist of 80 uniquely-characterized reservoirs - each 1 township in size. Lastly, the available remaining acreage within each cell for of each unit of analysis was determined by removal of all grid cells from which at least a quarter of the available acreage has been drilled. This approach produces a conservative estimate of remaining resources.

Results and Products

The primary result of this work has been the construction of detailed and disaggregated resource characterizations for major gas accumulations in the GGRB and WRB that will allow meaningful analyses of the relative impact of alternative future technology,



A-A' is cross-section shown in Figure 3

Figure 5: Isopach Map of Lewis-4 Sandstone

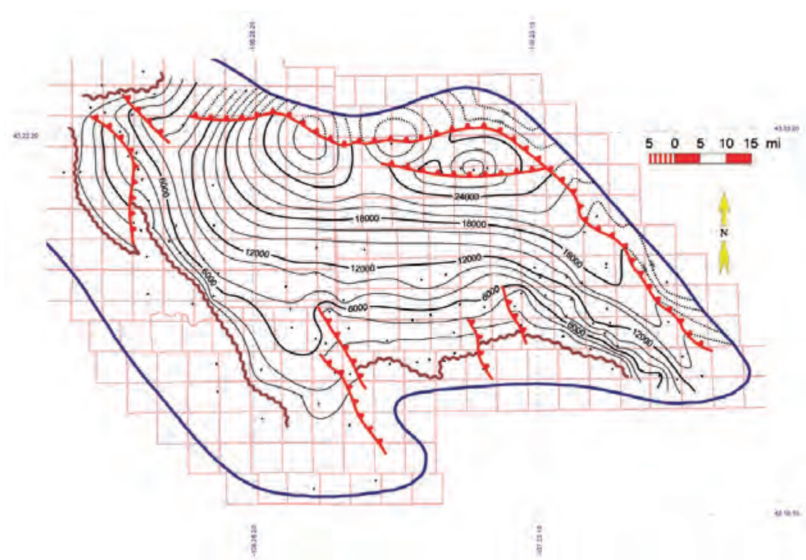


Figure 6: Drilling Depth map for the Frontier UOA, Wind River Basin (Depth is to the mid-point of the UOA)

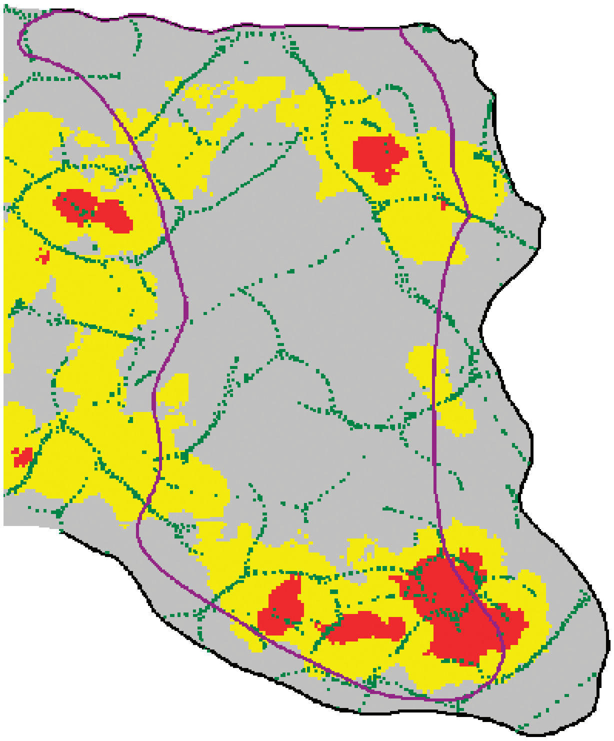


Figure 7: Structural Complexity Map for the Lewis UOA in the Eastern GGRB

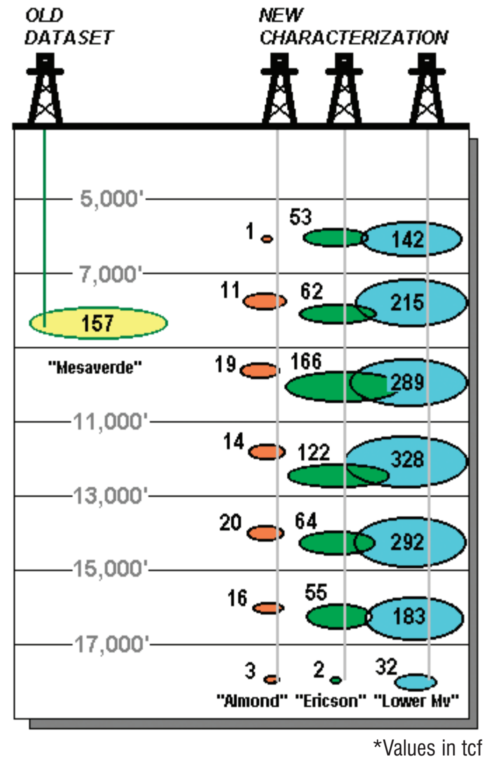


Figure 8: Analytical Methodology Provides More Detailed Resource Information

cost, and policy scenarios. This new dataset, by compartmentalizing the resource both geographically and vertically, contains many unique packets of resource that capture the natural variation in drilling depth, porosity, water saturation, pressure, temperature, and permeability (see Figure 8).

Table 2 summarizes the preliminary resource characterizations for the various plays. These data provide average values (with the exception of the acreage and gas volume totals) for key volumetric parameters that vary within 500 to 4000 individually-characterized, 4-square-mile-sized cells. For example, for the Lewis UOA, cell-level values for potential pay thickness vary from 0 to 699 feet with an average of 100 feet; depth varies from 5,000 to 17,600 feet with an average of 10,211 feet.

Given this database, NETL will now assess the impact of technology on roughly 3,013 tcf of marginal and sub-economic resource in the GGRB. Roughly half this resource resides within the sandstones of the lower Mesaverde UOA. Nearly one-quarter of the total GGRB resource (711 tcf) lies below 15,000 feet drilling depth. For the Wind River basin, 1,332 tcf of gas, with 533 tcf below 15,000 feet, have been characterized. Roughly half of this resource occurs in the thick sandstone packages of the Lance and Meeteetsee/ Mesaverde UOAs. The total appraised resource of 4,345 tcf represents a significant expansion of NETL's modeling capacity - previous datasets contained only 257 tcf in comparable formations across both basins.

These results provide our preliminary estimate of the gas-in-place in sandstones of the target formations with the exclusion of: (1) deposits above 5,000 feet of drilling depth; (2) areas already tapped by production, (3) areas likely to hold oil instead of gas — primarily an issue for the deeper WRB UOAs; (4) areas which calculate with water saturations in excess of 70 percent; and (5) gas in zones with porosities less than 4 percent as determined from logs. For the WRB Frontier, Muddy-Lakota, and Nugget UOAs, no gas resources above 13,000 feet were included. For the WRB Tensleep UOA, the cut-off to exclude likely oil accumulations was set at 15,000 feet. Also, as new and better information on R_w values is obtained, significant alterations in potential pay thickness and gas volume could occur.

The results obtained for the WRB are in close agreement with those provided by the USGS in 1996. For the

Table 2: Preliminary Results of Assessment for GGRB and WRB

GGRB Gas Resource: 3,013 Tcf Deep Gas Resource: 711 Tcf	GREATER GREEN RIVER BASIN UOAs					
	LEWIS	ALMOND	ERICSON	L. MSVD	FRONTIER	DAKOTA
Total Area (Acres)	3,891,200	6,097,920	7,782,400	8,125,440	11,258,880	10,749,440
Avg. Thickness (ft.)	100	44	173	369	47	52
Avg. Porosity (%)	7%	9%	9%	8%	8%	8%
Avg. Water Sat. (%)	56%	60%	47%	53%	43%	40%
Avg. Depth (ft.)	10,211	9,615	10,663	10,767	15,472	15,670
Avg. Pressure (psi)	5,428	5,075	5,488	5,559	10,186	10,415
Avg. Temperature (oF)	223	214	226	223	255	257
Avg. Z-Factor	1.05	1.03	1.06	1.06	1.39	1.4
Total Resource (tcf)	132	87	528	1,481	368	417
Deep Resource (tcf below 15,000')	10	3	60	214	198	226

WRB Gas Resource: 1,332 Tcf Deep Gas Resource: 533 Tcf	WIND RIVER BASIN UOAs						
	FORT UNION	LANCE	MEET/MSVD	FRONTIER	MUDDY +	NUGGET	TENSLEEP
Total Area (Acres)	1,103,360	1,354,240	1,546,240	1,525,760	1,672,960	1,681,920	1,246,720
Avg. Thickness (ft.)	441	512	461	91	34	76	285
Avg. Porosity (%)	10%	9%	8%	6%	6%	5%	6%
Avg. Water Sat. (%)	57%	51%	43%	46%	45%	47%	22%
Avg. Depth (ft.)	8,110	10,117	11,991	18,191	18,423	19,485	20,458
Avg. Pressure (psi)	3,627	5,104	6,933	12,420	12,559	13,444	14,184
Avg. Temperature (oF)	189	222	252	351	355	372	387
Avg. Z-Factor	0.94	1.03	1.16	1.52	1.52	1.57	1.61
Total Resource (tcf)	180	322	374	74	30	76	276
Deep Resource (tcf below 15,000')	0	2	109	62	23	61	276

GGRB, perhaps the most significant difference is a substantial reduction in pay thickness for the Lewis and Lower Mesaverde plays. For the deeper Frontier and Dakota plays in the GGRB, we have calculated larger gas volumes due primarily to higher assessed porosity.

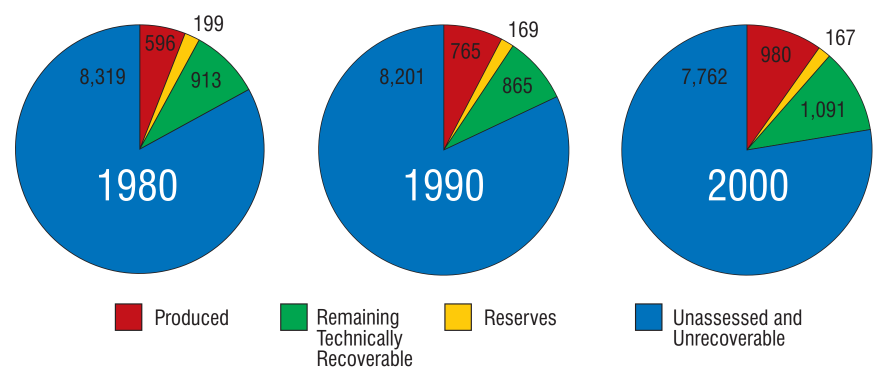
Next Steps

Our analyses indicate that approximately 4,345 Tcf of potentially accessible gas exists in-place in the

America's Growing Gas Resource: Can the Trend Continue?

Over the past two decades, the nation has produced roughly 390 tcf of gas. Over the same period, the amount of technically-recoverable gas thought to remain has grown by roughly 10 percent (from 1,112 tcf to 1,258 tcf based on estimates of the Potential Gas Committee). In short, we have more gas left now than we did 20 years ago!

The reasons for this remarkable record of resource growth are a series of quantum leaps forward in both technology and information that have allowed the nation to access previously overlooked or undervalued resources. Examples include coal-bed methane, gas shales, and tight sandstones. Once considered permanently "unrecoverable", these sources now represent roughly 25 percent of the nation's gas supply.



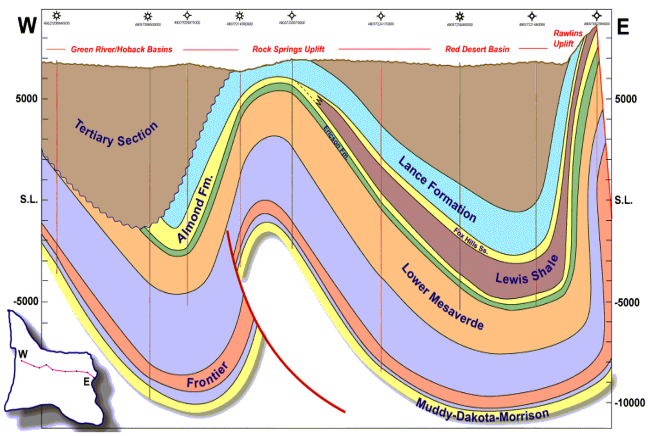
*Remaining recoverable estimates taken from reports of the Potential Gas Committee – for illustrative purposes, graphs assume a total domestic in-place resource of 10,000 tcf.

How long can resource growth continue? There is no question that it must continue in order to assure the vast and diverse resource bank that will enable production rates to keep pace with rising demand. However, the gas remaining in the ground is located in deeper, more geologically complex, and in general, more technically challenging places. Compounded by declining industry investment in gas supply R&D, it will be difficult to sustain past trends. Clearly, future resource growth will depend heavily on DOE's success in developing new tools and information that will unlock more of the nation's "unrecoverable" resource.

subject intervals of the Greater Green River and Wind River basins. In the coming months, this resource characterization will be subjected to intense analysis using NETL's analytical models. These analyses will focus on determining the recoverability profile (the proportion of the resource that is the technically- and economically-recoverable) under a variety of technology/cost scenarios. These data will be used internally by DOE planners to support project selection and other programmatic activities. In addition, the data will be closely compared to information recently gathered by DOE on federal land access restrictions to more accurately quantify the impacted resource under both current and potential future technology/cost/policy conditions. In August 2002, NETL will kick off Phase II of this effort, consisting of similar resource characterization studies of the marginal and sub-economic resources of the Anadarko (Oklahoma) and Uinta (Utah) basins. ■

For more information on the status of this project, contact James Ammer, NETL Project Manager for Natural Gas Supply and Storage, at 304-285-4383 or at james.ammer@nelt.doe.gov/.

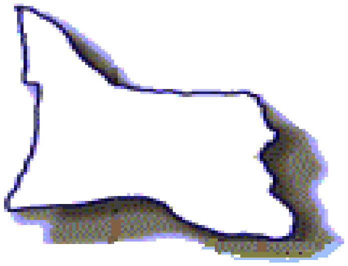
Energy and Environmental Solutions



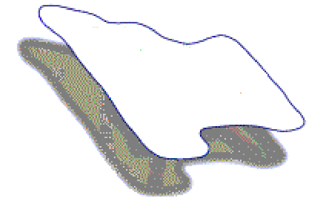
Assessing Technology Needs of Sub-economic Gas Resources

Phase I: Greater Green River and Wind River basins

Ray Boswell, Ashley Douds, Skip Pratt, Kelly Rose, Jim Pancake, Kathy Bruner-EG&G Services
Vello Kuuskraa, Randy Billingsley, Greg Bank-Advanced Resources International



Presentation in Brief



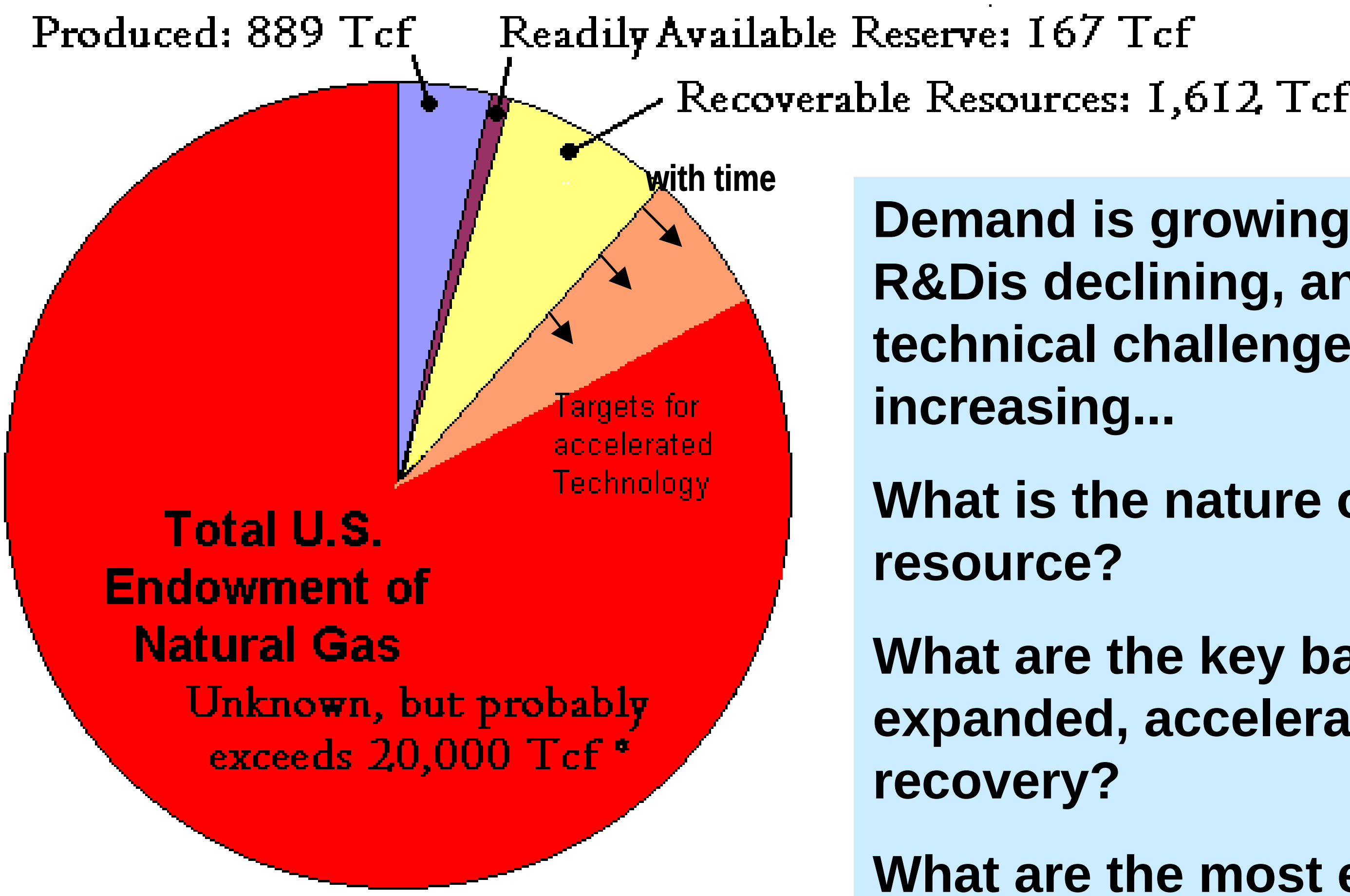
WHAT? **Studies in the Greater Green and Wind River basins as part of a new program of detailed characterizations of marginal and sub-economic resources**

HOW? **Log-based, gas-in-place approach focusing on detailed geographic and vertical dissaggragation of the resource**

WHY? **Primarily - to allow NETL to model the role of technology in expanding the nation's recoverable resource base**

Also - to add new information on natural gas resources and, where applicable, resources on federal lands

Vast Resources Await New Technologies
for Entry Into Nation's Resource Base



* Excluding Methane Hydrate

Demand is growing, private R&Dis declining, and technical challenges are increasing...

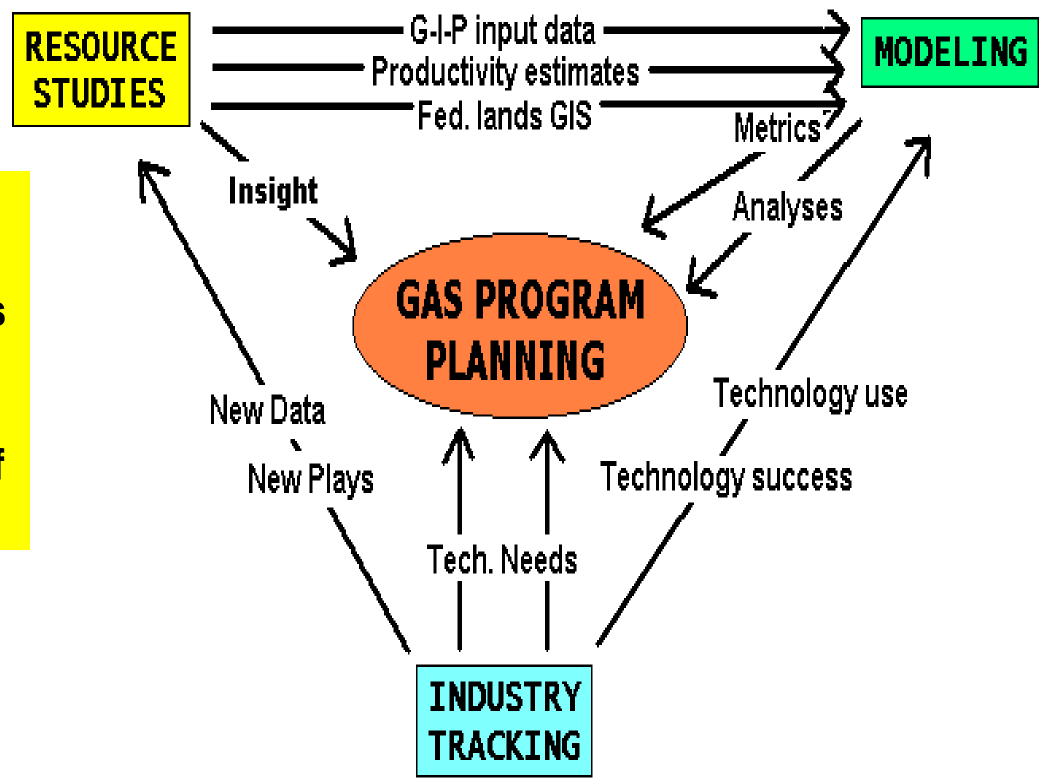
What is the nature of this resource?

What are the key barriers to expanded, accelerated recovery?

What are the most effective R&D approaches?

E^{2}S Support to NETL Natural Gas E&P Program

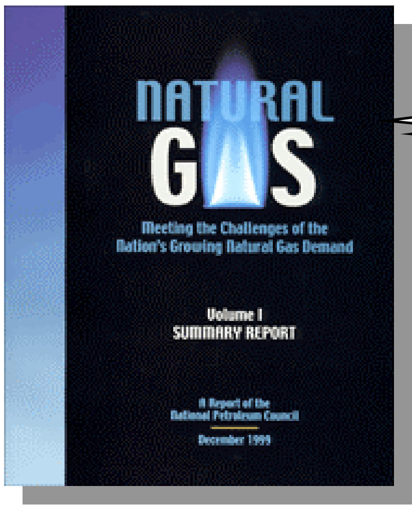
Providing detailed characterizations of emerging resources that are the targets of the program



Conducting analytical studies of the relative potential of alternative R&D approaches

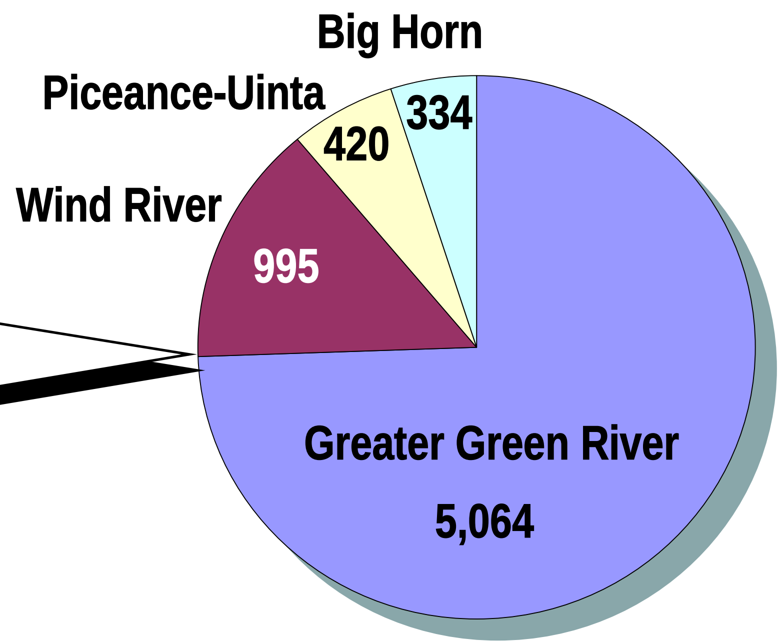
Tracking the use and effectiveness of advanced technologies

What to Study First?



NPC's 1999 REPORT RECOMMENDED SPECIFIC ATTENTION BE GIVEN TO ROCKY MOUNTAIN RESOURCE, TECHNOLOGY, AND POLICY ISSUES

A SERIES ('87-'99) OF USGS/DOE GAS-IN-PLACE RESOURCE ASSESSMENTS IDENTIFIED THE GGRB AND WRB AS HOLDING THE BULK OF THE ROCKY MTN. RESOURCE



98% of GIP Considered Not Recoverable

USGS Assessments of Resources in GGRB and WRB

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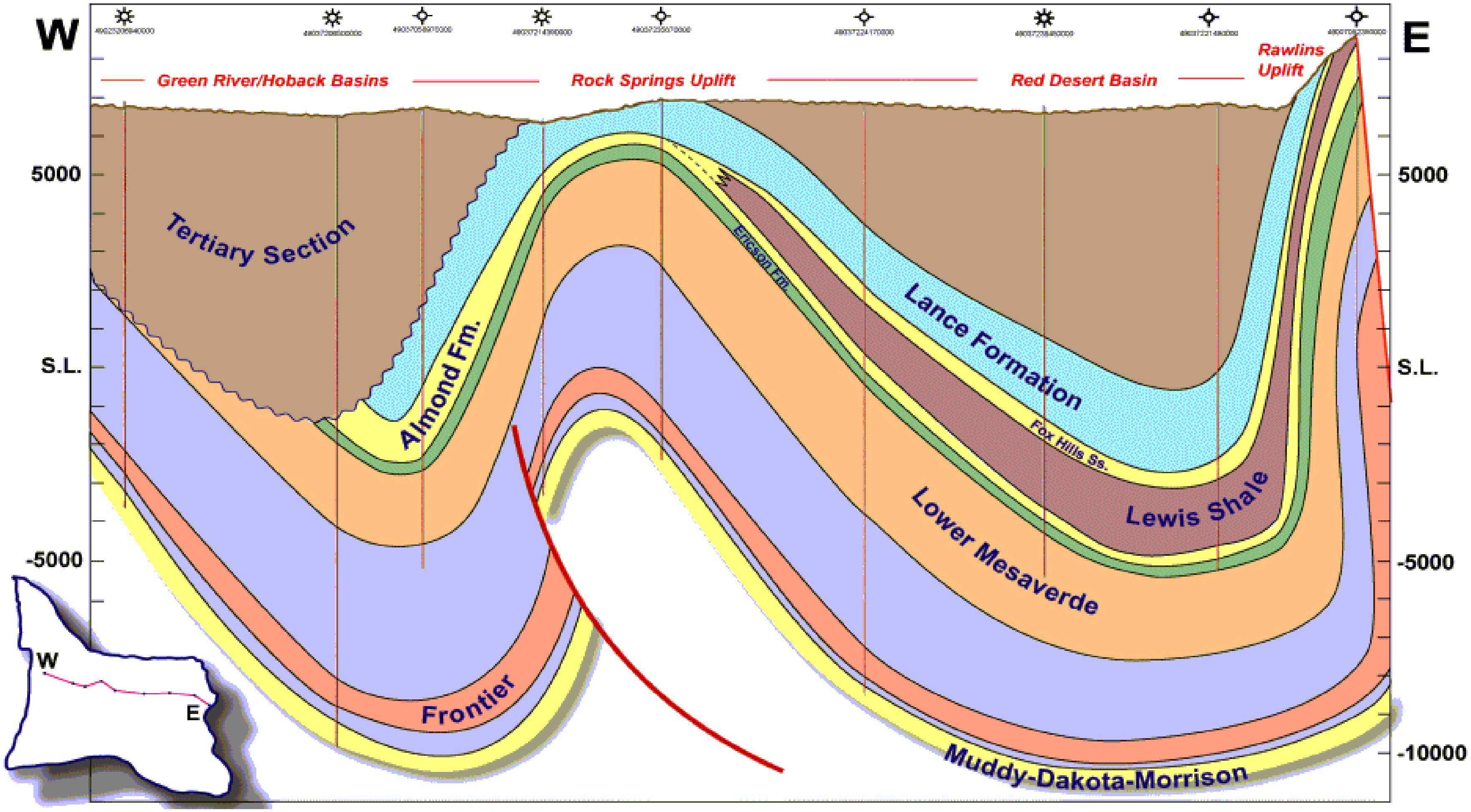
Frontier-Cloverly	307	37	Frontier	151	Not Assessed
TOTAL	**5,063**	**119**	**TOTAL**	**995**	**Not Assessed**

Values in trillion cubic feet of gas

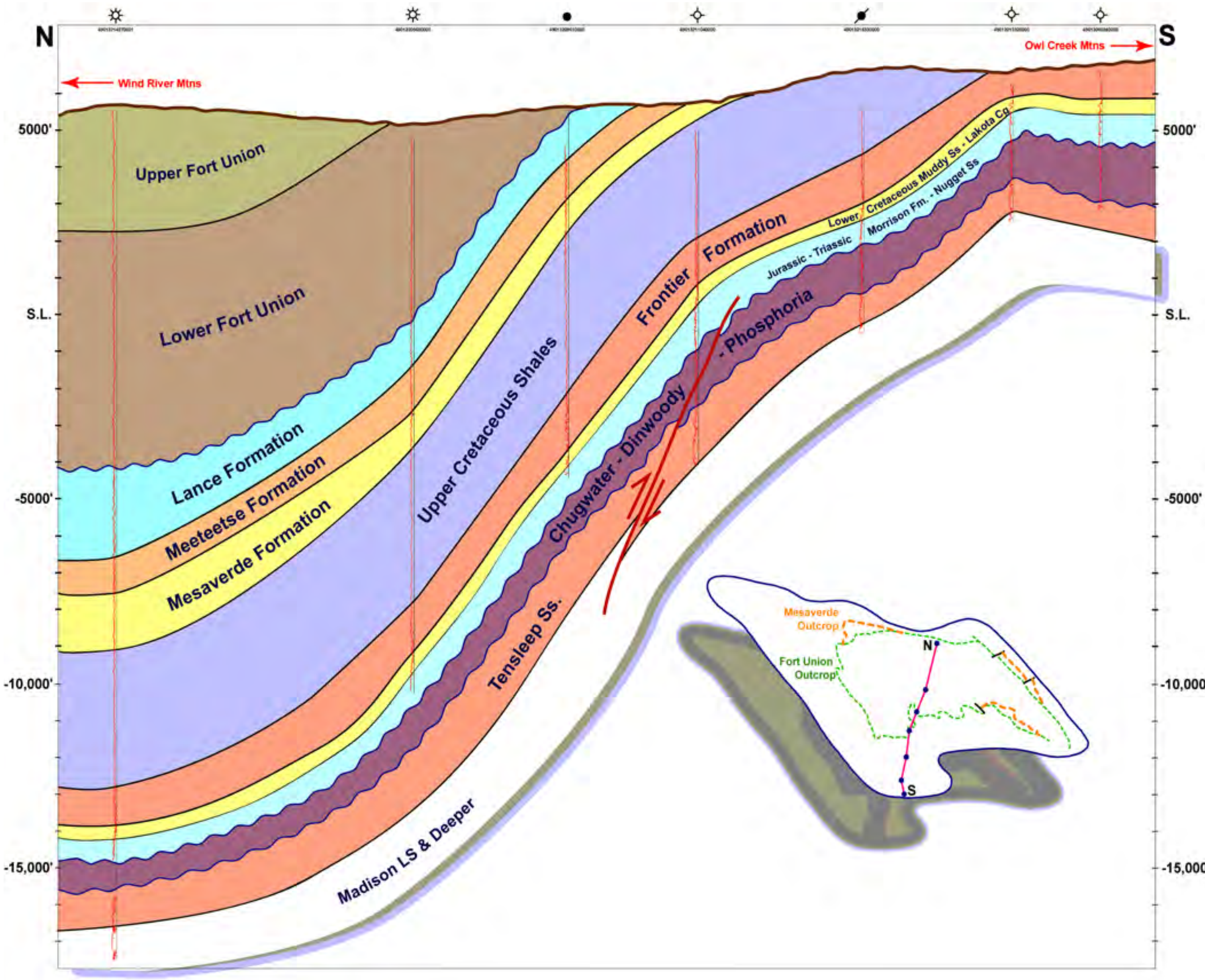
Greater Green River Basin

West-East Structural Cross Section (VE=26x)

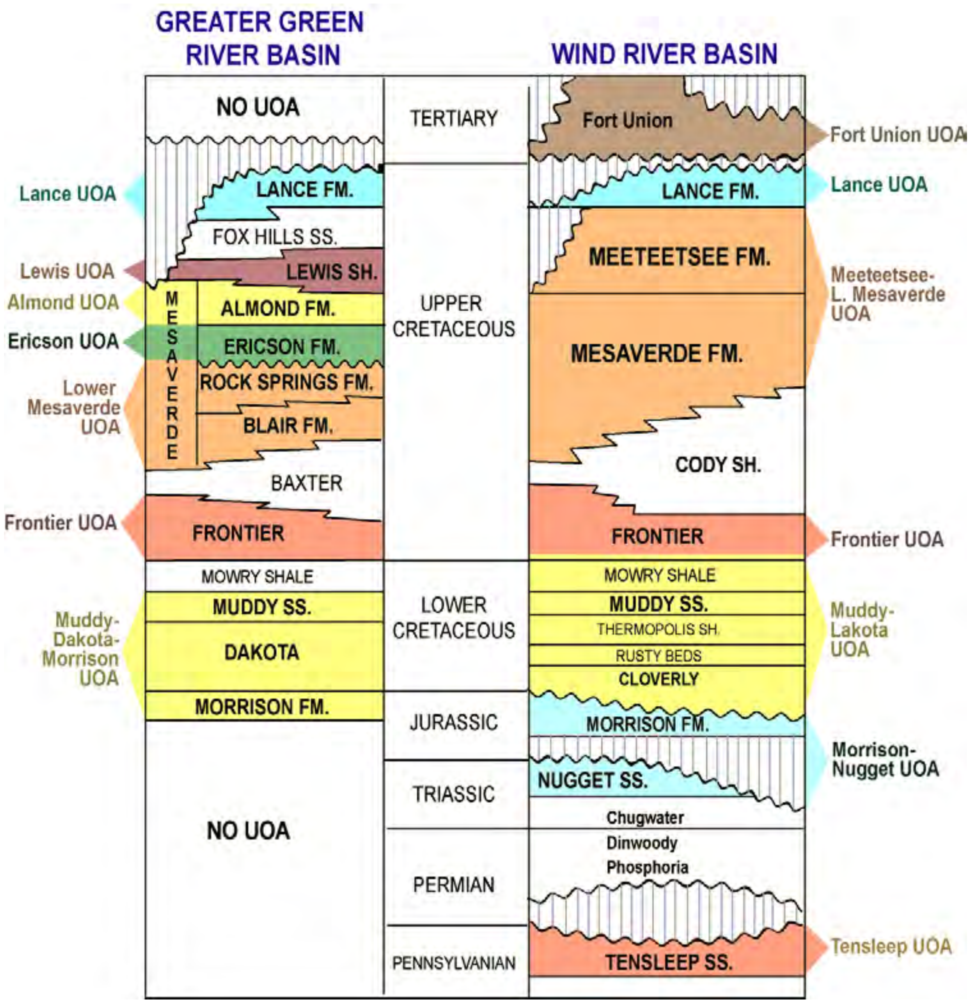


Wind River Basin

North-South Structural Cross-section (VE=15x)



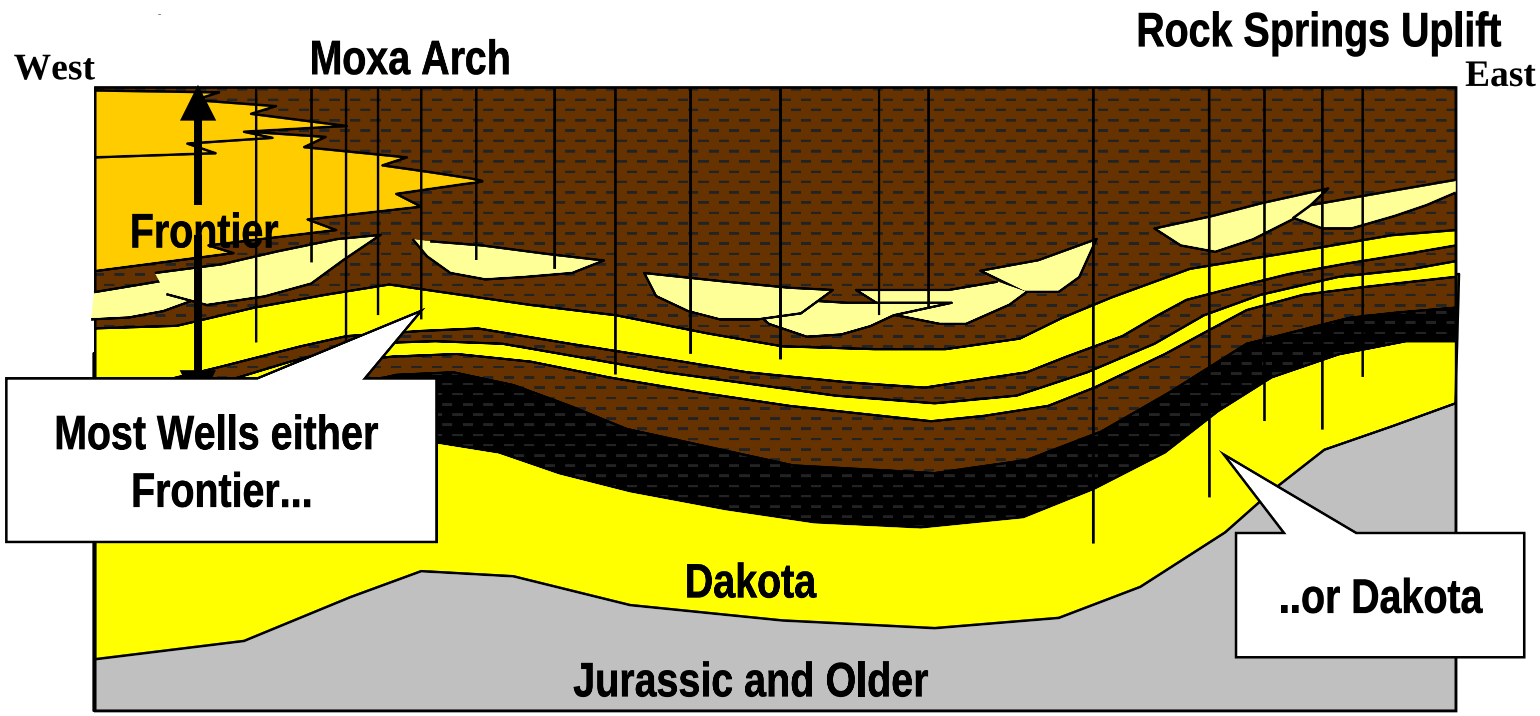
The Units of Analysis (UOAs)



- **Similar to Plays**
- **Encompass vast majority of target resource**
- **Deeper units lack data required for this methodology**
- **Partition resource into units consistent with our goal of modeling industry behavior: UOAs represent resources to be targeted by a single well**

Determining UOA; Frontier-Dakota; GGRB

5-township survey of completion practice

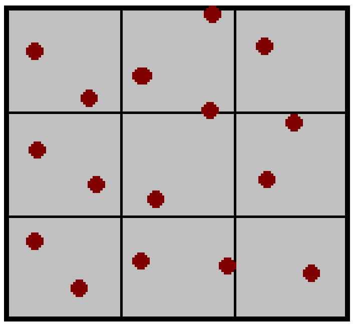


- Single Completions = 68%
- Dual Completions = 19%
- Recompletions = 16%

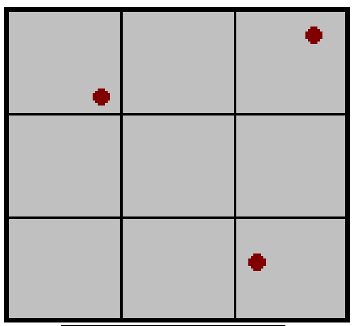
Total exceeds 100% as values are township averages

Data Density

The search for complete well log suites



LEWIS



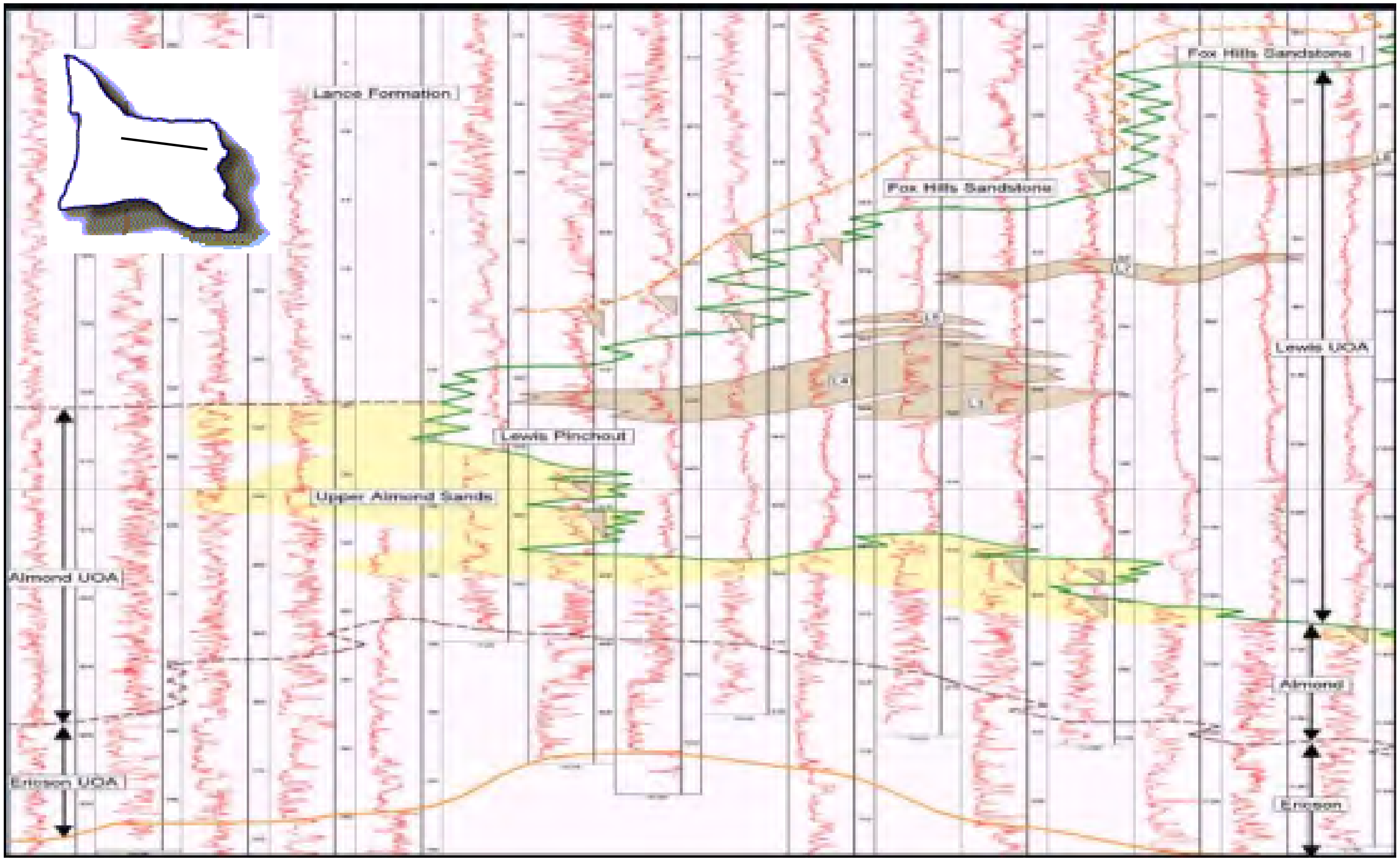
FRONTIER

	UOA	No. of Wells	Full Log Suites in Appraised Area	Townships in Appraised Area	Full Suites per Township
GGRB	LEWIS	399	297	168.9	1.76
	ALMOND	369	293	264.7	1.11
	ERICSON	301	242	337.8	0.72
	L. MESAVERDE	153	136	352.7	0.39
	FRONTIER	266	158	488.7	0.32
	MUDDY-MORRISON	192	131	466.6	0.28
WRB	FORT UNION	75	44	47.9	0.92
	LANCE	63	28	58.8	0.48
	MEET.-MESAVERDE	60	27	67.1	0.40
	FRONTIER	136	19	56.2	0.34
	MUDDY-LAKOTA	123	16	56.6	0.28
	NUGGET	95	8	55.0	0.15
	TENSLEEP	82	4	24.8	0.06

Variable data density = varying degrees of resolution in resource computation

West-East Stratigraphic Cross-Section

Lewis, Almond, Ericson UOAs; GGRB

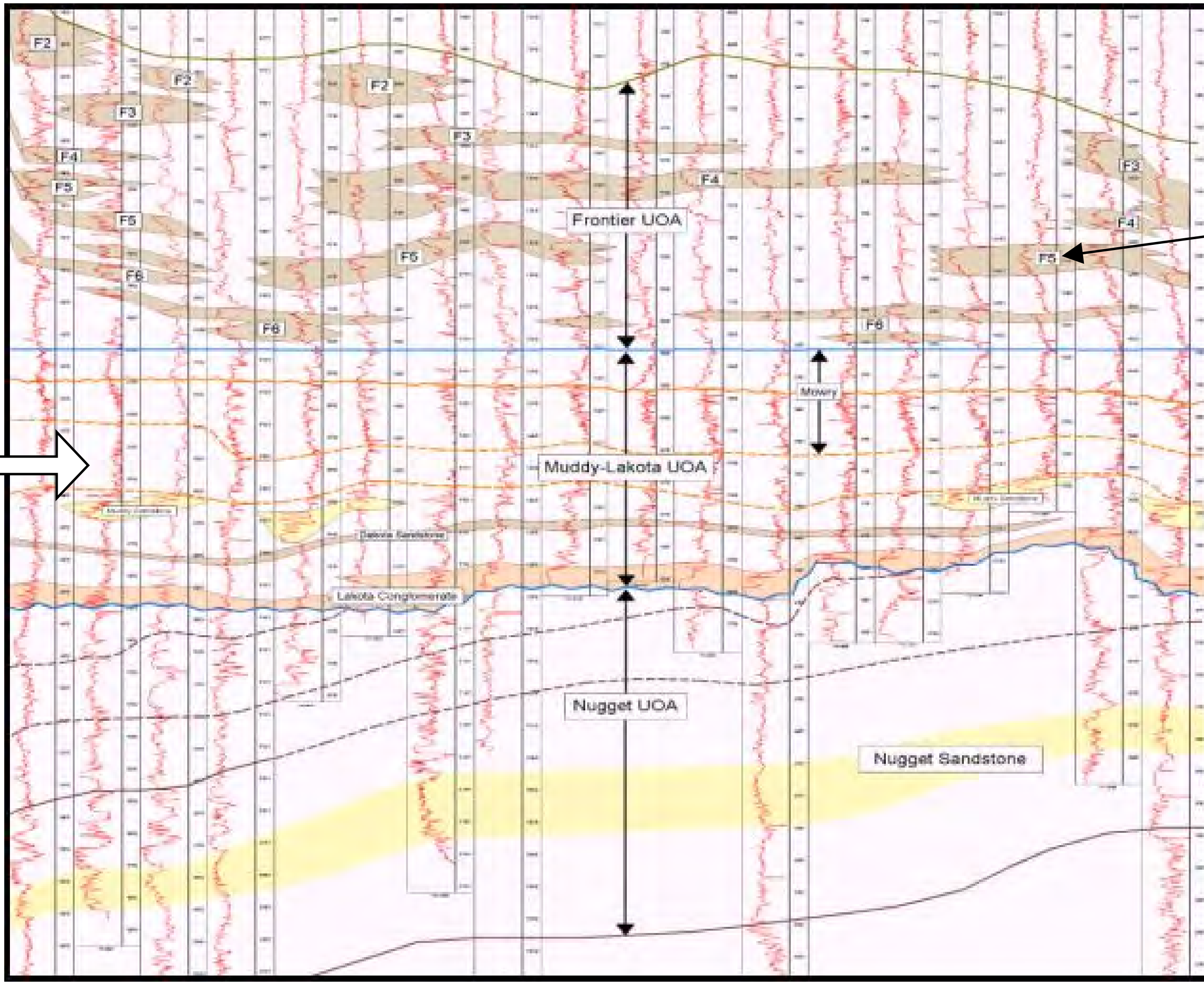


West-East Stratigraphic Cross Section

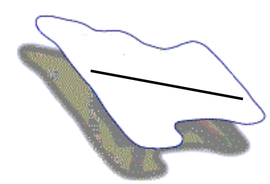
Frontier, Muddy-Lakota, Nugget UOAs; Wind River basin

Sandstone Isolith Maps for UOAs

Drilling depth to UOA midpoint

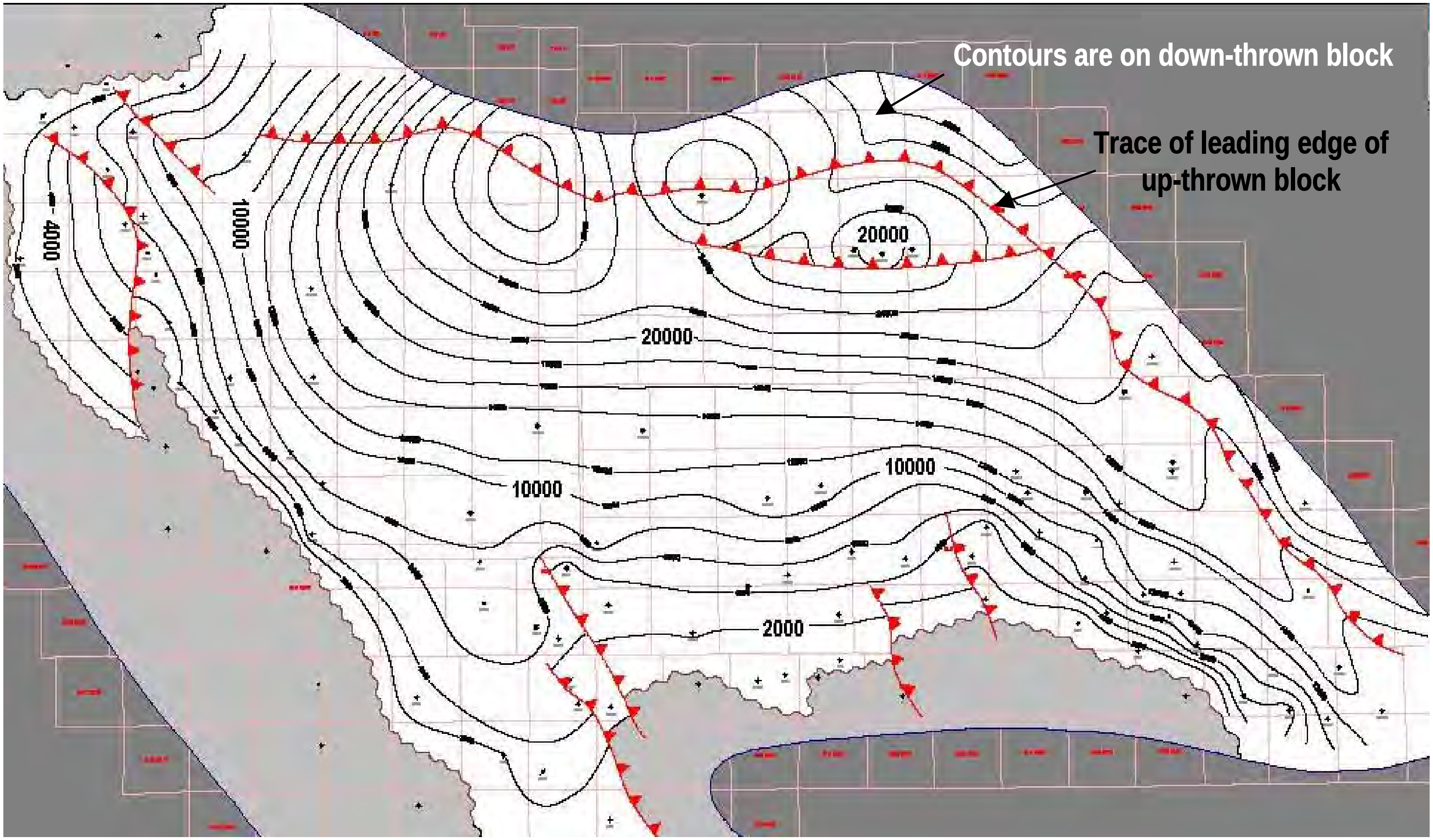


Isopach maps on individual sandstones (Lewis, Almond, Frontier, Muddy-Dakota UOAs)



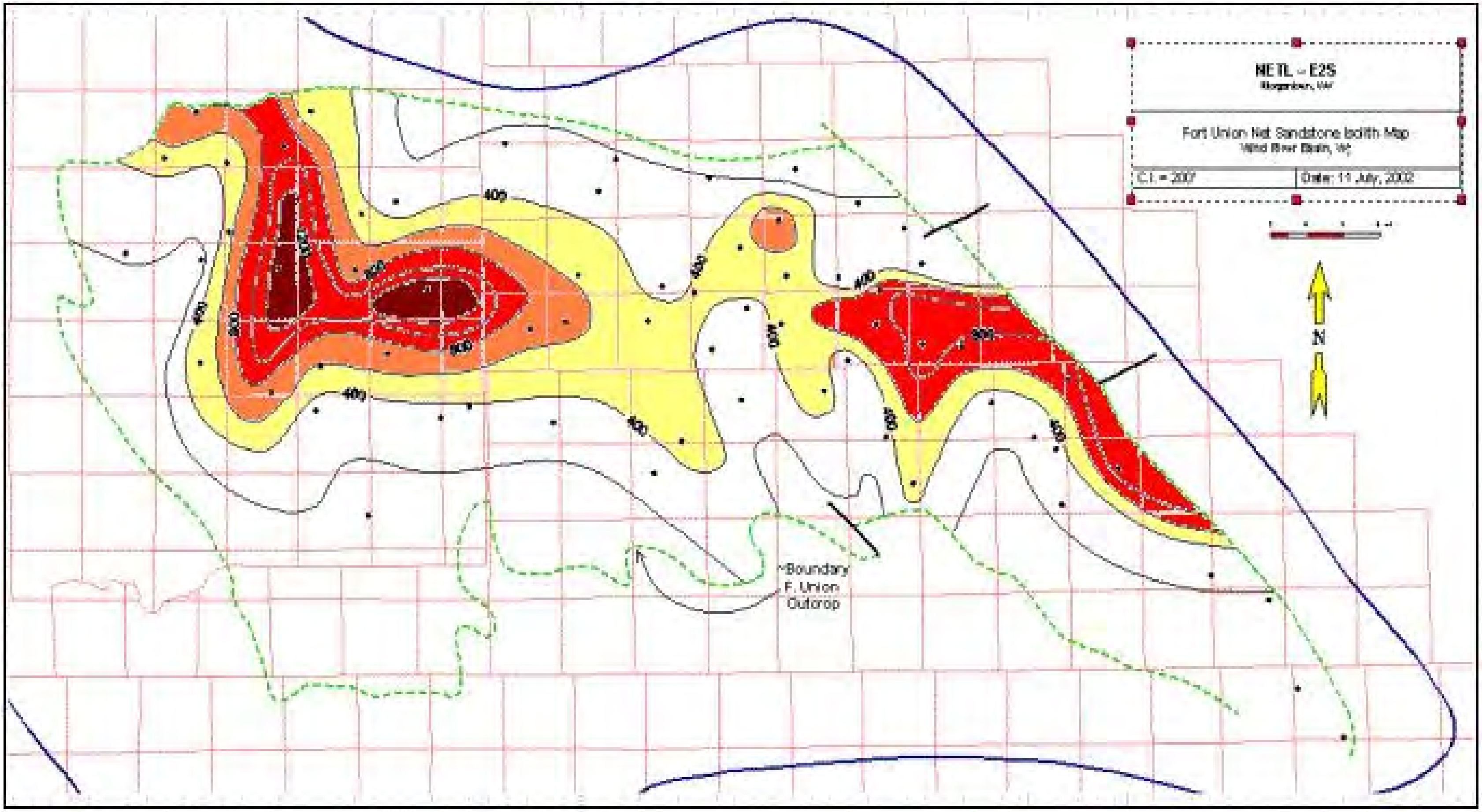
Drilling Depth to UOA Mid-point

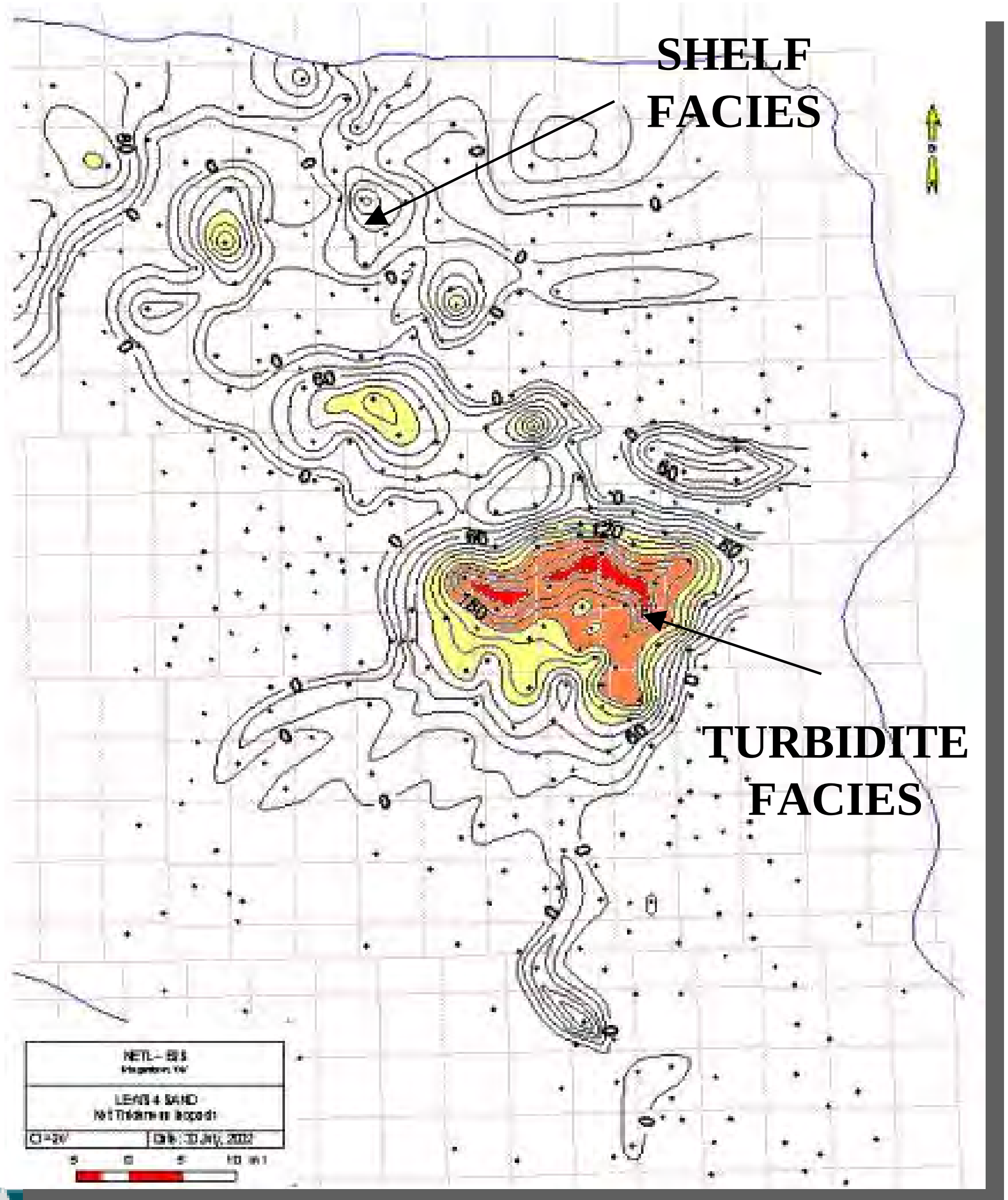
Frontier UOA, Wind River Basin



Net Sandstone Isolith

Fort Union UOA: Wind River Basin



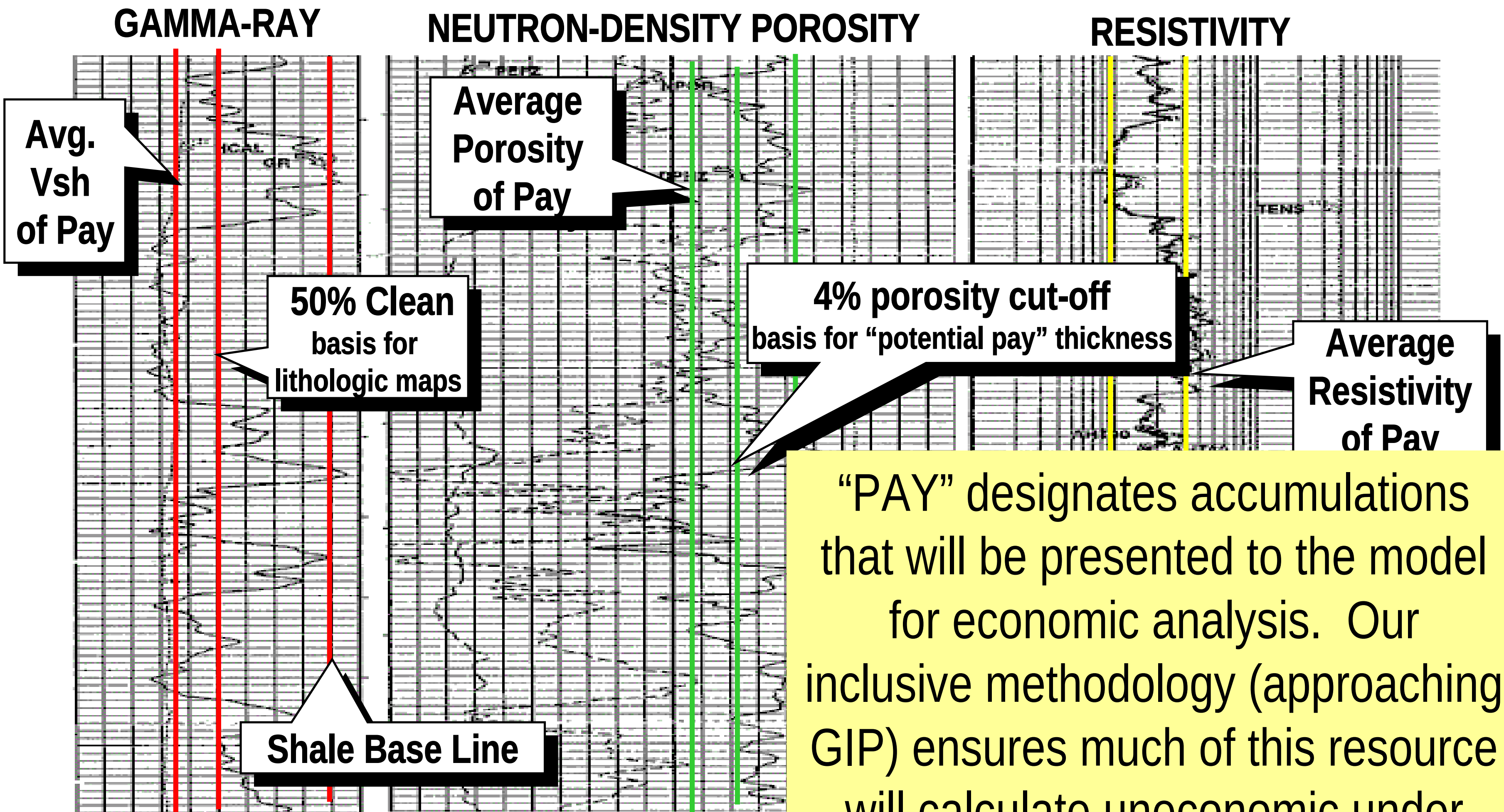


Sandstone Isopach Map

Lewis “4” sand: Eastern Greater Green River Basin

Well Log Analysis

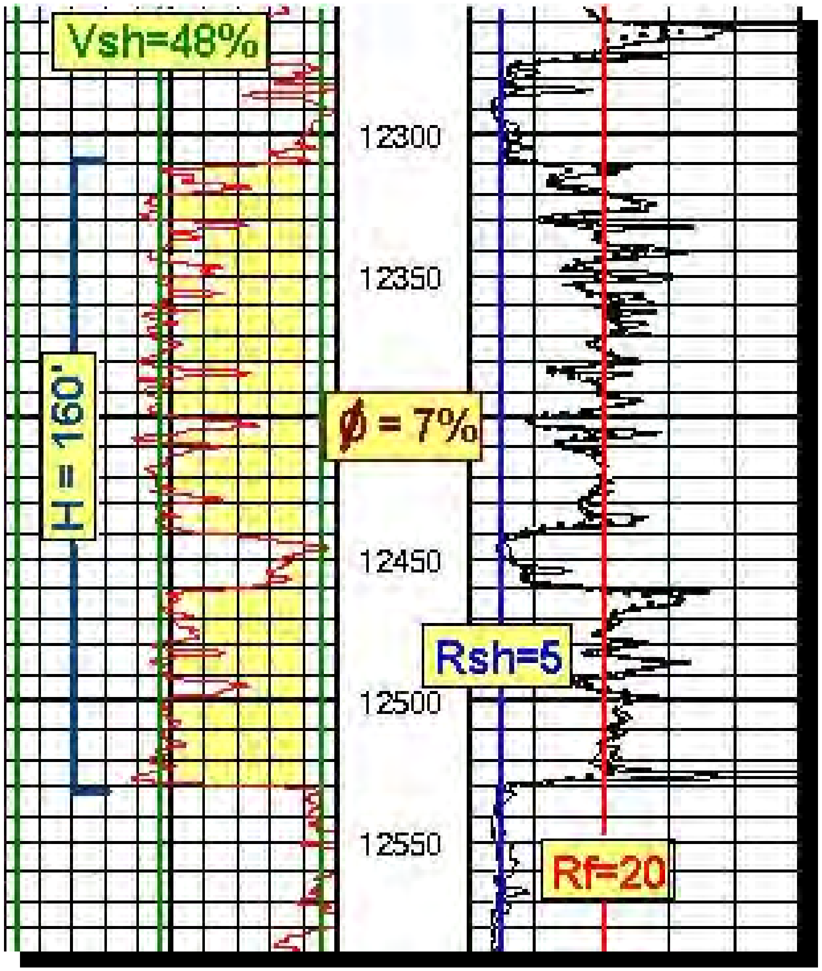
Example from Frontier Fm. Wind River Basin



“PAY” designates accumulations that will be presented to the model for economic analysis. Our inclusive methodology (approaching GIP) ensures much of this resource will calculate uneconomic under most technology scenarios

Uncertainty in Rw = ?Sw = ?GIP

Example from Lewis UOA, Eastern GGRB



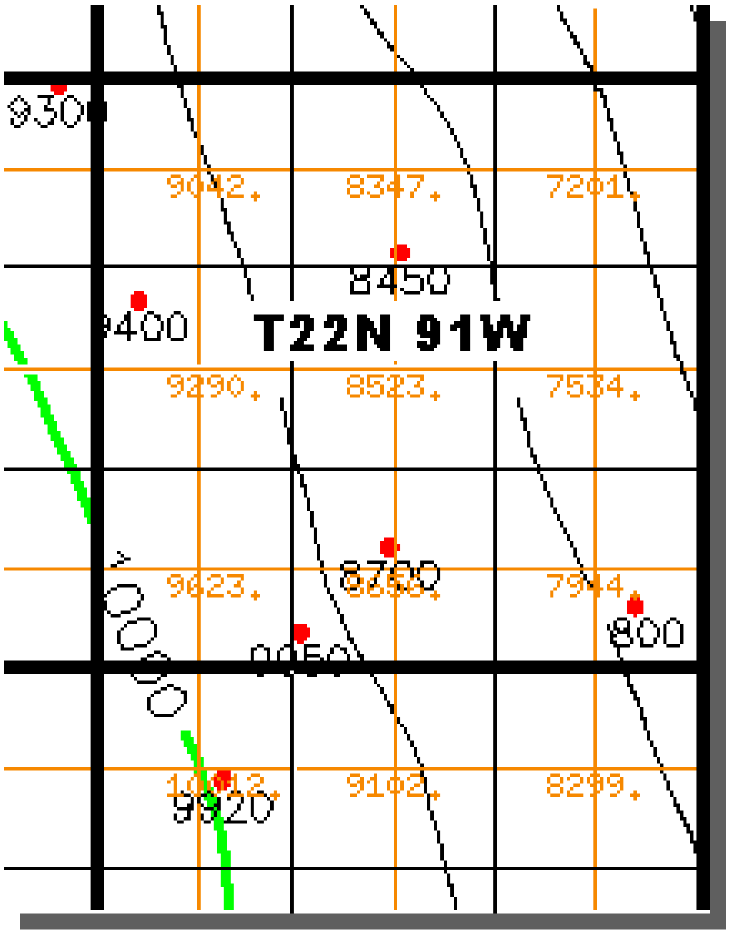
- **Rw assigned from best available data - but generally is poorly known**

- **High Shale Volume**
- **Low Porosity**
- **Moderate Resistivity**

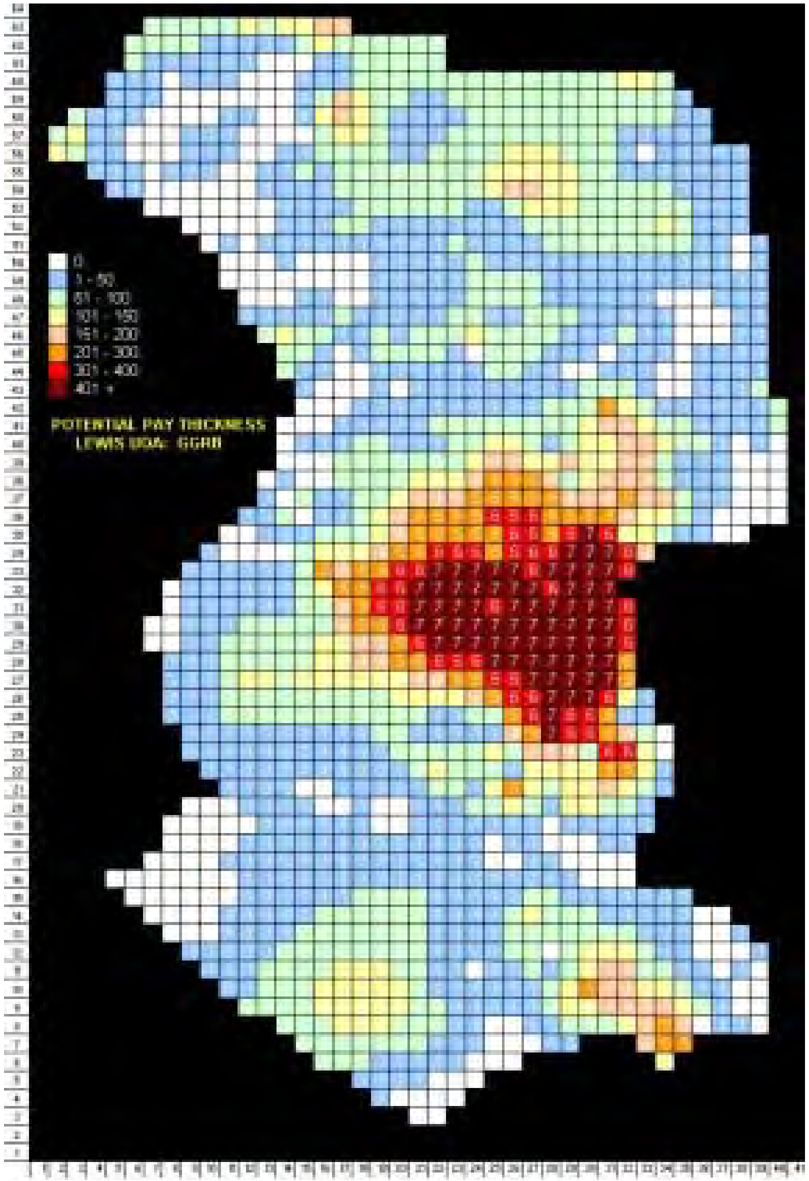
Rw = 0.005	**Sw = 18%**
Rw = 0.05	**Sw = 37%**
Rw = 0.5	**Sw = 49%**

Gridding

Translating Well Data to Cell Data



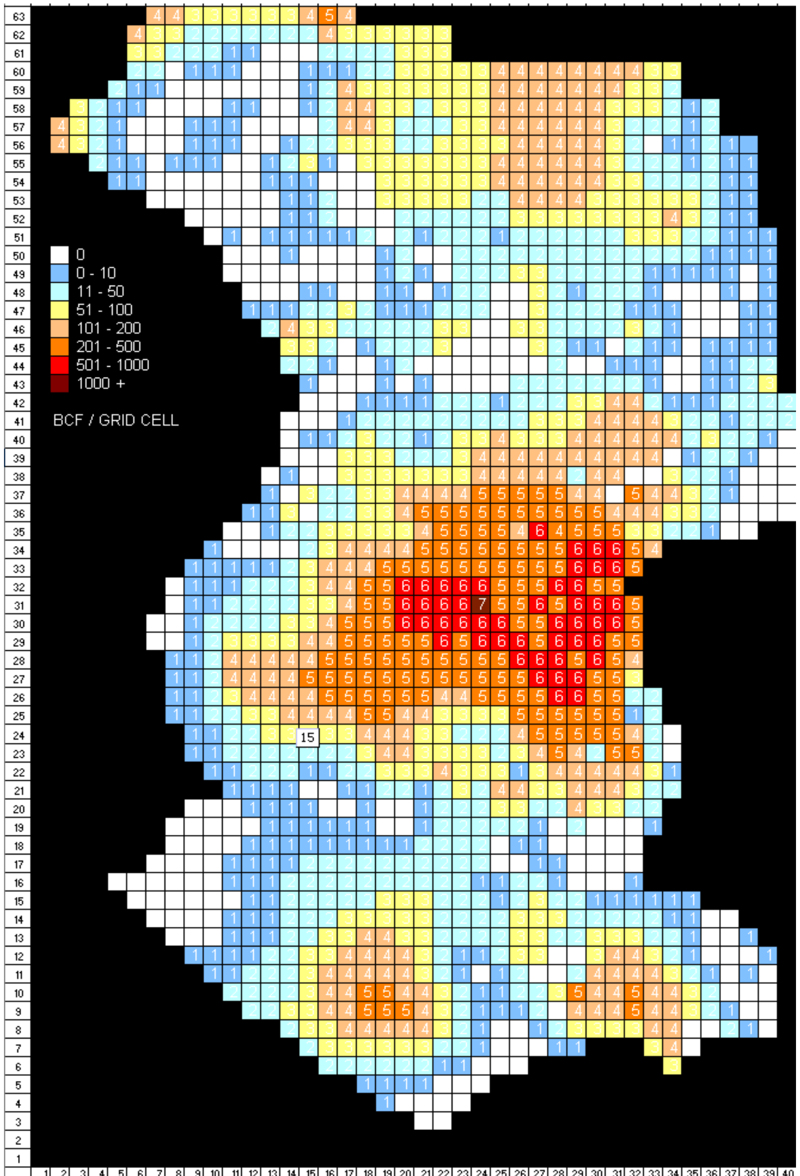
- **Example; computer interpolates drilling depth from well data for nine 2,560-acre cells per Township**
- **Grid Cell size is based on the data density for the play**
- **Identical gridding for remaining volumetric parameters (Thickness, Porosity, Sw, Pressure)**



Potential Pay Thickness Per Cell

Lewis UOA; GGRB

- **Values for 3,477 grid cells with average drilling depth > 5,000’**
- **Dark red = area with >400’ potential pay**



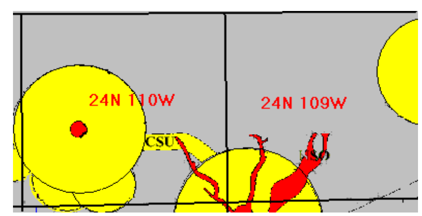
Gas-in-Place Per Cell

Lewis UOA : GGRB

- ***Achieves a detailed geographic representation of resource parameters***

- **White = areas of historical production or no sand**

WILL ALLOW FOR DIRECT COMPARISON TO LAND ACCESS INFORMATION



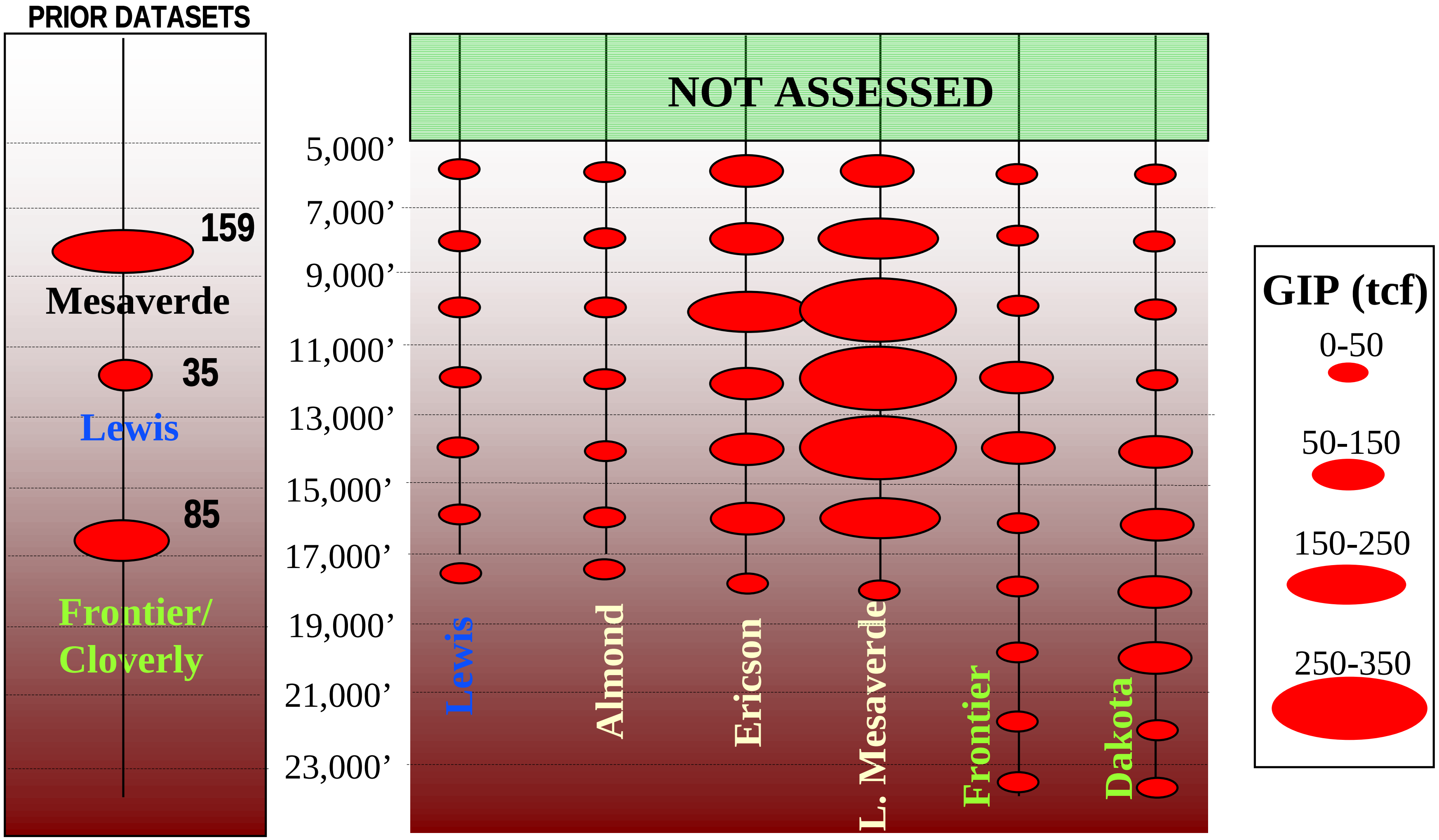
Summary Volumetric Results: GGRB UOAs

3,013 Tcf gas-in-place: 711 tcfg below 15,000'

	LEWIS	ALMOND	ERICSON	L. MSVD	FRONTIER	DAKOTA
Total Area (Acres)	3,891,200	6,097,920	7,782,400	8,125,440	11,258,880	10,749,440
Avg. Thickness (ft.)	100	44	173	369	47	52
Avg. Porosity (%)	7%	9%	9%	8%	8%	8%
Avg. Water Sat. (%)	56%	60%	47%	53%	43%	40%
Avg. Depth (ft.)	10,211	9,615	10,663	10,767	15,472	15,670
Avg. Pressure (psi)	5,428	5,075	5,488	5,559	10,186	10,415
Avg. Temperature (oF)	223	214	226	223	255	257
Avg. Z-Factor	1.05	1.03	1.06	1.06	1.39	1.4
Total Resource (tcf)	132	87	528	1,481	368	417
Deep Resource (tcf below 15,000')	10	3	60	214	198	226

Vertical Resource Dissaggragation

Greater Green River Basin



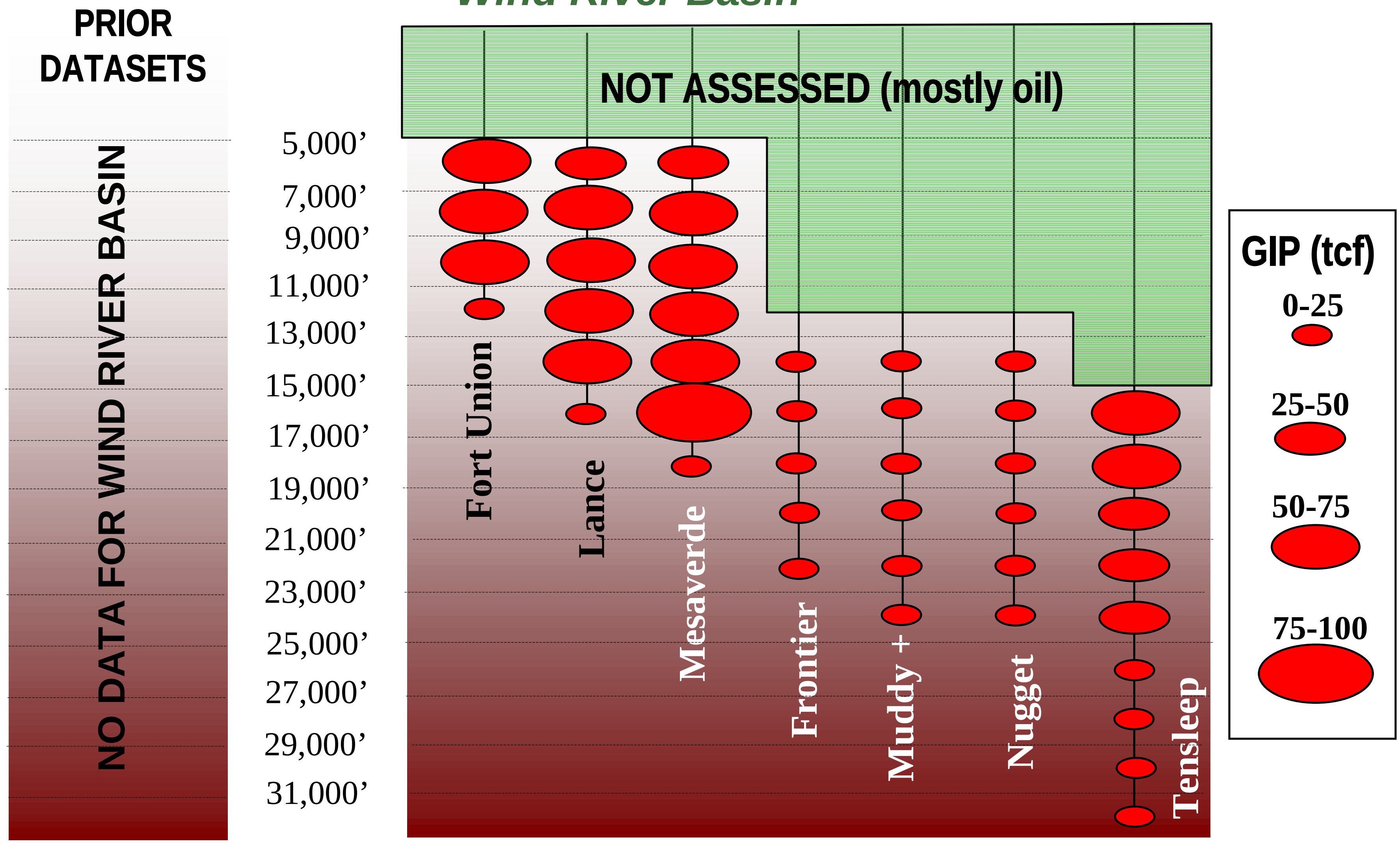
Summary Volumetric Results: WRB UOAs

1,322 Tcf gas-in place; 533 tcfg below 15,000'

	FORT UNION	LANCE	MEET/MSVD	FRONTIER	MUDDY +	NUGGET	TENSLEEP
Total Area (Acres)	1,103,360	1,354,240	1,546,240	1,525,760	1,672,960	1,681,920	1,246,720
Avg. Thickness (ft.)	441	512	461	91	34	76	285
Avg. Porosity (%)	10%	9%	8%	6%	6%	5%	6%
Avg. Water Sat. (%)	57%	51%	43%	46%	45%	47%	22%
Avg. Depth (ft.)	8,110	10,117	11,991	18,191	18,423	19,485	20,458
Avg. Pressure (psi)	3,627	5,104	6,933	12,420	12,559	13,444	14,184
Avg. Temperature (oF)	189	222	252	351	355	372	387
Avg. Z-Factor	0.94	1.03	1.16	1.52	1.52	1.57	1.61
Total Resource (tcf)	180	322	374	74	30	76	276
Deep Resource (tcf below 15,000')	0	2	109	62	23	61	276

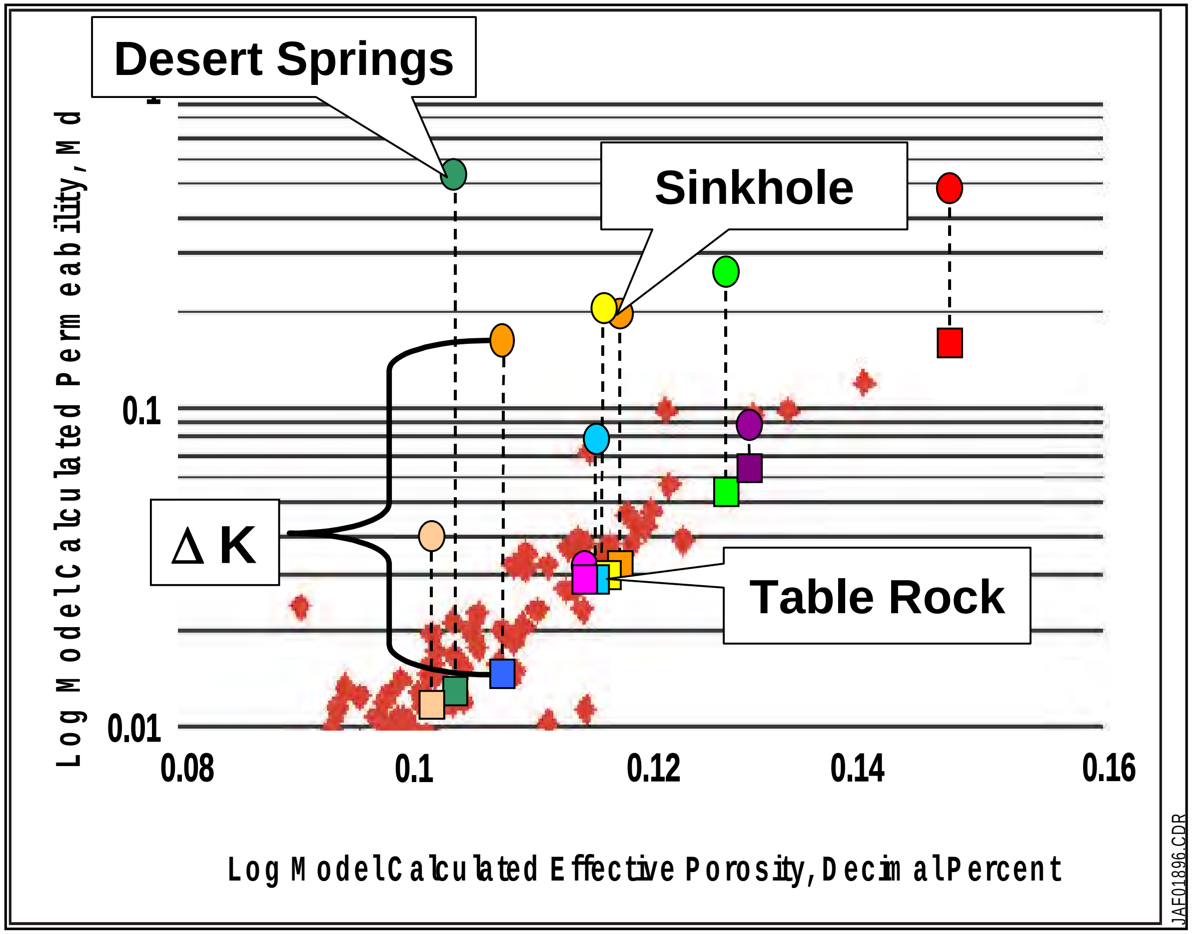
Vertical Resource Dissaggragation

Wind River Basin



Estimation of Permeability

Total Reservoir Permeability vs. Matrix Permeability

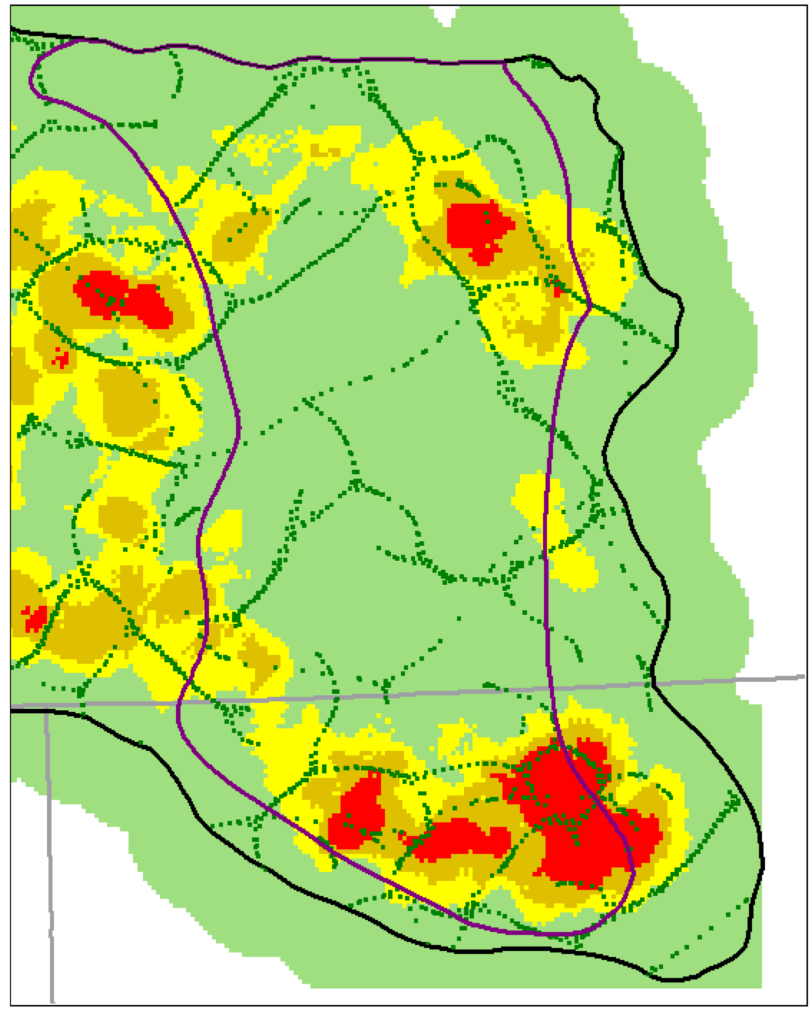


- **Matrix Perm estimated through porosity-perm. Relationships**
- **Estimated Bulk Perm compared to expected matrix perm - the difference (Δ K) is attributed to natural fracture overprint**
- **How to estimate fracture overprint?**

Estimating Fracture Overprint

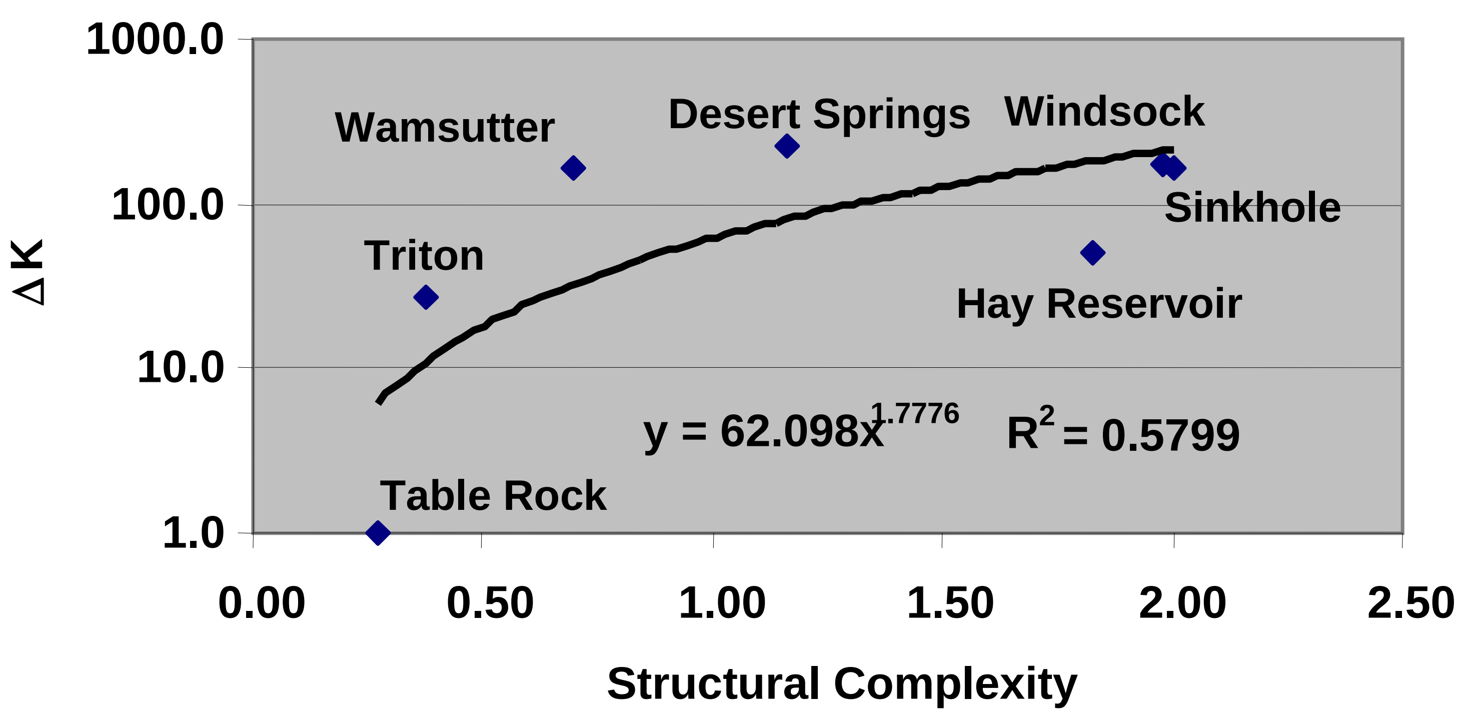
Predicting Structural Complexity

- **Estimate Structural complexity by Township or 1/4 Twn. through reference to aeromagnetic and gravity data**
- **Correlate incremental permeability in Type fields to Structural Complexity**
- **Estimate Fracture perm overprint**



Testing the Permeability Methodology

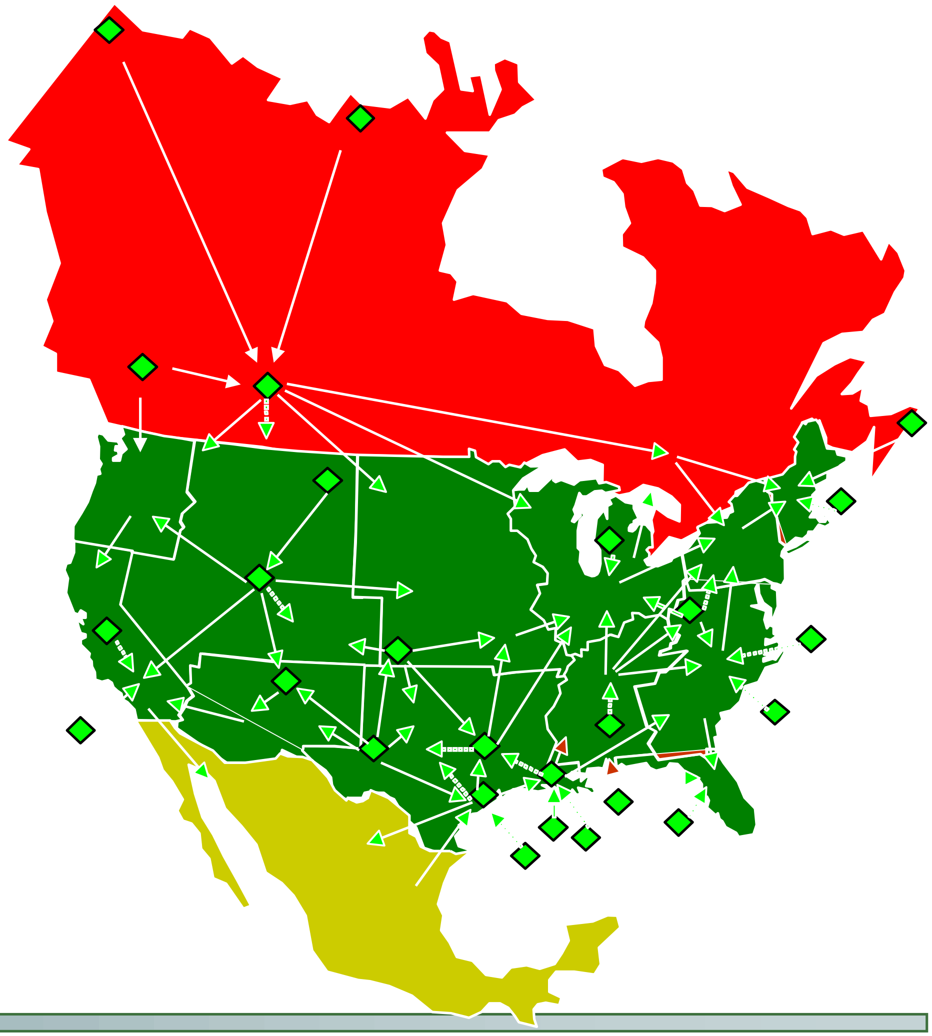
58% R-squared: Lewis UOA - GGRB



Gas Systems Analysis Model

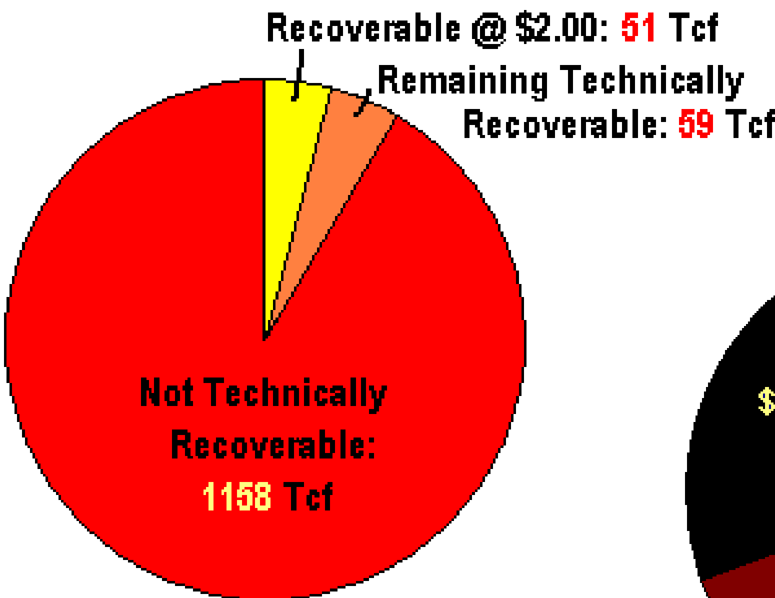
The Nation's leading tool for estimating the impact of technology/policy on North American gas supply and prices

- **A national model designed to analyze the impact of future technology/cost on total use production and use.**
- **Estimates unique response for each of 15,000 reservoirs.**
- **Integrates supply, demand, and infrastructure characterizations.**
- **Has supported numerous analyses for the federal and private sectors.**



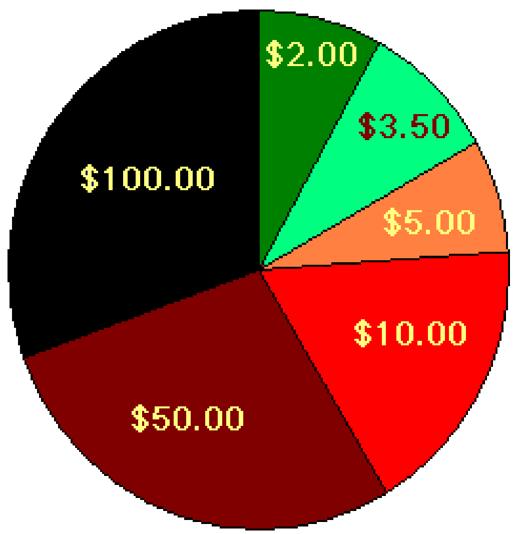
Impact of Technology on Resource Economics

Lower Mesaverde UOA: GGRB

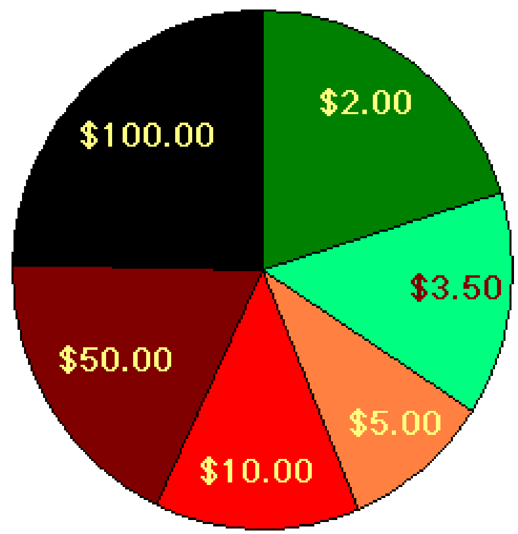


Recoverability of GIP by Volume

Economics of the Technically-Recoverable by Acreage



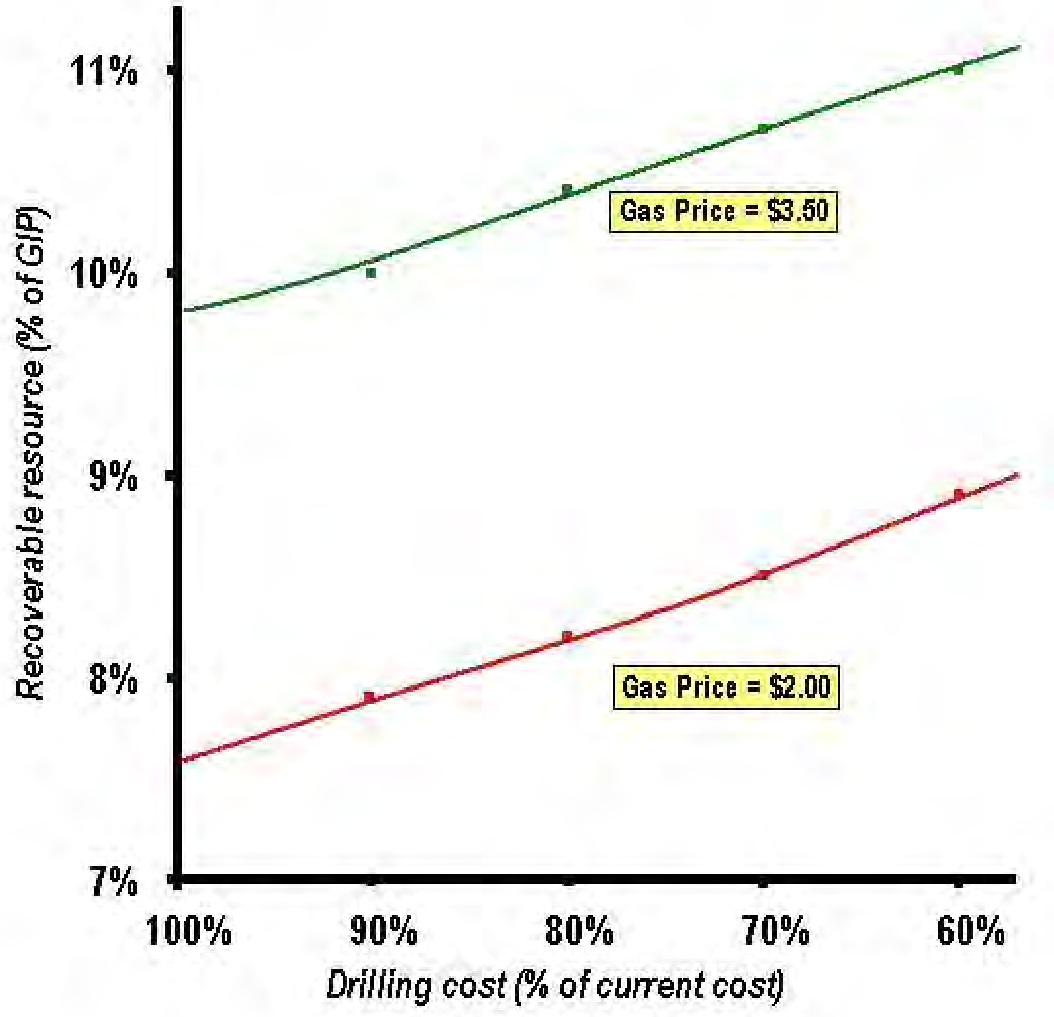
2002 Technology



2020 Technology

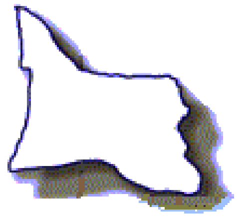
Modeling the Impact of Specific Technologies

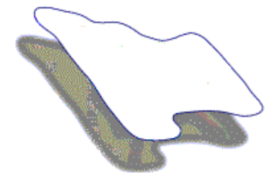
Drilling Cost Reduction v. Recoverable Resource



In LOWER MESAVERDE; each 10% reduction in drilling costs increases economically-recoverable by 0.3% (4 Tcf)

Summary



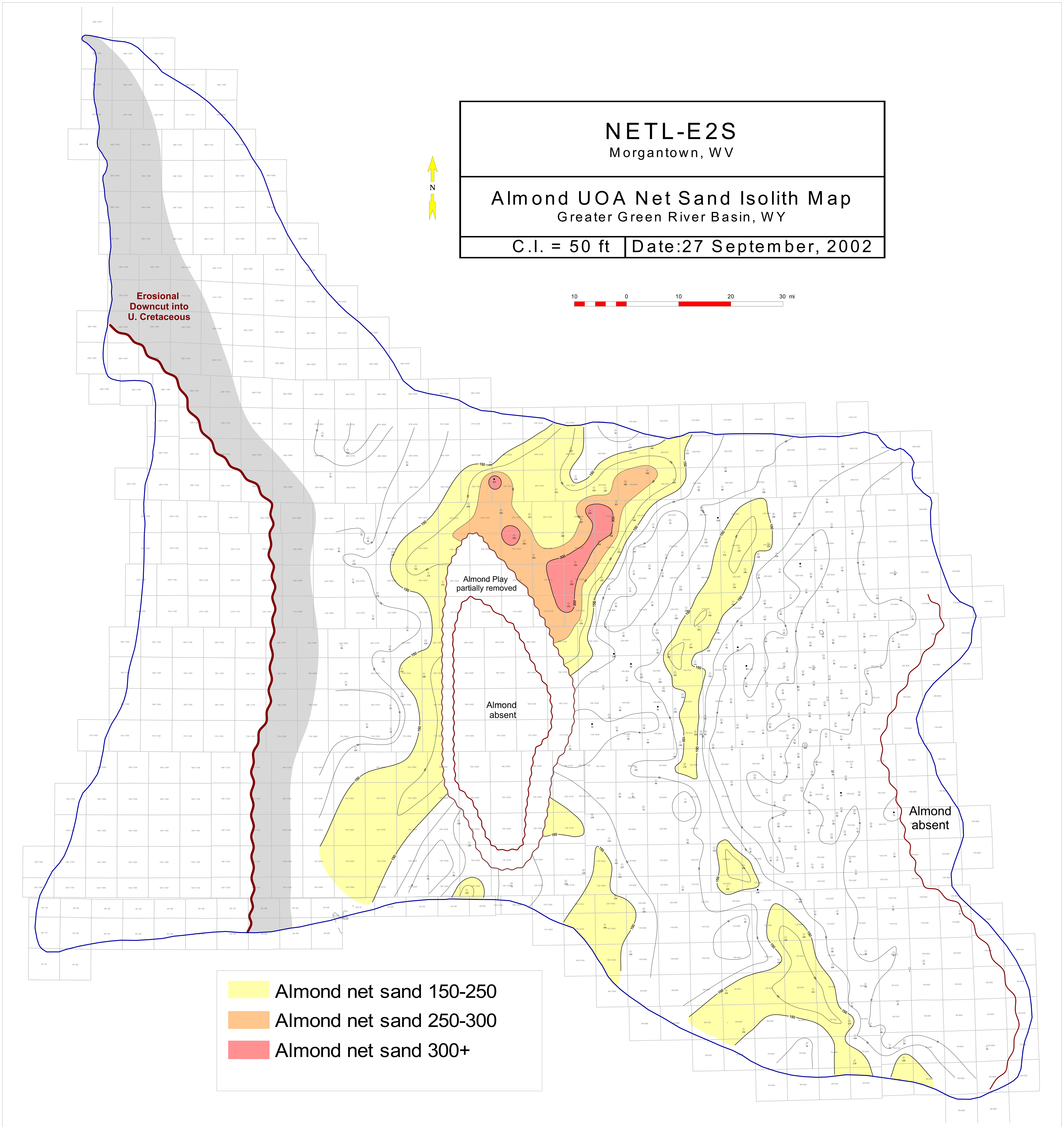


NETL has completed detailed characterizations of the gas resources of the Greater Green River and Wind River basins.

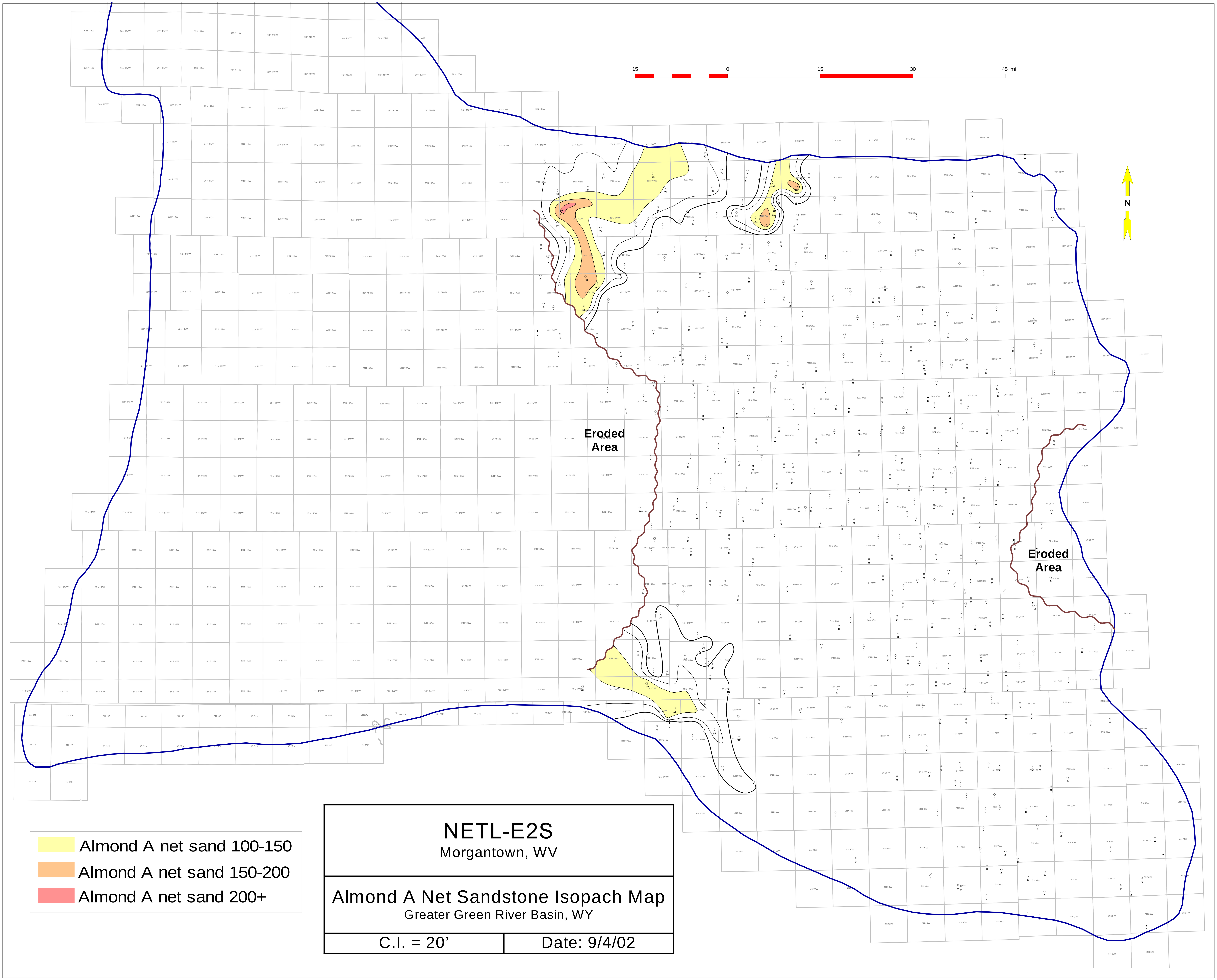
A preview of products and results is available on CD in the meeting room and is described in the current ***GasTIPS.***

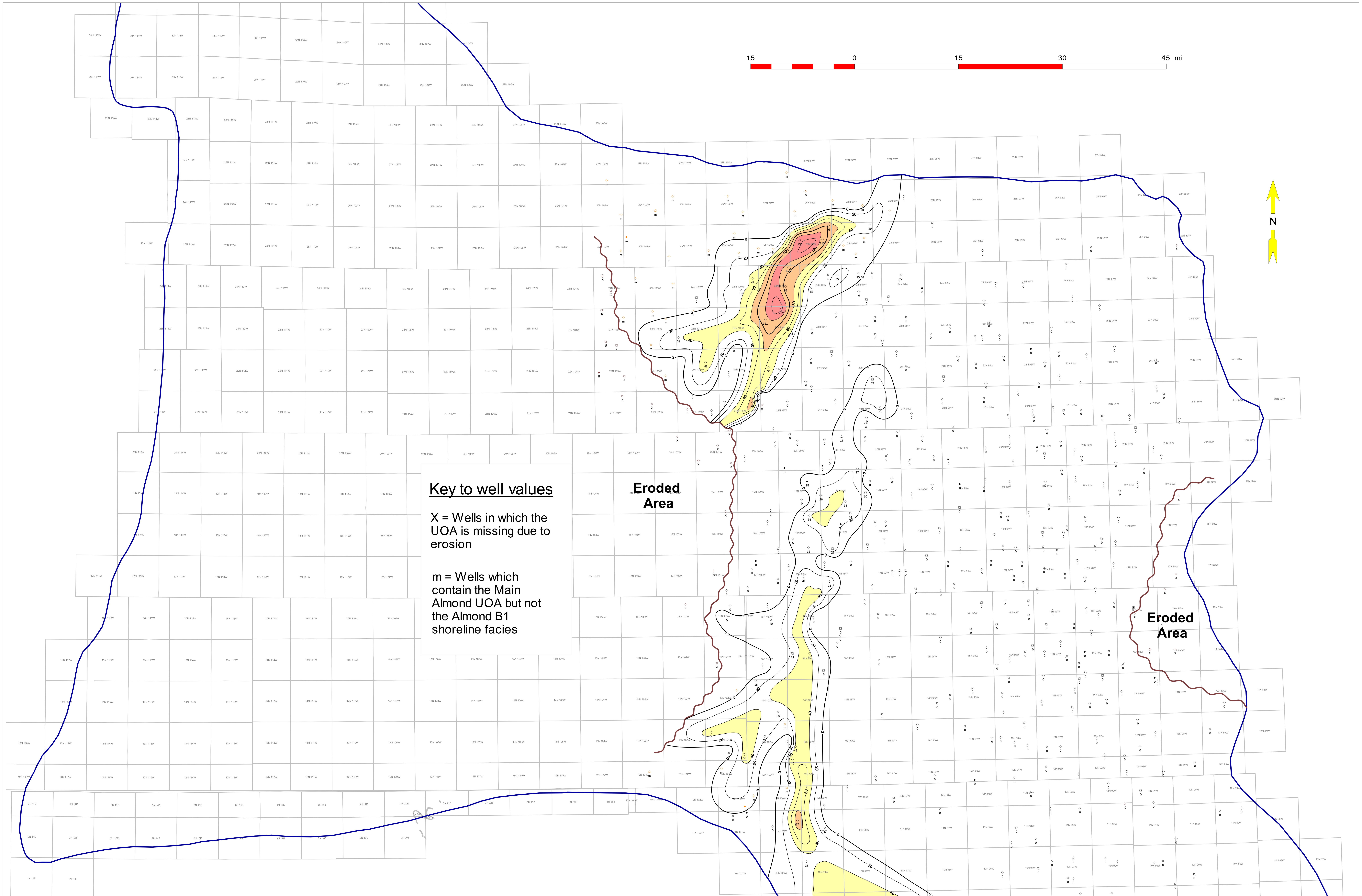
NEXT STEPS

- **finalize GGRB-WRB reports and post to web**
- **conduct analytical studies of the impact of technology**
- **initiate resource studies for the ANADARKO and UINTA basins**
- **compare GGRB resource data to detailed land access information to provide new insight into the impact of federal land policy**



NETL-E2S
Morgantown, WV
Almond UOA Net Sand Isolith Map
Greater Green River Basin, WY
C.I. = 50 ft
Date:27 September, 2002
N
10 0 10 20 30 mi
Erosional Downcut into U. Cretaceous
Almond Play partially removed
Almond absent
Almond absent
Almond net sand 150-250
Almond net sand 250-300
Almond net sand 300+


15
0
15
30
45 mi
N
Eroded Area
Eroded Area
Almond A net sand 100-150
Almond A net sand 150-200
Almond A net sand 200+
NETL-E2S
Morgantown, WV
Almond A Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02

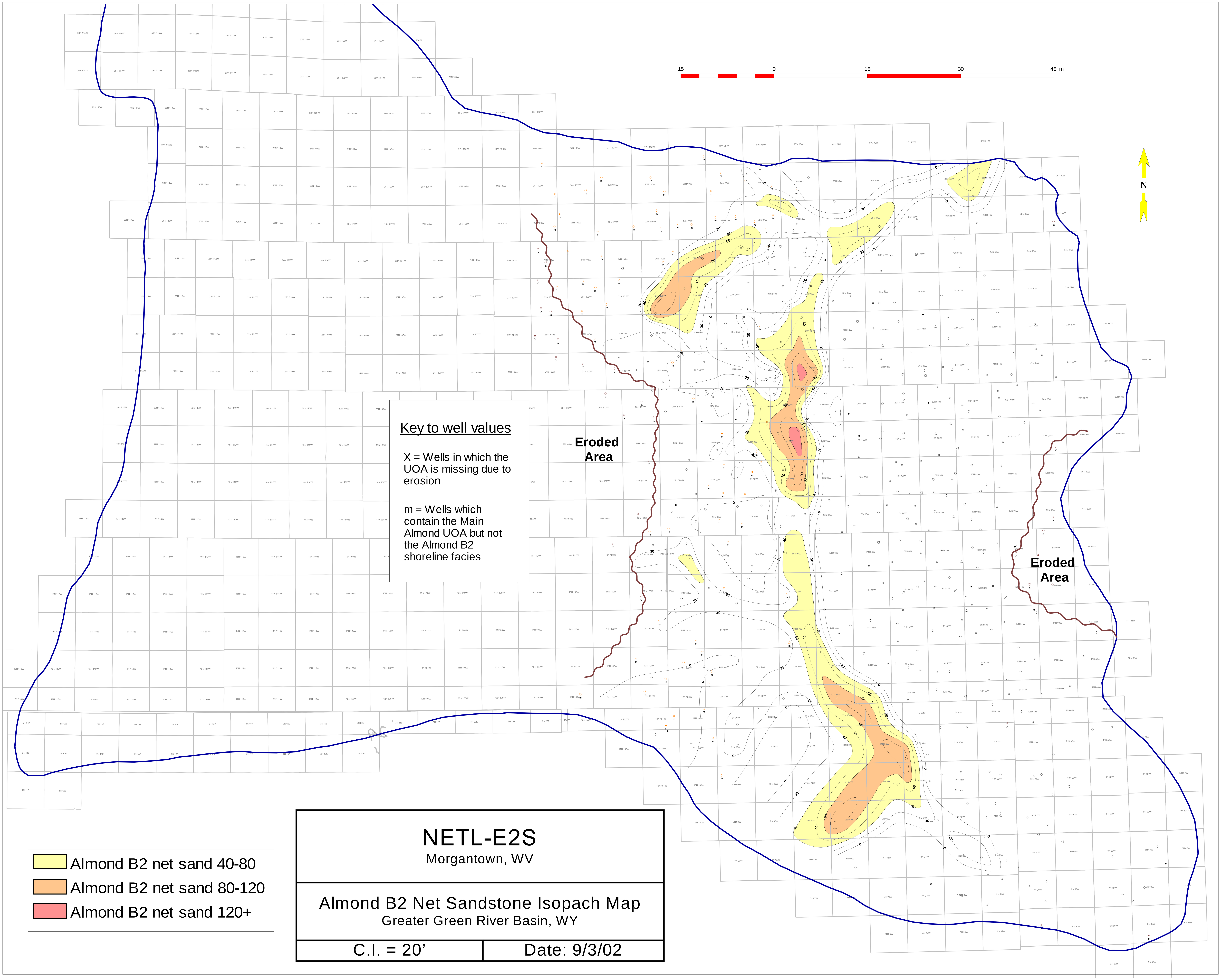


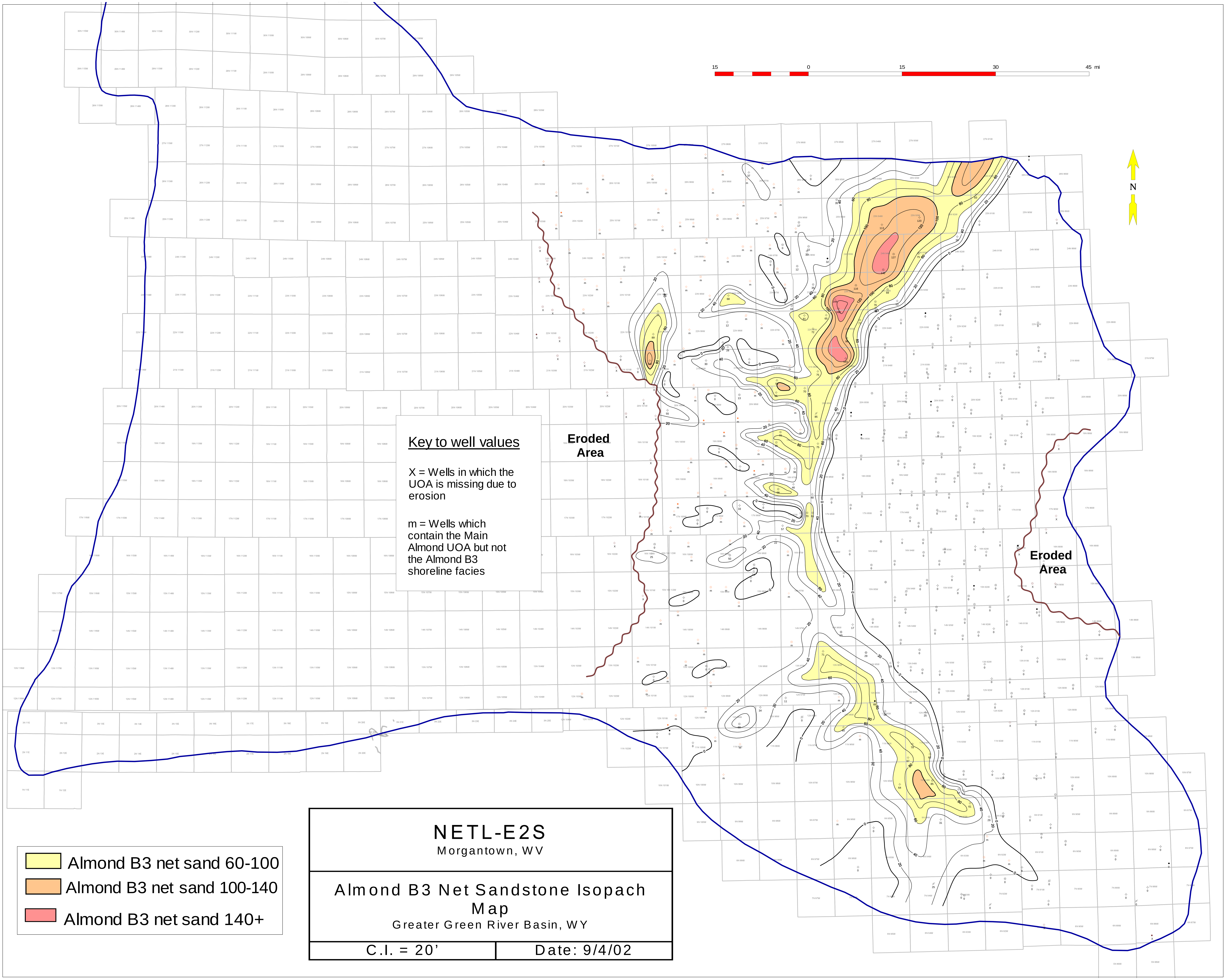
NETL-E2S
Morgantown, WV

Almond B1 Net Sandstone Isopach Map
Greater Green River Basin, WY

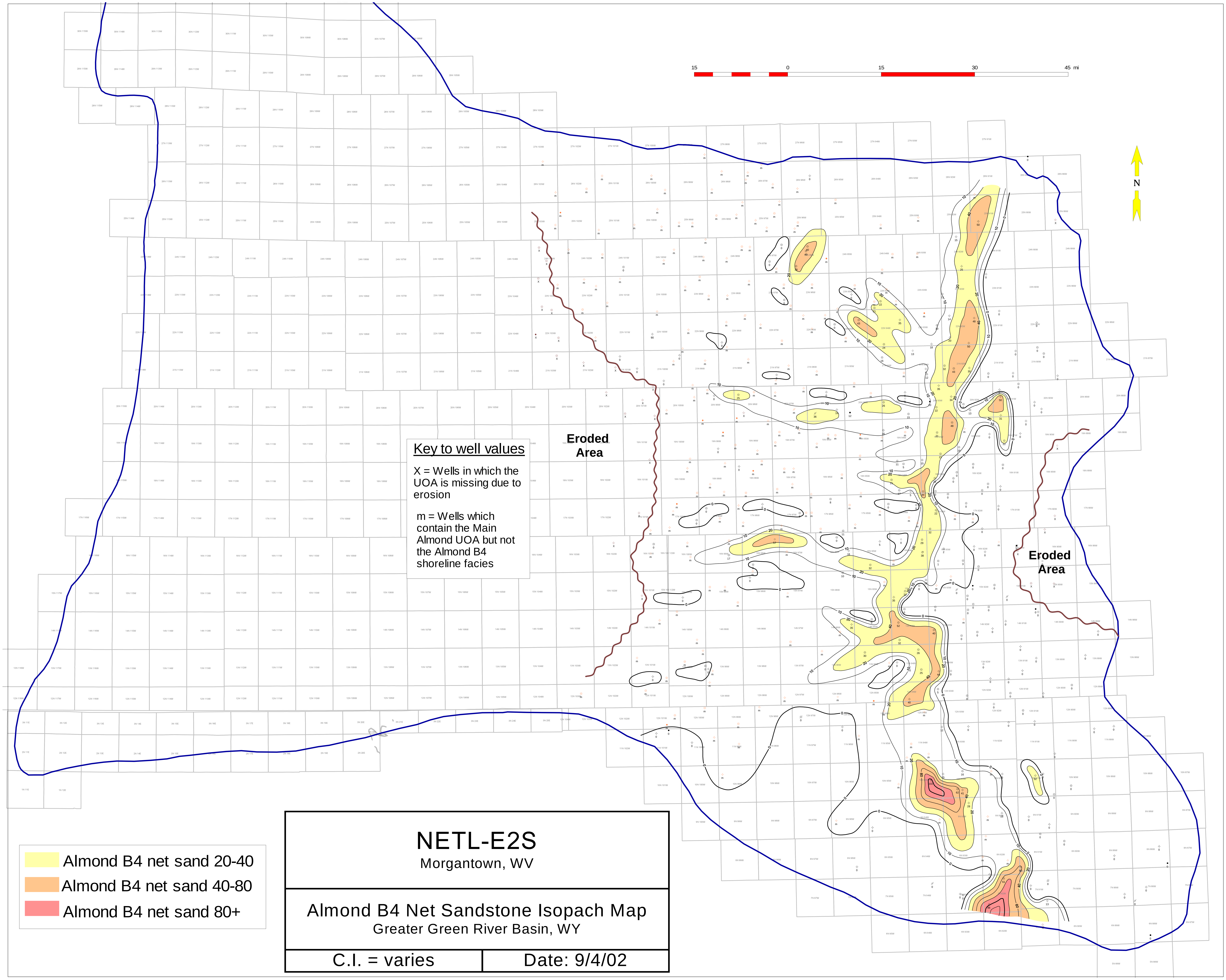
C.I. = 20'

Date: 9/4/02

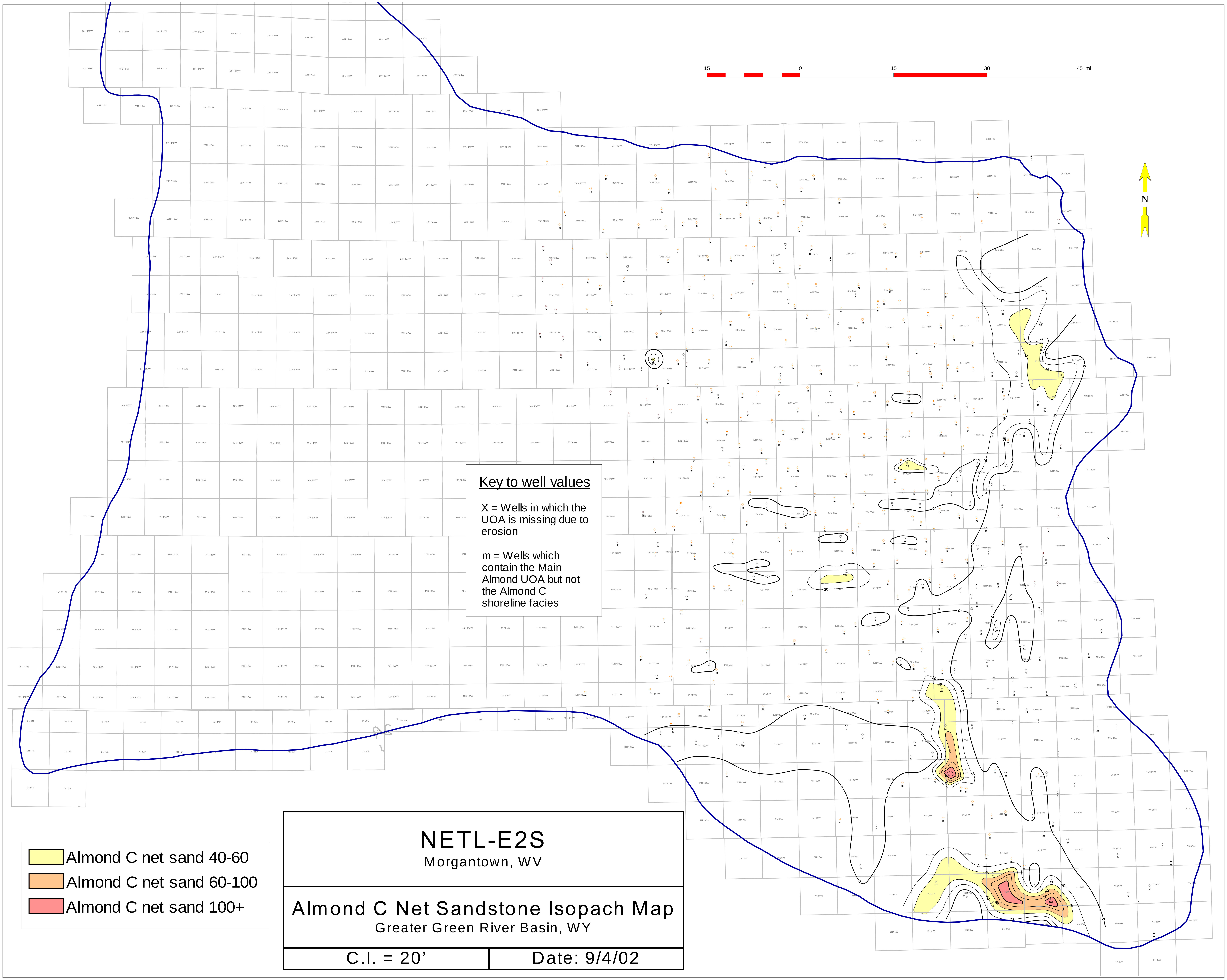

15
0
15
30
45 mi
N
Key to well values
X = Wells in which the UOA is missing due to erosion
m = Wells which contain the Main Almond UOA but not the Almond B2 shoreline facies
Eroded Area
Eroded Area
Almond B2 net sand 40-80
Almond B2 net sand 80-120
Almond B2 net sand 120+
NETL-E2S
Morgantown, WV
Almond B2 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/3/02



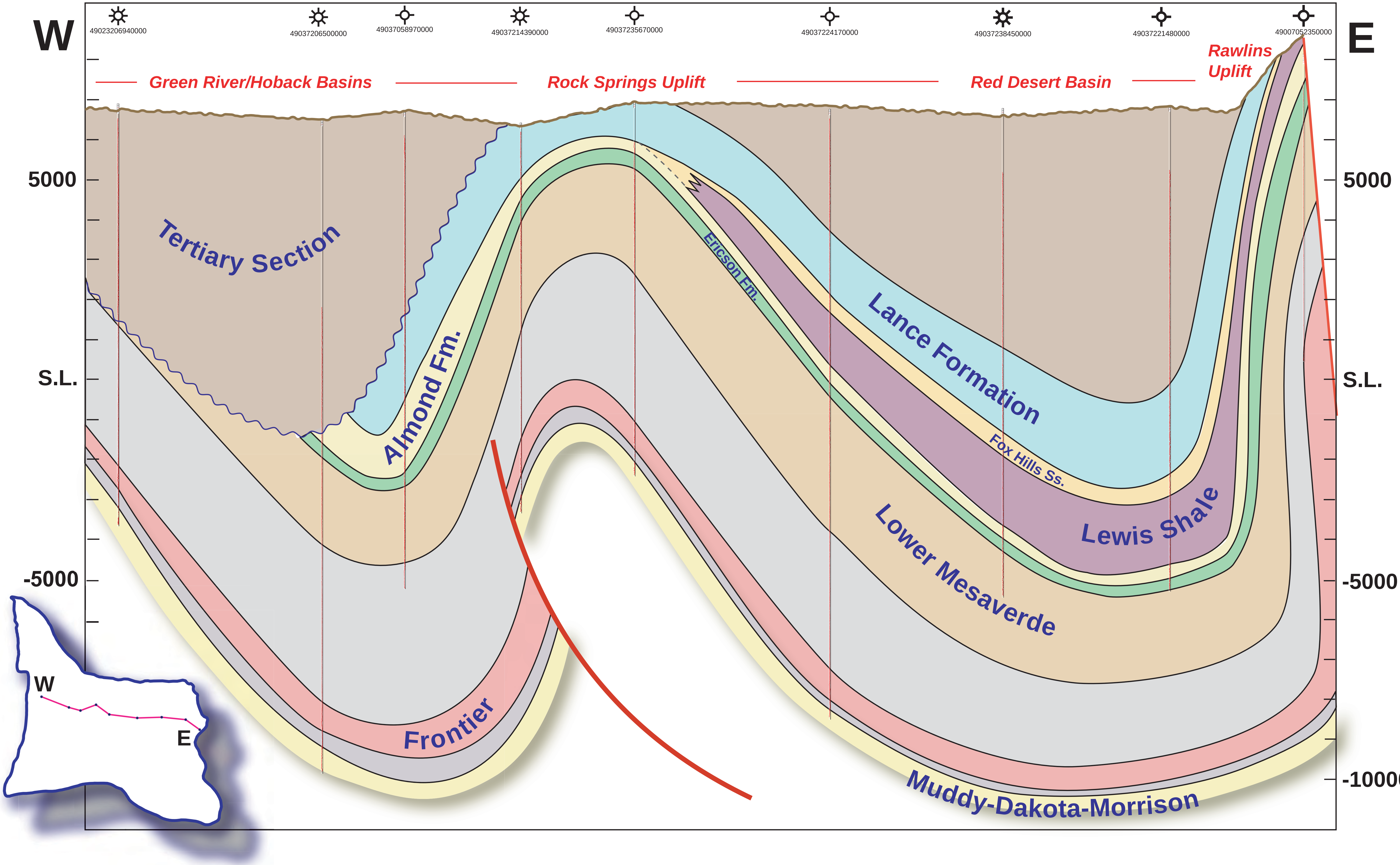
15 0 15 30 45 mi
N
Eroded Area
Eroded Area
Key to well values
X = Wells in which the UOA is missing due to erosion
m = Wells which contain the Main Almond UOA but not the Almond B3 shoreline facies
Almond B3 net sand 60-100
Almond B3 net sand 100-140
Almond B3 net sand 140+
NETL-E2S
Morgantown, WV
Almond B3 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02

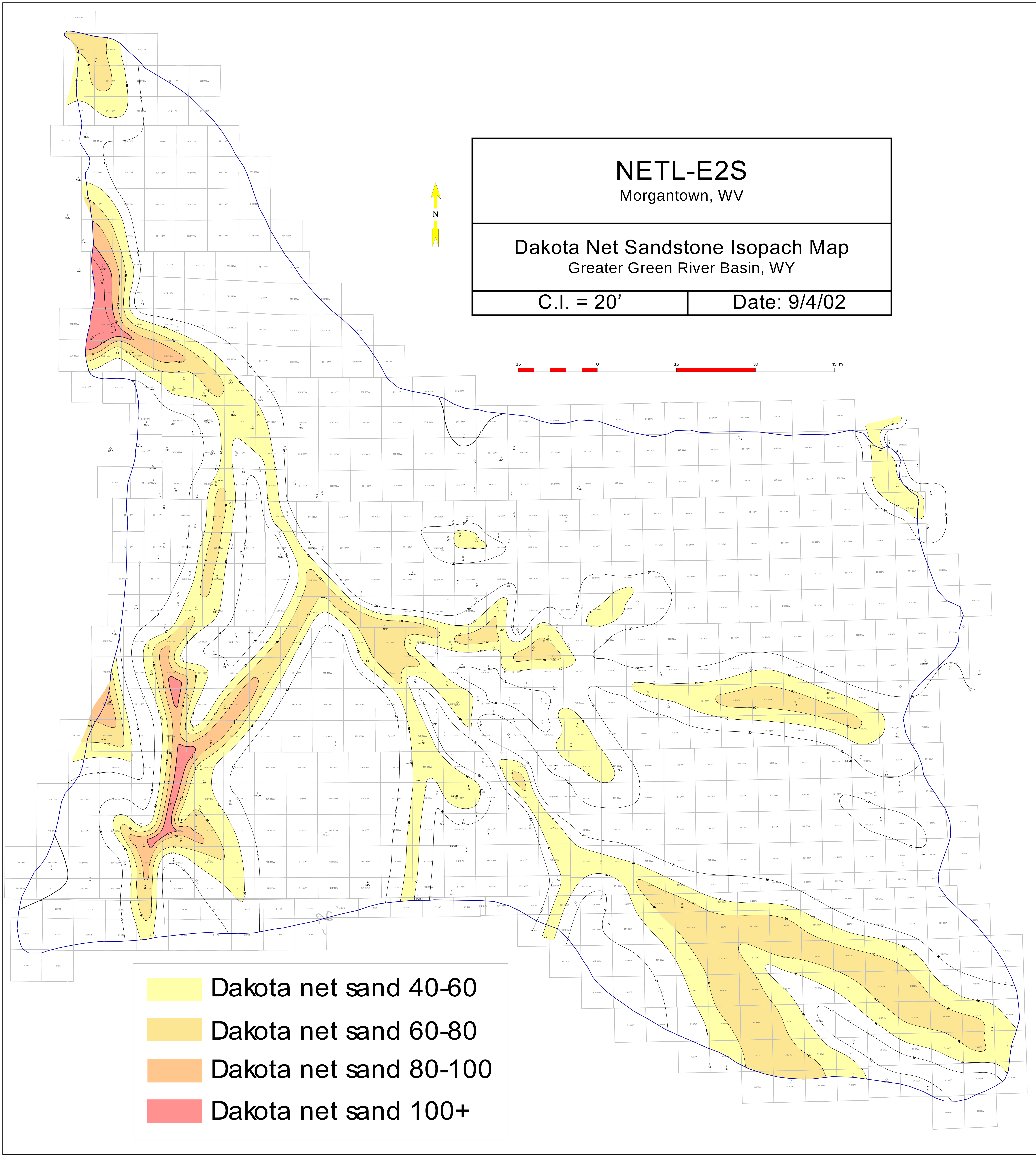


Key to well values
X = Wells in which the UOA is missing due to erosion
m = Wells which contain the Main Almond UOA but not the Almond B4 shoreline facies
Eroded Area
Eroded Area
N
15 0 15 30 45 mi
Almond B4 net sand 20-40
Almond B4 net sand 40-80
Almond B4 net sand 80+
NETL-E2S
Morgantown, WV
Almond B4 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = varies
Date: 9/4/02

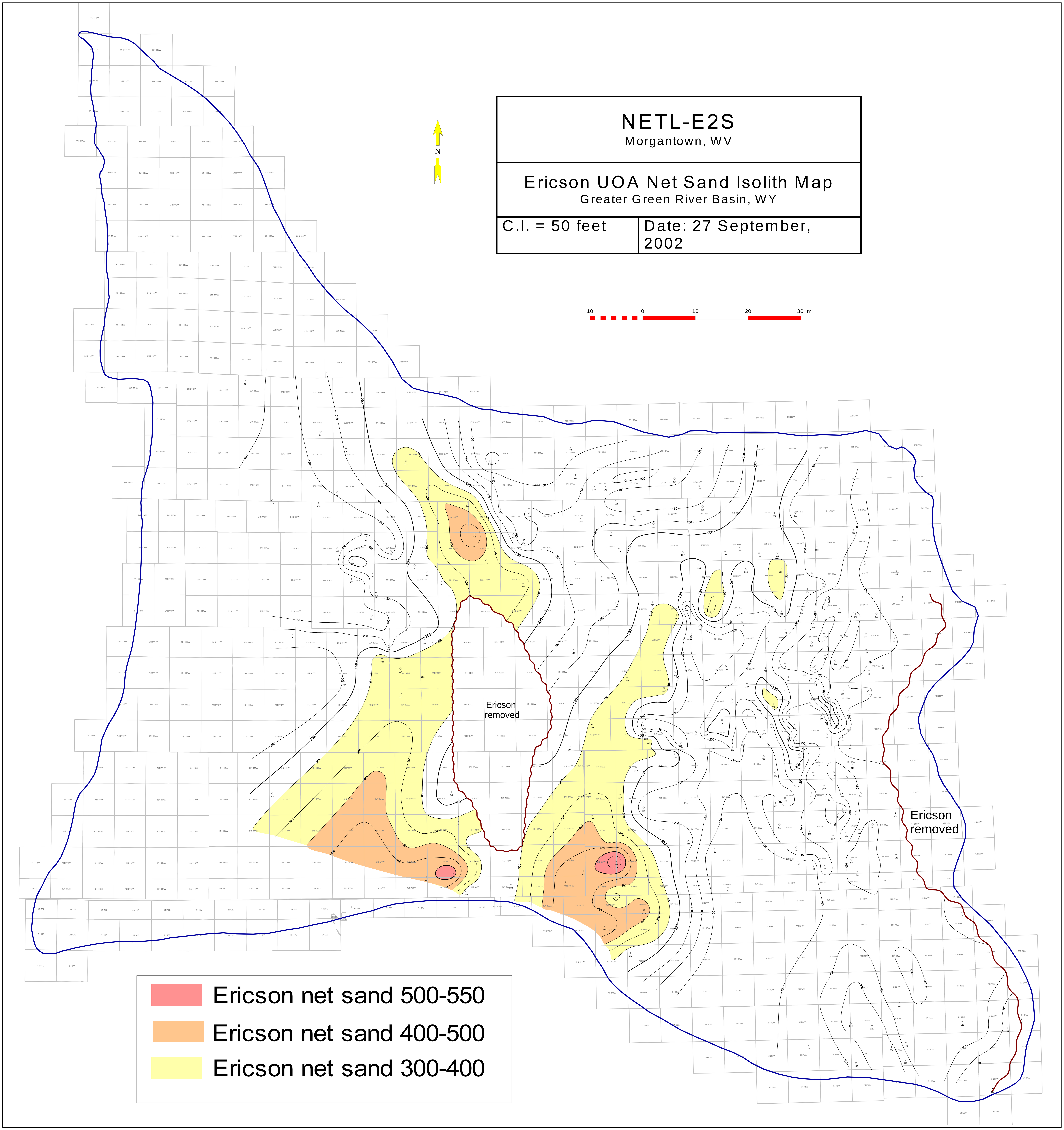

15 0 15 30 45 mi
N
Key to well values
X = Wells in which the UOA is missing due to erosion
m = Wells which contain the Main Almond UOA but not the Almond C shoreline facies
Almond C net sand 40-60
Almond C net sand 60-100
Almond C net sand 100+
NETL-E2S
Morgantown, WV
Almond C Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20’
Date: 9/4/02

Greater Green River Basin - Structural Cross Section
Vertical Exaggeration 26.5X

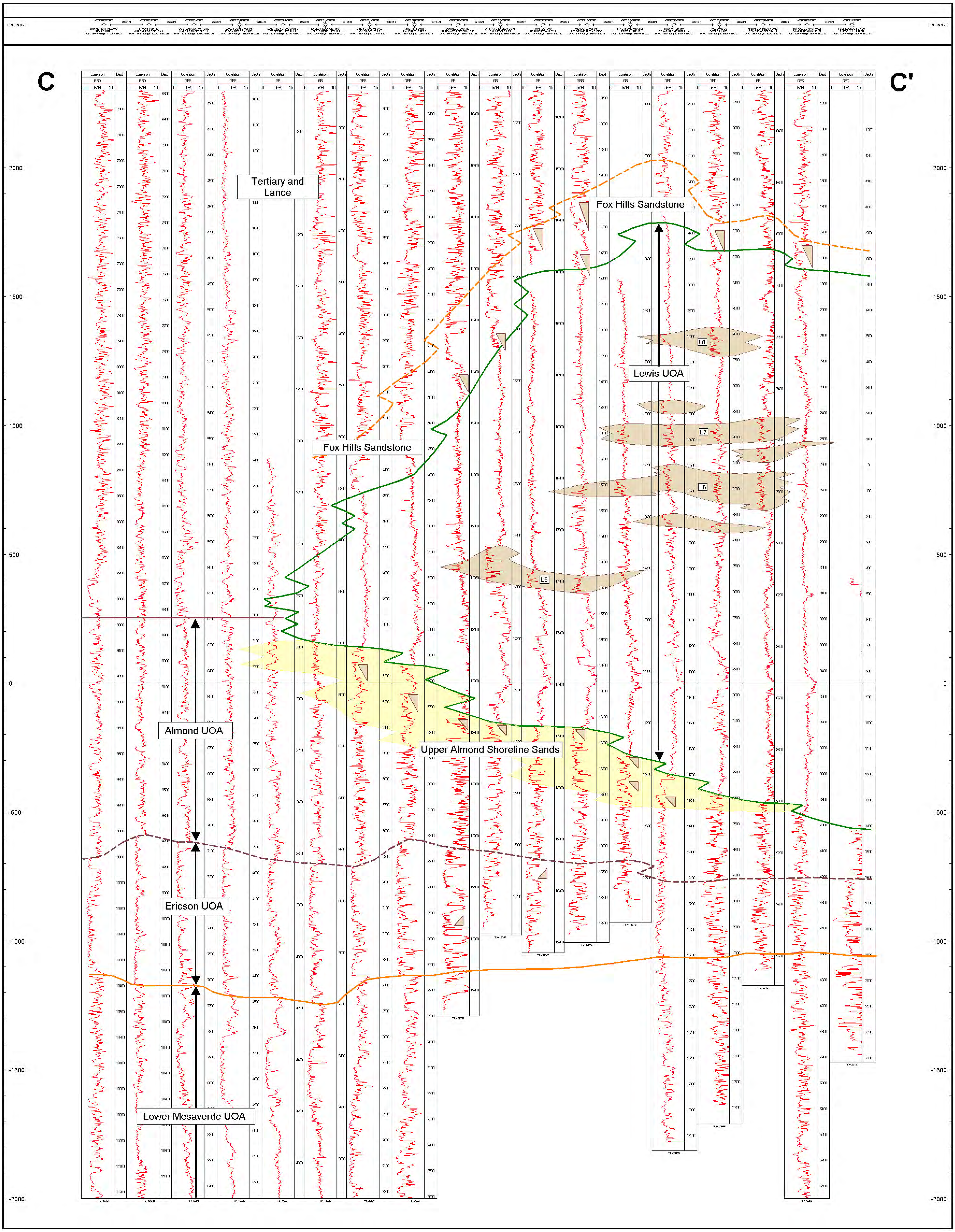



NETL-E2S
Morgantown, WV
Dakota Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02
N
15
0
15
30
45 mi
Dakota net sand 40-60
Dakota net sand 60-80
Dakota net sand 80-100
Dakota net sand 100+


49037209410000
47270 ft
AMOCO PROD CO
CHAMPLIN446AMOCO-A 1
TWP: 22N - Range: 90W - Sec. 15
49037221480000
37214 ft
NAT GAS CORP OF CALI
WINDY HILL 3-25
TWP: 21N - Range: 91W - Sec. 25
49037210860000
21699 ft
CITIES SERV OIL CO
FEDERAL-Y 1
TWP: 20N - Range: 91W - Sec. 32
49007202690000
33025 ft
DAVIS OIL CO
TOM FEDERAL 1
TWP: 19N - Range: 91W - Sec. 20
49007210290000
33640 ft
AMOCO PROD CO
CRESTON NOSE UNIT 1
TWP: 18N - Range: 92W - Sec. 9
49007207690000
14398 ft
SNYDER OIL CORP
PTS-FEDERAL 1-8
TWP: 17N - Range: 92W - Sec. 8
49007208100000
40608 ft
SNYDER OIL CORP
SNYDER HUSKY 1-28
TWP: 17N - Range: 92W - Sec. 28
49007206830000
35326 ft
SNYDER OIL CORP
HAMILTON-FEDERAL 1-33
TWP: 16N - Range: 92W - Sec. 33
49007203750000
18635 ft
SINCLAIR OIL CORP
FAIR-FEDERAL 3-1
TWP: 14N - Range: 92W - Sec. 3
49007204340000
31002 ft
GETTY OIL COMPANY
SW ROBBERS GULCH 11-23
TWP: 14N - Range: 92W - Sec. 23
49007206040000
13621 ft
DIAMOND SHMROCK CORP
RED PRONG-FEDERAL 1
TWP: 13N - Range: 92W - Sec. 21
49007207800000
52137 ft
SNYDER OIL CORP
NORTH BAGGS-FEDERAL 1-34
TWP: 13N - Range: 92W - Sec. 34
05081066710000
63993 ft
QUINTANA PET CORP
SOUTH SAND HILLS FE 1-34
TWP: 12N - Range: 91W - Sec. 34
05081065100000
35518 ft
IMPERIAL OIL COMPANY
STATE 1-36
TWP: 10N - Range: 91W - Sec. 36
05081067130000
44482 ft
GLG ENERGY L P
BLUE GRAVEL 3-1
TWP: 8N - Range: 91W - Sec. 3
05081067100000
34558 ft
COCKRELL OIL CORP
STELBAR-SCOTT 1
TWP: 7N - Range: 91W - Sec. 17
05081066720000
K-N OPRTNG CORPRTN
CRAIG-STATE 15-2
TWP: 6 N - Range: 91 W - Sec. 15
D
D'
2000
1500
1000
500
0
-500
-1000
L8
L9
L7
L8
L7
L7
L6
L5
L4
L3
L3
Lewis UOA
Upper Almond Shoreline Sands
Almond UOA
Ericson UOA
TD=14953
TD=12166
TD=10083
TD=9186
TD=17060
TD=8997
TD=8516
TD=8141
TD=10000
TD=9780
TD=9716
TD=8120
TD=6350
TD=6621
TD=7676
TD=6447
TD=8088



NETL-E2S
Morgantown, WV
Ericson UOA Net Sand Isolith Map
Greater Green River Basin, WY
C.I. = 50 feet
Date: 27 September, 2002
N
10 0 10 20 30 mi
Ericson removed
Ericson removed
Ericson net sand 500-550
Ericson net sand 400-500
Ericson net sand 300-400


C
C'
Tertiary and Lance
Fox Hills Sandstone
Fox Hills Sandstone
Lewis UOA
L8
L7
L6
L5
Almond UOA
Upper Almond Shoreline Sands
Ericson UOA
Lower Mesaverde UOA
2000
1500
1000
500
0
-500
-1000
-1500
-2000

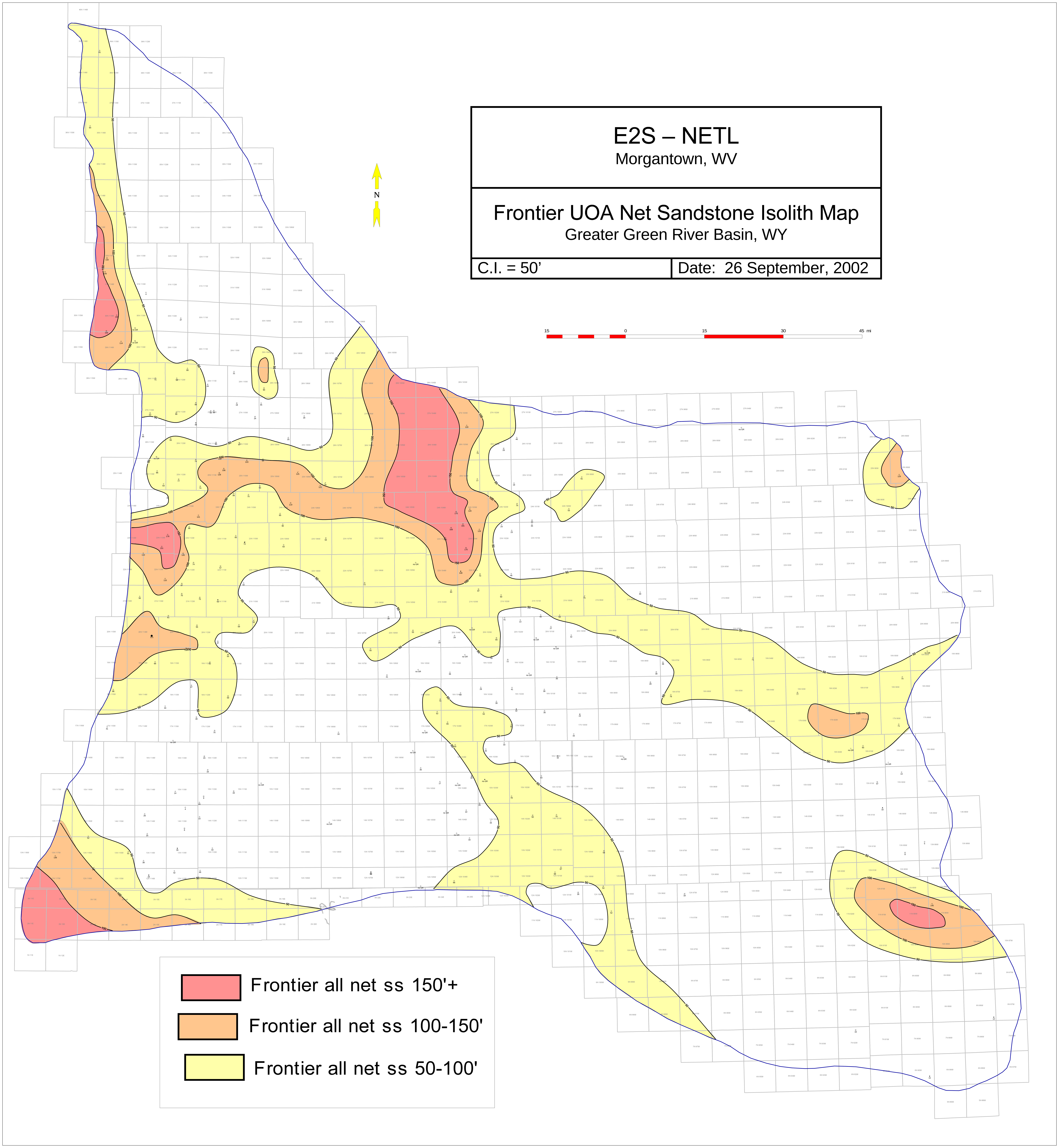

H
H'
Cross Section Tie Well for K-K'
Cross Section Tie Well for L-L'
FRONTIER
UOA
Stratigraphic
Datum
DAKOTA
UOA
GR
Resistivity
Frontier 0
Frontier 1
Frontier 2a
Frontier 2b
Frontier 3-4
Frontier 5
Bentonite
Muddy
Dakota
Morrison

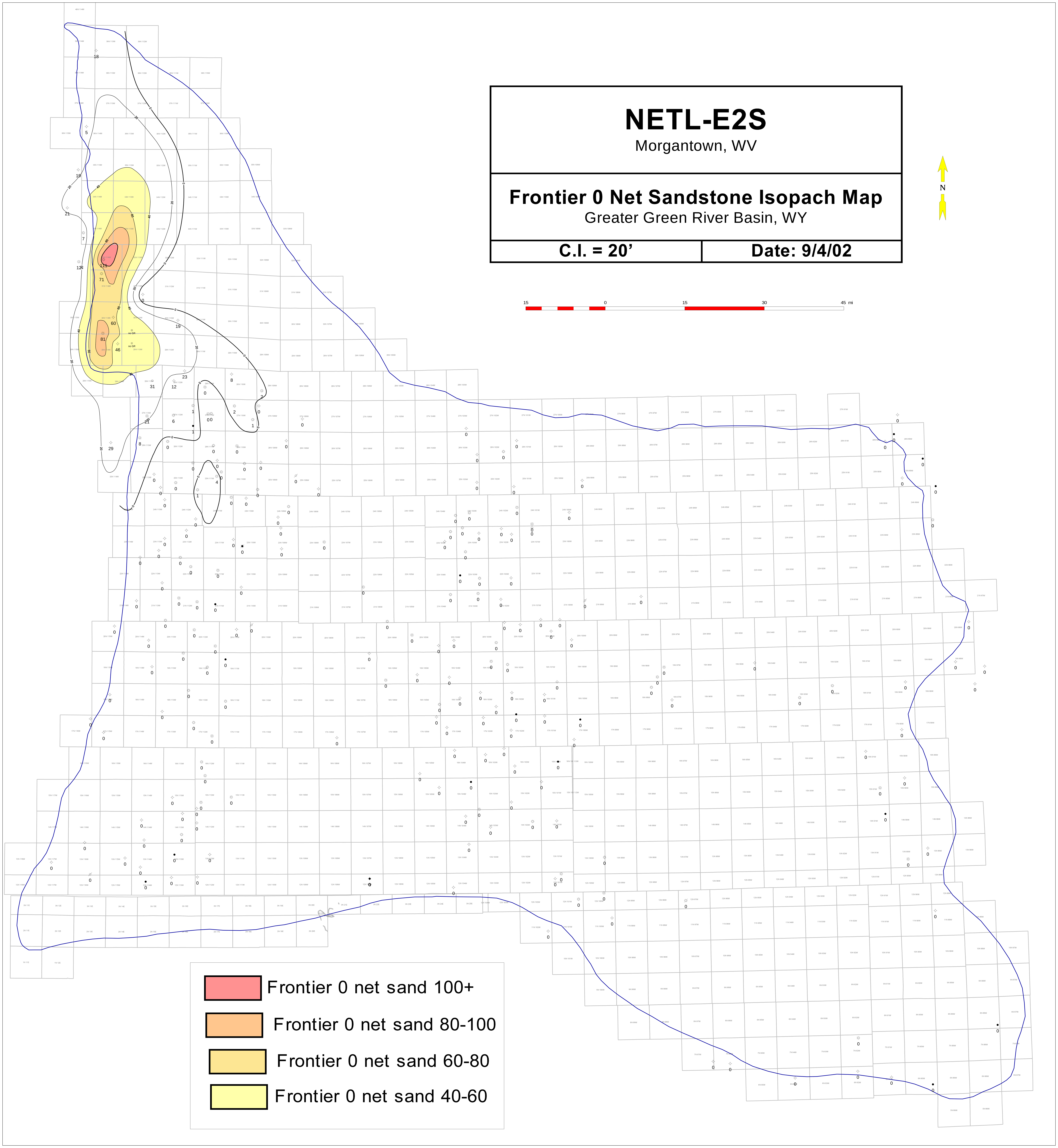

49035204470000
WILLIAMS EXPL CO
FED-PACIFIC CREEK 1-34
TWP: 27 N - Range: 103W - Sec. 34
49037214250000
WOODS PETROLEUM CORP
PACKSADDLE UNIT 1
TWP: 25N - Range: 103W - Sec. 24
49037220130000
LUFF EXPL CO
AMOCO CHAMPLIN N-23
TWP: 22N - Range: 103W - Sec. 23
49037203060000
TERRA RESOURCES INC
TERRA-FEDERAL 18-1
TWP: 20N - Range: 103W - Sec. 18
49037202760000
MOUNTAIN FUEL SUPLY
C R HETZLER 5
TWP: 18N - Range: 103W - Sec. 8
49037205170000
AMOCO PROD CO
USA-M J HARVEY JR 1
TWP: 16N - Range: 103W - Sec. 8
49037212500000
NORTH CENTRAL OIL
FEDERAL 1-21
TWP: 14N - Range: 103W - Sec. 21
49037214500000
ENERGY RESV GRP INC
KENAI-PINE MOUNTAIN 1
TWP: 12N - Range: 103W - Sec. 10
Cross Section Tie Well for K-K'
Cross Section Tie Well for L-L'
I
I'
GR
Resistivity
SP
Depth
1000
500
0
-500
FRONTIER
UOA
Stratigraphic
Datum
DAKOTA
UOA
TD=25764
TD=14850
TD=8104
TD=4973
TD=3133
TD=4950
TD=12067
TD=14630

49037217620000
FLORIDA EXPL CO
ABLE CREEK-FEDERAL 1-23
TWP: 26N - Range: 90W - Sec. 23
40201 ft
49007200550000
TENNECO OIL CO
STEWART CREEK 1
TWP: 25N - Range: 89W - Sec. 29
34255 ft
49007205280000
BURTON-HAWKS INC
SHERARD-FEDERAL 5-1
TWP: 24N - Range: 88W - Sec. 5
33671 ft
49007208620000
DOLEZAL GEORGE JR
FEDERAL 5-6
TWP: 23N - Range: 88W - Sec. 6
135607 ft
49007052350000
PRAY MAX
UNIT 1
TWP: 19N - Range: 89W - Sec. 15
35997 ft
49007201170000
TENNECO OIL CO
UNIT 3
TWP: 18N - Range: 90W - Sec. 11
86975 ft
49007200970000
TRUE OIL CO
DEEP CREEK UNIT 31-31
TWP: 16N - Range: 90W - Sec. 31
46027 ft
49007205510000
TRIGG DRLG CO INC
TRIGG-BROWNING-FED 1-12
TWP: 14N - Range: 91W - Sec. 12
50322 ft
49007204740000
ENERGY OPER CORP
DENNY ALVIN E 1
TWP: 13N - Range: 90W - Sec. 27
58063 ft
05081062350000
GULF OIL CORP
SLATER CREEK UNIT 1
TWP: 11 N - Range: 89 W - Sec. 7
129649 ft
05107060900000
DOME PETROLEUM LTD
STATE 1-36
TWP: 8N - Range: 88W - Sec. 36
J
J'
Cross Section Tie Well for K-K'
Cross Section Tie Well for L-L'
GR
Resisitivity
SP
Dpth
1500
1000
500
0
-500
-1000
FRONTIER UOA
Stratigraphic Datum
DAKOTA UOA
TD=8980
TD=14830
TD=3239
TD=2448
TD=7543
TD=10330
TD=12560
TD=11085
TD=10130
TD=16622
TD=11127

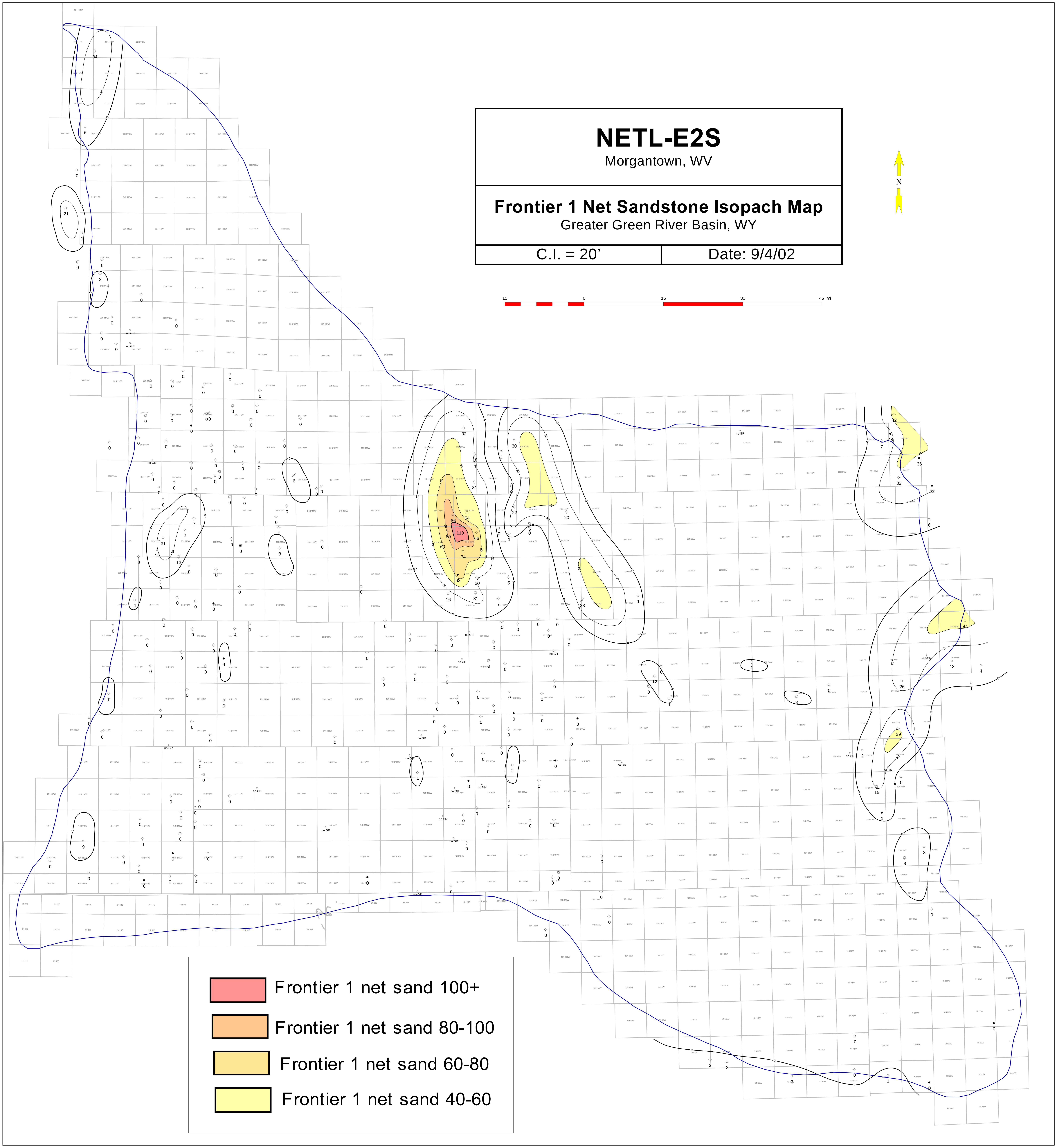

49023202170000
AMOCO PROD CO
CHAMPLIN 422 AMOCO 1
TWP: 20N - Range: 115W - Sec. 11
36877 ft
49023204150000
AMOCO PROD CO
CHAMPLIN 262 AMOCO 1
TWP: 20N - Range: 114W - Sec. 23
46575 ft
49023206200000
AMOCO PROD CO
WHISKEY BUTTES-FED 1-8
TWP: 20N - Range: 112W - Sec. 8
57260 ft
49037208480000
DAVIS OIL CO
LACOY-FEDERAL 1
TWP: 20N - Range: 110W - Sec. 6
120665 ft
49037219580000
DAVIS OIL CO
DAGGER UNIT 1
TWP: 19N - Range: 107W - Sec. 2
69555 ft
49037207480000
DAVIS OIL CO
NE PILOT BUTTE 1
TWP: 20N - Range: 105W - Sec. 25
35366 ft
49037203060000
TERRA RESOURCES INC
TERRA-FEDERAL 18-1
TWP: 20N - Range: 103W - Sec. 18
34192 ft
49037228890000
DAUBE COMPANY
DAUBE FEDERAL 1-6
TWP: 20 N - Range: 102W - Sec. 6
47348 ft
49037213710000
AMOCO PROD CO
CHAMPLIN172 AMOCO B
TWP: 20N - Range: 101W - Sec. 15
22126 ft
49037203780000
TRUE OIL CO
SHANAHAN-FEDERAL 14-20
TWP: 20N - Range: 100W - Sec. 20
93168 ft
49037227590000
TEXACO INCORPORATED
TABLE ROCK UNIT 102
TWP: 19N - Range: 98W - Sec. 36
247078 ft
49007201170000
TENNECO OIL CO
UNIT 3
TWP: 18N - Range: 90W - Sec. 11
36010 ft
49007052350000
PRAY MAX
UNIT 1
TWP: 19N - Range: 89W - Sec. 15
25543 ft
49007203460000
BRAUN C F
UPRR-CHAMPLIN 1-21
TWP: 19N - Range: 88W - Sec. 21
K
K'
Cross Section Tie Well for H-H'
Cross Section Tie Well for I-I'
Cross Section Tie Well for J-J'
GR
Resistivity
SP
FRONTIER UOA
Stratigraphic Datum
DAKOTA UOA
1000
500
0
-500

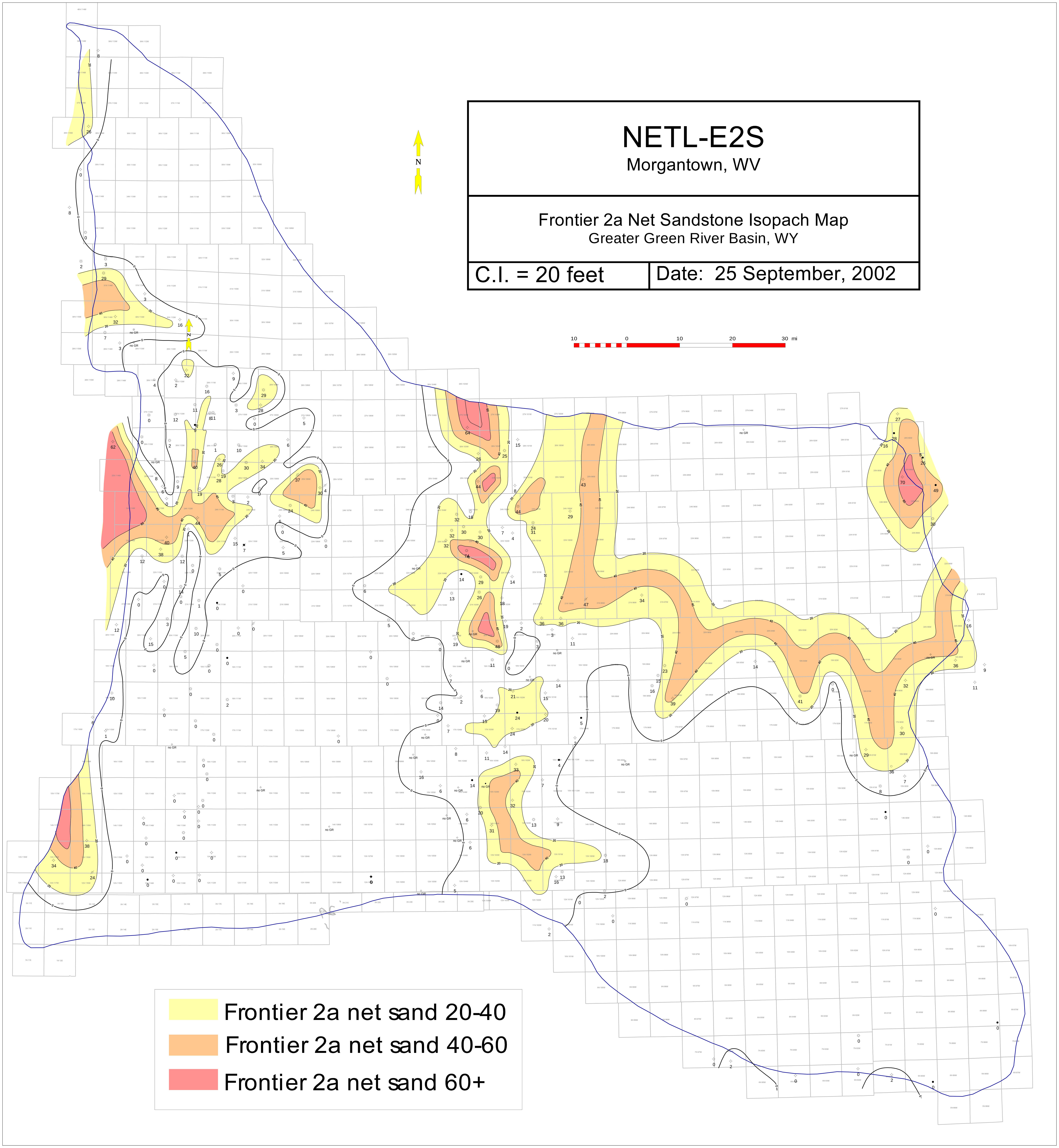

L
L'
49041206920000
EXXON CORPORATION
MUMFORD RIDGE UNIT 1
TWP: 13N - Range: 117W - Sec. 21
40388 ft
49041207320000
MARATHON OIL COMPANY
THUNDERBOLT MOUNTAI 1
TWP: 13N - Range: 116W - Sec. 35
38342 ft
49041204540000
AMINOIL USA INC
AUSA-FEDERAL 1-14
TWP: 13N - Range: 115W - Sec. 14
49360 ft
49041205050000
FIRST ENERGY CORPORA
MARATHON-FEDERAL 16
TWP: 13N - Range: 113W - Sec. 16
35178 ft
49037210650000
TEXACO INCORPORATED
BURNT FORK UNIT 1
TWP: 13N - Range: 112W - Sec. 15
161224 ft
49037204660000
LONE STAR PROD COMP
GOVERNMENT 1X-3
TWP: 12N - Range: 107W - Sec. 3
51759 ft
49037064180000
MOUNTAIN FUEL SUPLY
RICHARDS MTN UNIT 1
TWP: 12 N - Range: 105W - Sec. 19
34036 ft
49037207540000
MARATHON OIL COMPANY
TEPEE MOUNTAIN II 1
TWP: 12N - Range: 104W - Sec. 17
45659 ft
49037214500000
ENERGY RESV GRP INC
KENAI-PINE MOUNTAIN 1
TWP: 12N - Range: 103W - Sec. 10
62502 ft
49037051040000
MOUNTAIN FUEL SUPLY
UNIT 17
TWP: 12N - Range: 101W - Sec. 3
46689 ft
05081065180000
WEXPRO COMPANY
HIAWATHA DEEP UNIT 3
TWP: 12N - Range: 100W - Sec. 15
211477 ft
05081066270000
MUELLER C LEE
THORNBURG FEDERAL 14-27
TWP: 7N - Range: 96W - Sec. 27
66285 ft
05081053290000
BIG HORN CORP
BIG HORN USC A-1
TWP: 6N - Range: 94W - Sec. 10
62829 ft
05081053430000
MCCULLOCH OIL CORP
ROBERTSON 1
TWP: 6 N - Range: 92 W - Sec. 3
75906 ft
05081053220001
MALCO REFINERIES INC
KOWACH 1
TWP: 6 N - Range: 90 W - Sec. 25
87531 ft
05107060900000
DOME PETROLEUM LTD
STATE 1-36
TWP: 8N - Range: 88W - Sec. 36
Cross Section Tie Well for H-H'
Cross Section Tie Well for I-I"
Cross Section Tie Well for J-J'
GR
Resistivity
SP
Sonic
Frontier UOA
Stratigraphic Datum
Dakota UOA
1000
500
0
-500
-1000

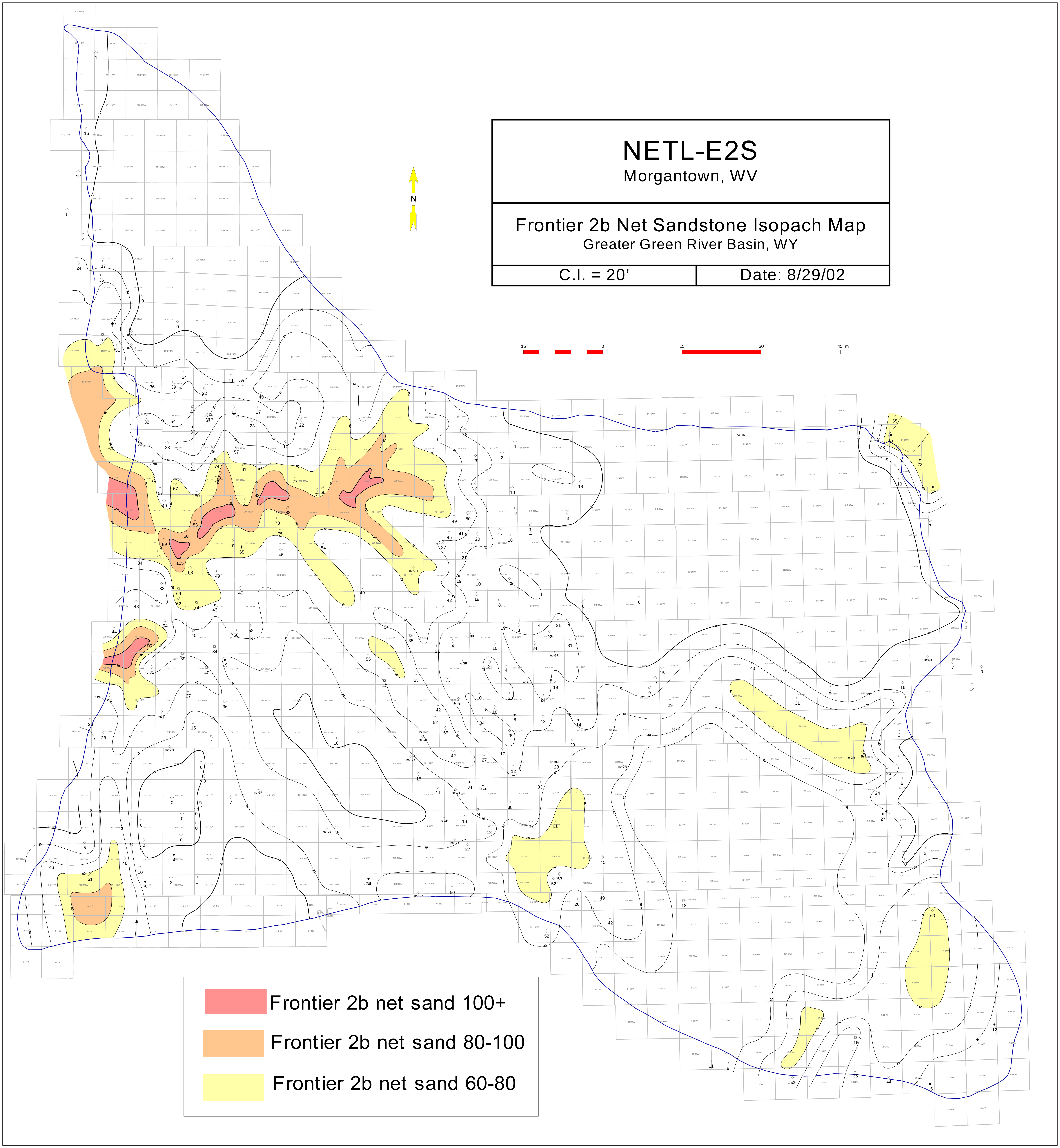

E2S – NETL
Morgantown, WV
Frontier UOA Net Sandstone Isolith Map
Greater Green River Basin, WY
C.I. = 50'
Date: 26 September, 2002
N
15
0
15
30
45 mi
Frontier all net ss 150'+
Frontier all net ss 100-150'
Frontier all net ss 50-100'

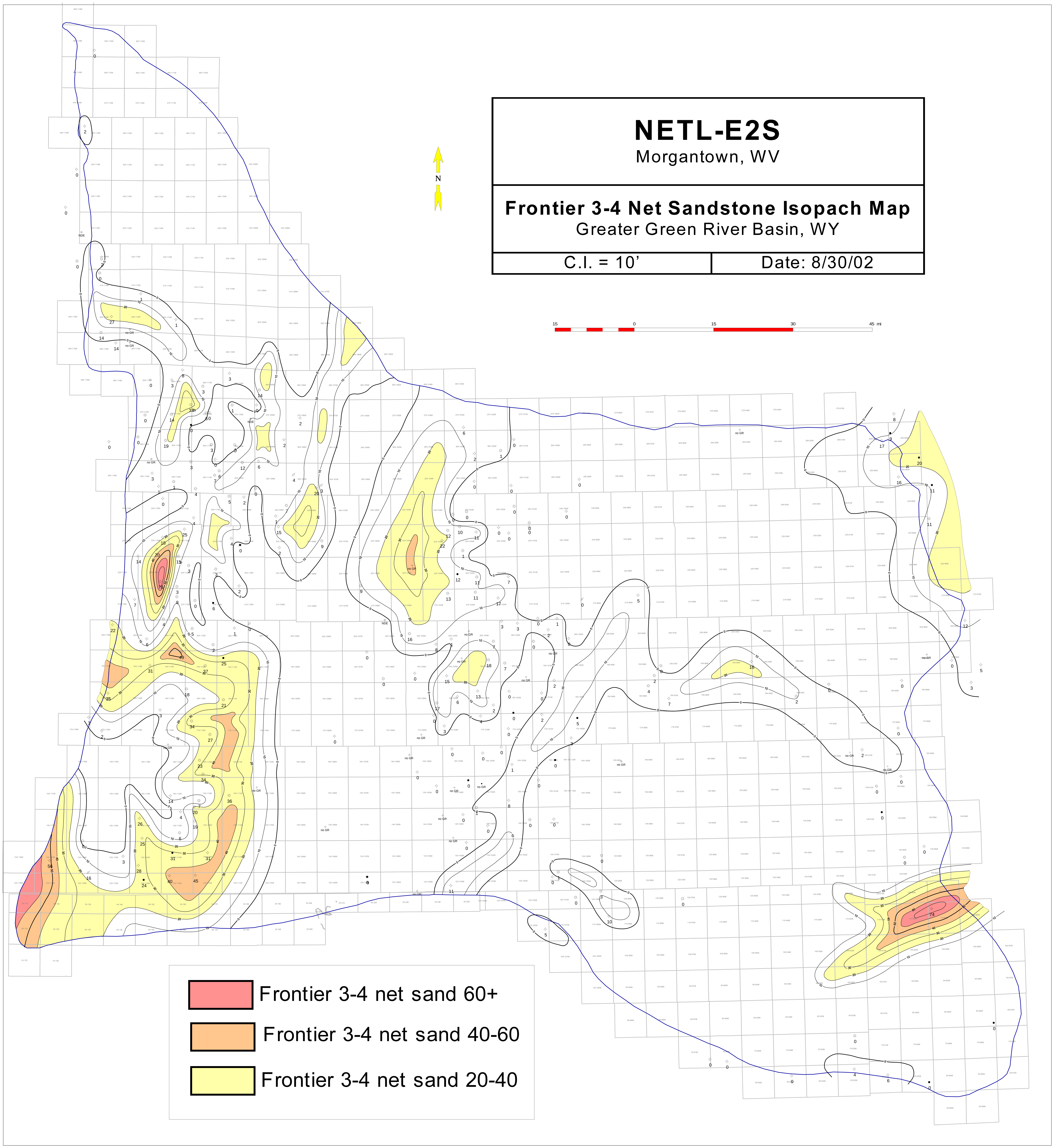


NETL-E2S
Morgantown, WV
Frontier 0 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02
N
15 0 15 30 45 mi
Frontier 0 net sand 100+
Frontier 0 net sand 80-100
Frontier 0 net sand 60-80
Frontier 0 net sand 40-60

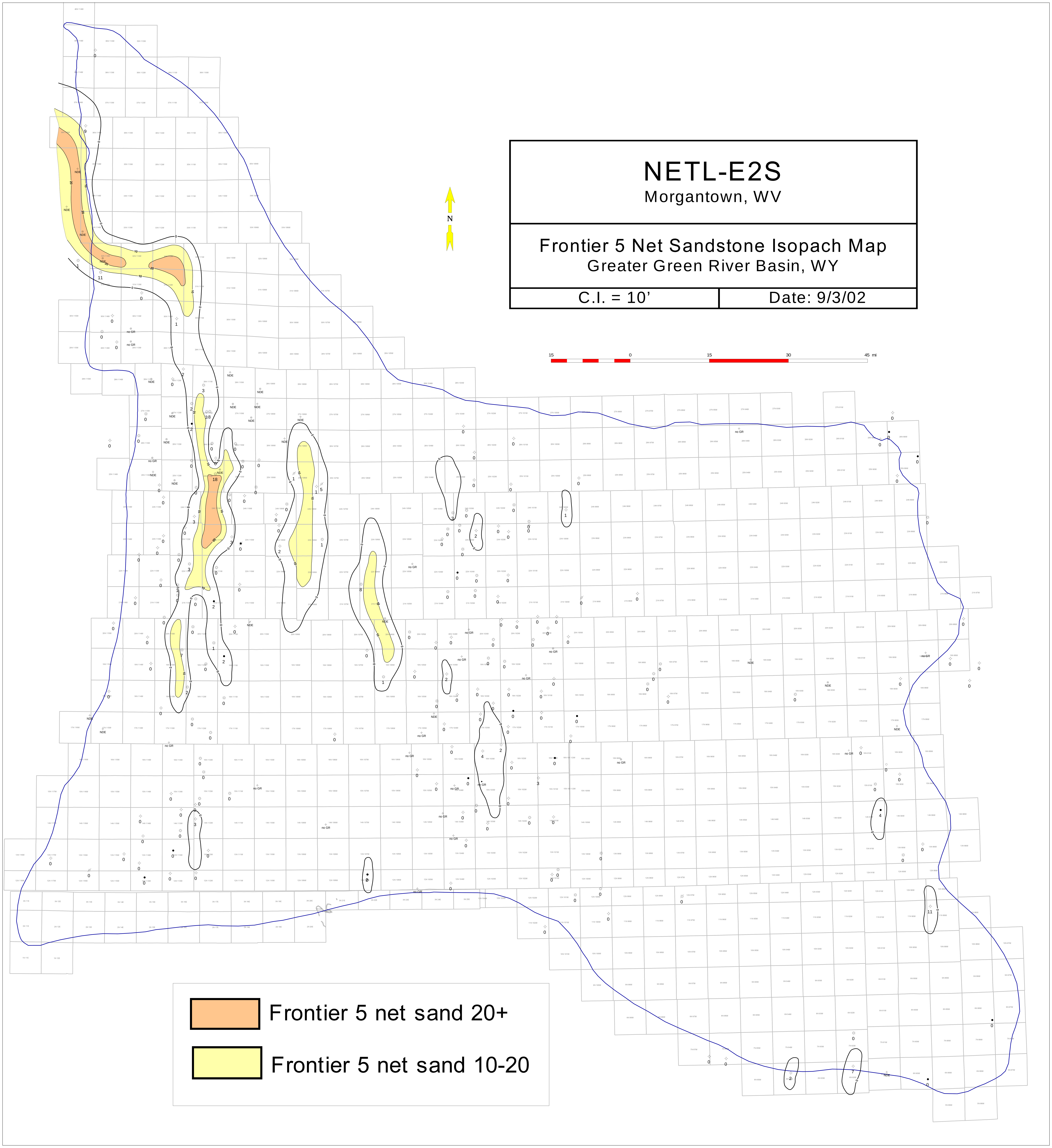

NETL-E2S
Morgantown, WV
Frontier 1 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02
N
15
0
15
30
45 mi
Frontier 1 net sand 100+
Frontier 1 net sand 80-100
Frontier 1 net sand 60-80
Frontier 1 net sand 40-60


NETL-E2S
Morgantown, WV
Frontier 2a Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20 feet
Date: 25 September, 2002
N
10 0 10 20 30 mi
Frontier 2a net sand 20-40
Frontier 2a net sand 40-60
Frontier 2a net sand 60+

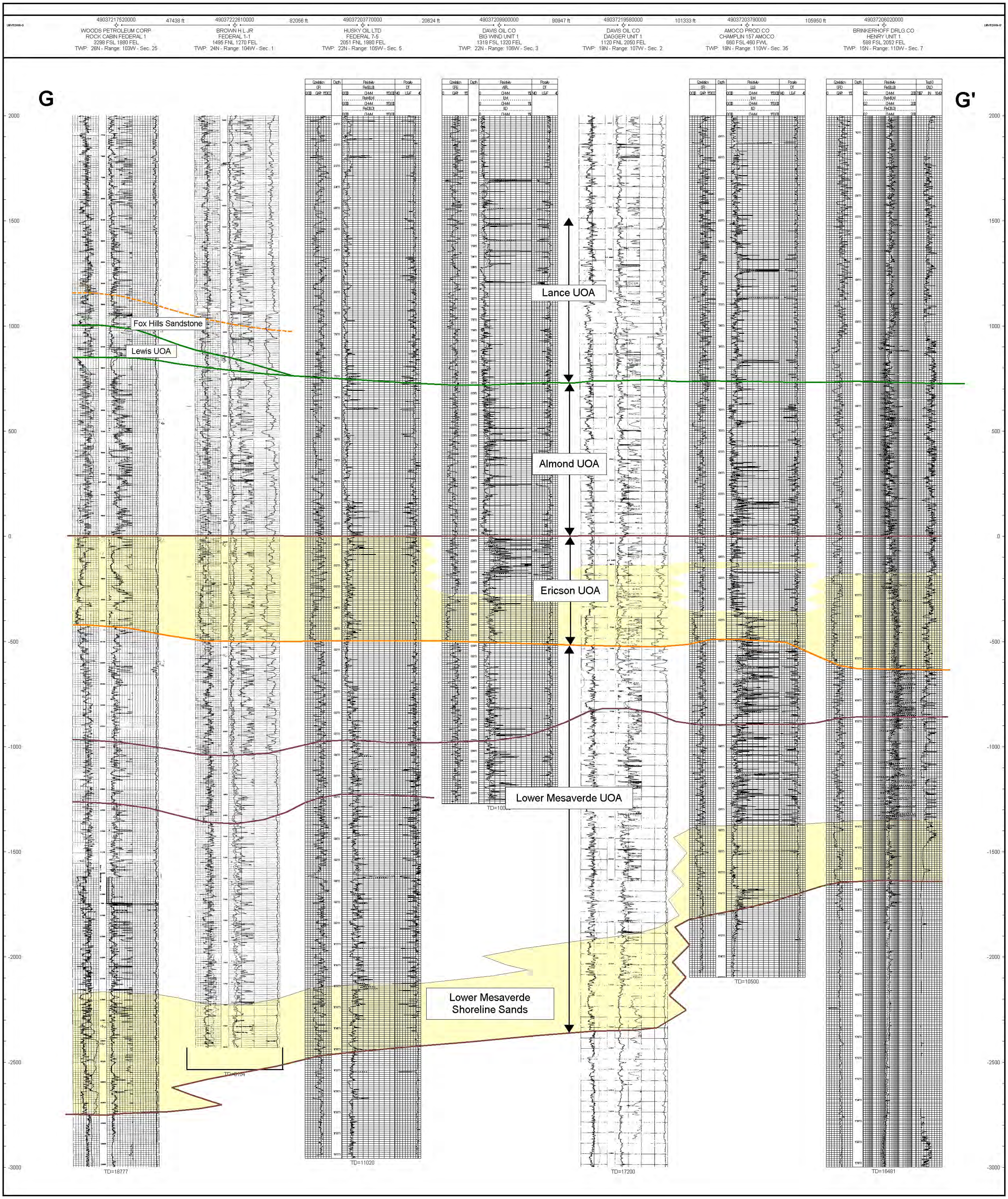

NETL-E2S
Morgantown, WV
Frontier 2b Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 8/29/02
N
15
0
15
30
45 mi
Frontier 2b net sand 100+
Frontier 2b net sand 80-100
Frontier 2b net sand 60-80



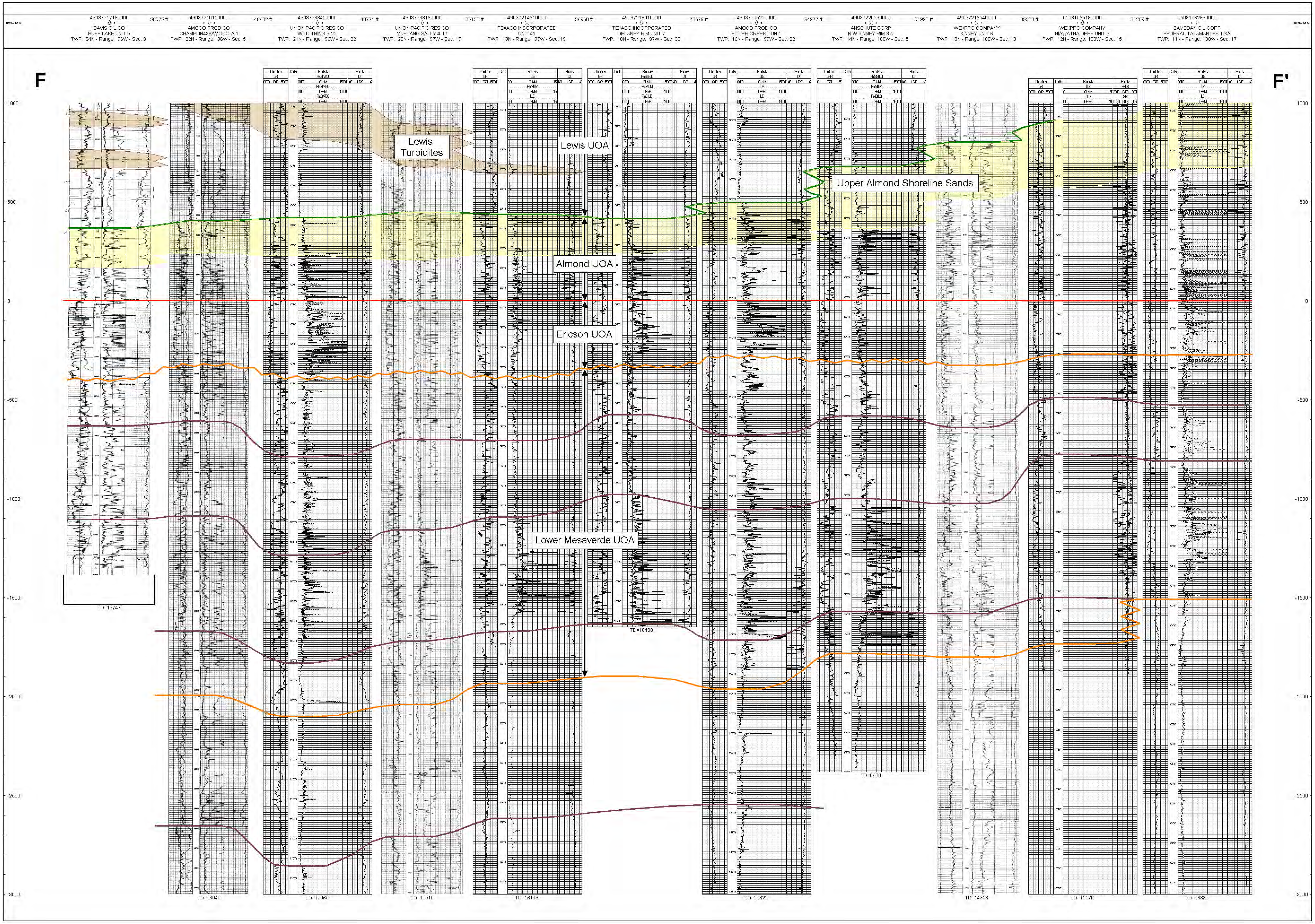
NETL-E2S
Morgantown, WV
Frontier 3-4 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 10'
Date: 8/30/02
N
15 0 15 30 45 mi
Frontier 3-4 net sand 60+
Frontier 3-4 net sand 40-60
Frontier 3-4 net sand 20-40



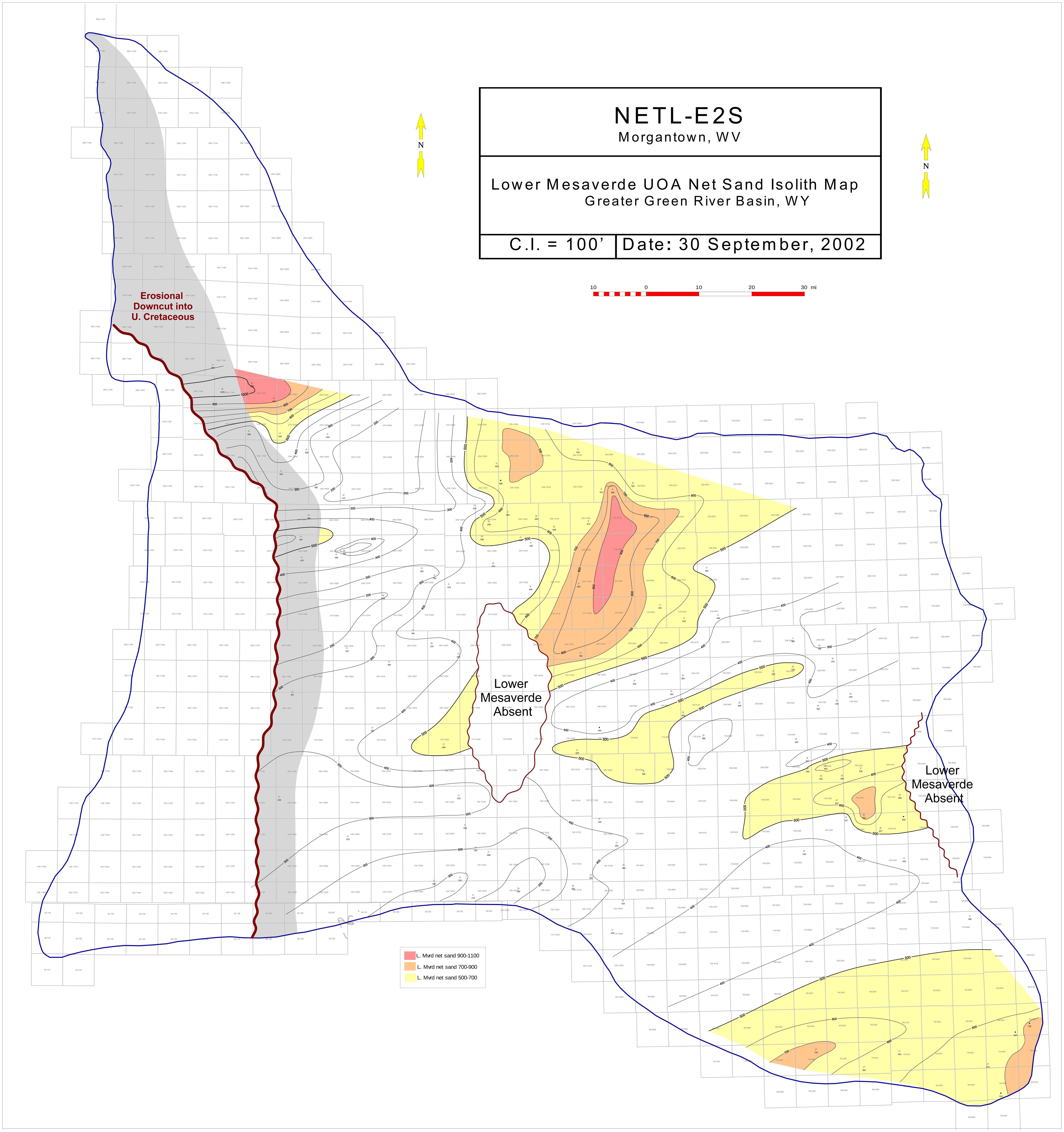
NETL-E2S
Morgantown, WV
Frontier 5 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 10'
Date: 9/3/02
N
15
0
15
30
45 mi
Frontier 5 net sand 20+
Frontier 5 net sand 10-20

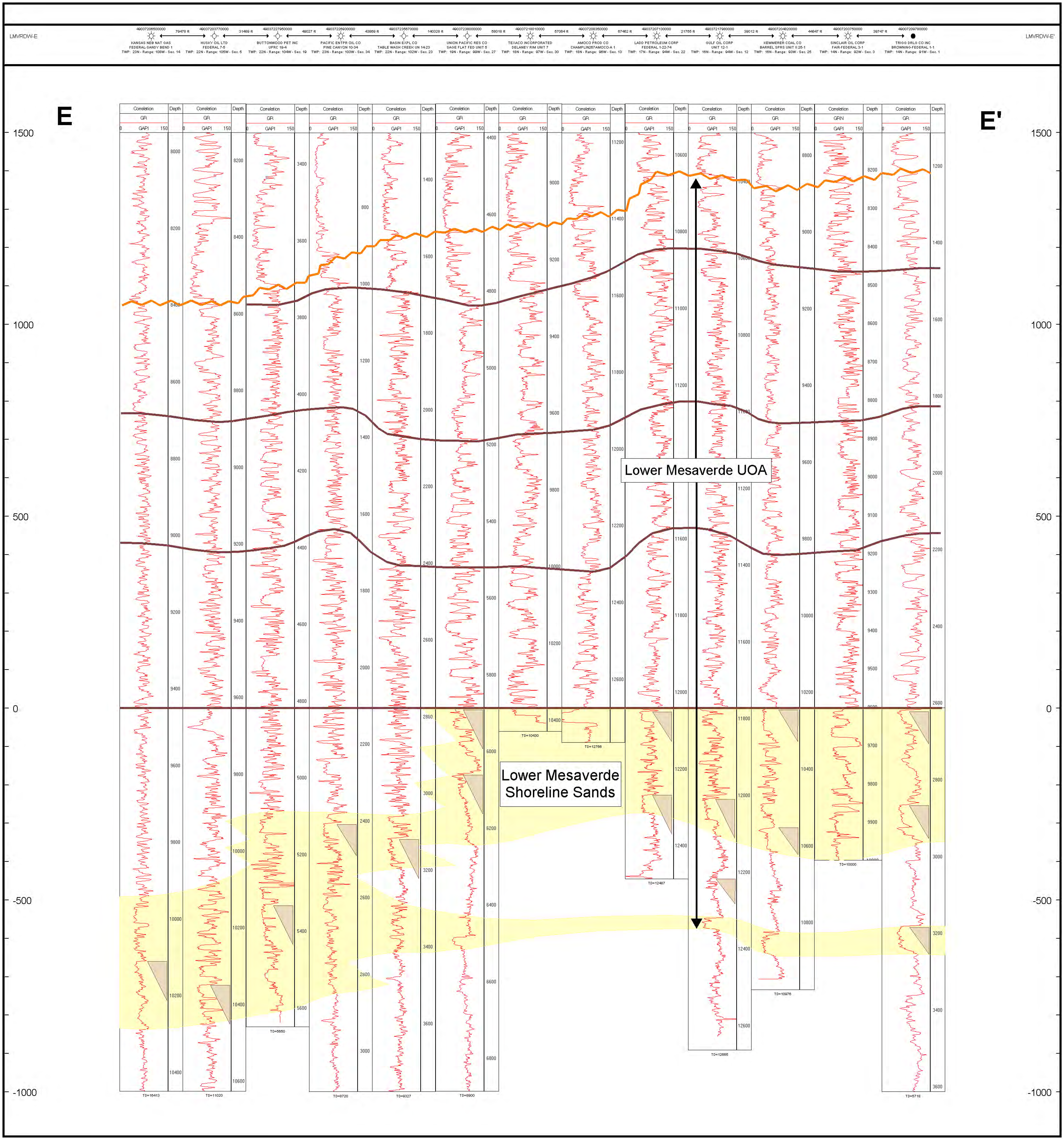


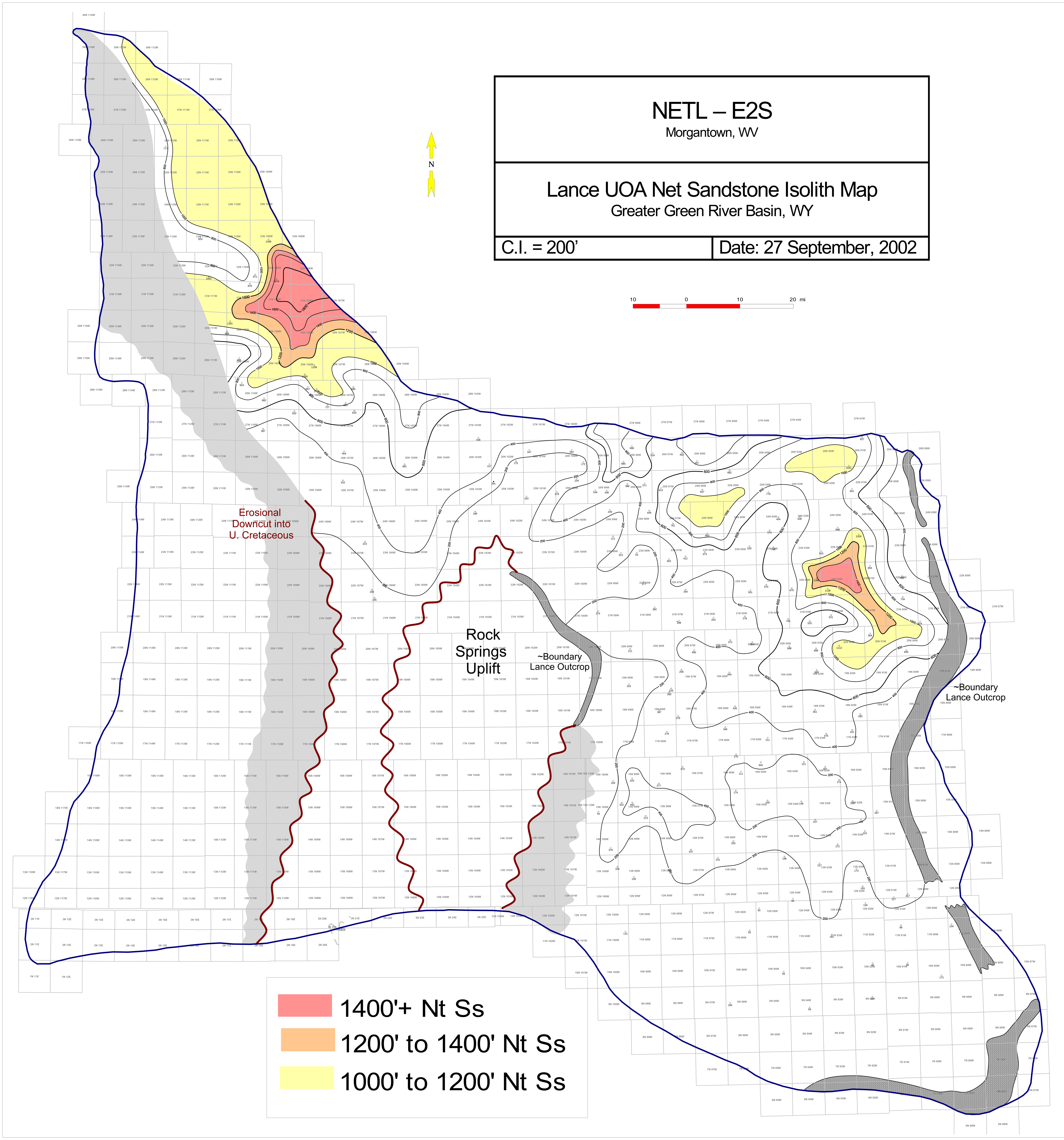
LMVRDWN-S
49037217520000
WOODS PETROLEUM CORP
ROCK CABIN FEDERAL 1
3298 FSL 1880 FEL
TWP: 26N - Range: 103W - Sec. 25
47438 ft
49037222610000
BROWN H L JR
FEDERAL 1-1
1495 FNL 1270 FEL
TWP: 24N - Range: 104W - Sec. 1
82056 ft
49037203770000
HUSKY OIL LTD
FEDERAL 7-5
2051 FNL 1980 FEL
TWP: 22N - Range: 105W - Sec. 5
20624 ft
49037209900000
DAVIS OIL CO
BIG WIND UNIT 1
1319 FSL 1320 FEL
TWP: 22N - Range: 106W - Sec. 3
90947 ft
49037219580000
DAVIS OIL CO
DAGGER UNIT 1
1120 FNL 2050 FEL
TWP: 19N - Range: 107W - Sec. 2
101333 ft
49037203790000
AMOCO PROD CO
CHAMPLIN 157 AMOCO
660 FSL 460 FWL
TWP: 19N - Range: 110W - Sec. 35
105950 ft
49037206020000
BRINKERHOFF DRLG CO
HENRY UNIT 1
588 FSL 2052 FEL
TWP: 15N - Range: 110W - Sec. 7
LMVRDWN-S'
G
G'
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
Fox Hills Sandstone
Lewis UOA
Lance UOA
Almond UOA
Ericson UOA
Lower Mesaverde UOA
Lower Mesaverde Shoreline Sands
TD=18777
TD=8104
TD=11020
TD=17200
TD=10500
TD=16481



49037217160000
DAVIS OIL CO
BUSH LAKE UNIT 5
TWP: 24N - Range: 96W - Sec. 9
58575 ft
49037210150000
AMOCO PROD CO
CHAMPLIN438AMOCO-A 1
TWP: 22N - Range: 96W - Sec. 5
48682 ft
49037238450000
UNION PACIFIC RES CO
WILD THING 3-22
TWP: 21N - Range: 96W - Sec. 22
40771 ft
49037238160000
UNION PACIFIC RES CO
MUSTANG SALLY 4-17
TWP: 20N - Range: 97W - Sec. 17
35133 ft
49037214610000
TEXACO INCORPORATED
UNIT 41
TWP: 19N - Range: 97W - Sec. 19
36960 ft
49037218010000
TEXACO INCORPORATED
DELANEY RIM UNIT 7
TWP: 18N - Range: 97W - Sec. 30
70679 ft
49037205220000
AMOCO PROD CO
BITTER CREEK II UN 1
TWP: 16N - Range: 99W - Sec. 22
64977 ft
49037220290000
ANSCHUTZ CORP
N W KINNEY RIM 3-5
TWP: 14N - Range: 100W - Sec. 5
51990 ft
49037216540000
WEXPRO COMPANY
KINNEY UNIT 6
TWP: 13N - Range: 100W - Sec. 13
35580 ft
05081065180000
WEXPRO COMPANY
HIAWATHA DEEP UNIT 3
TWP: 12N - Range: 100W - Sec. 15
31289 ft
05081062890000
SAMEDAN OIL CORP
FEDERAL TALAMANTES 1-XA
TWP: 11N - Range: 100W - Sec. 17
F
F'
Lewis Turbidites
Lewis UOA
Upper Almond Shoreline Sands
Almond UOA
Ericson UOA
Lower Mesaverde UOA
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
TD=13747
TD=13040
TD=12065
TD=10510
TD=16113
TD=10430
TD=21322
TD=8600
TD=14353
TD=15170
TD=16832

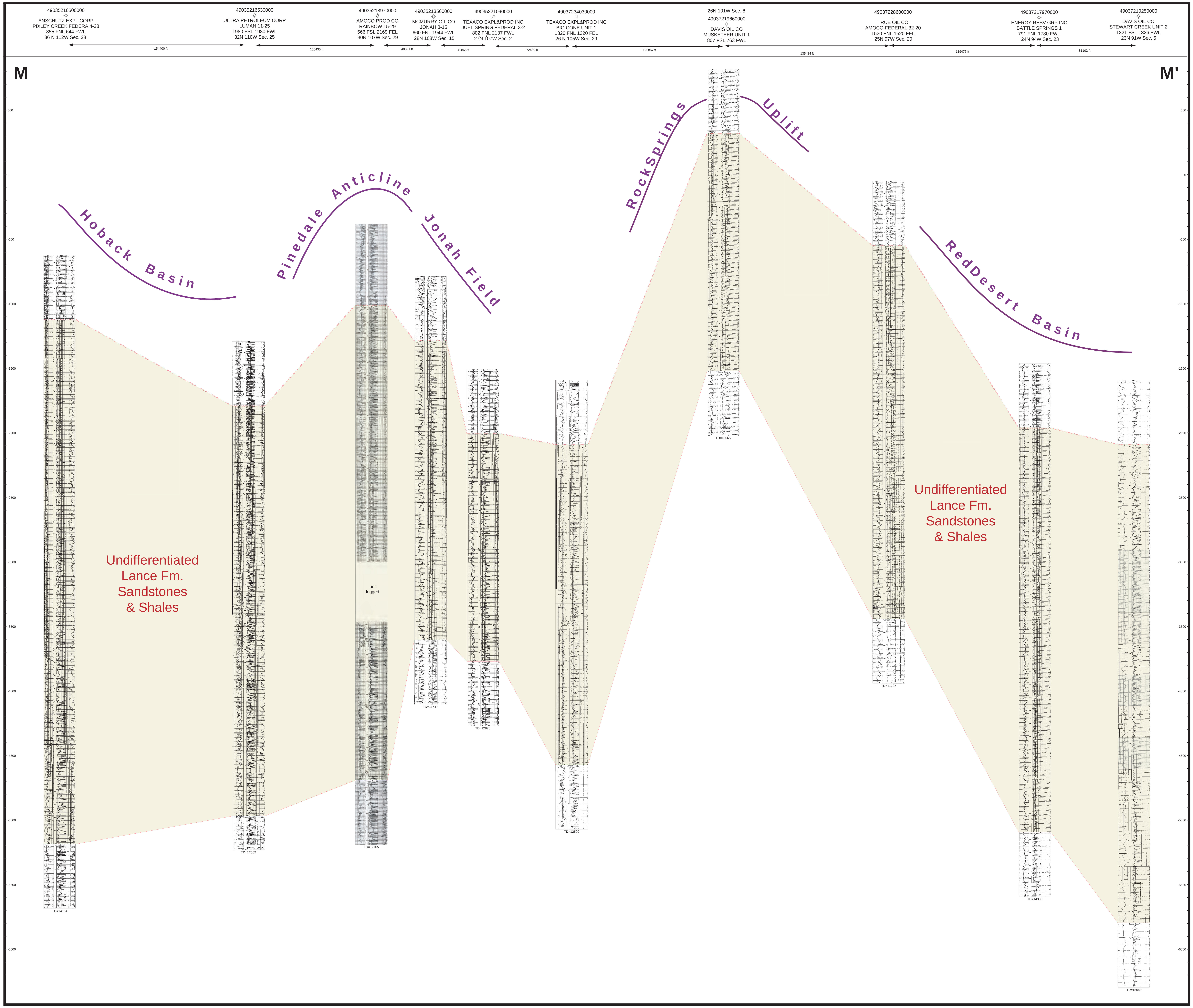

NETL-E2S
Morgantown, WV
Lower Mesaverde UOA Net Sand Isolith Map
Greater Green River Basin, WY
C.I. = 100'
Date: 30 September, 2002
N
N
10 0 10 20 30 mi
Erosional Downcut into U. Cretaceous
Lower Mesaverde Absent
Lower Mesaverde Absent
L. Mvrd net sand 900-1100
L. Mvrd net sand 700-900
L. Mvrd net sand 500-700

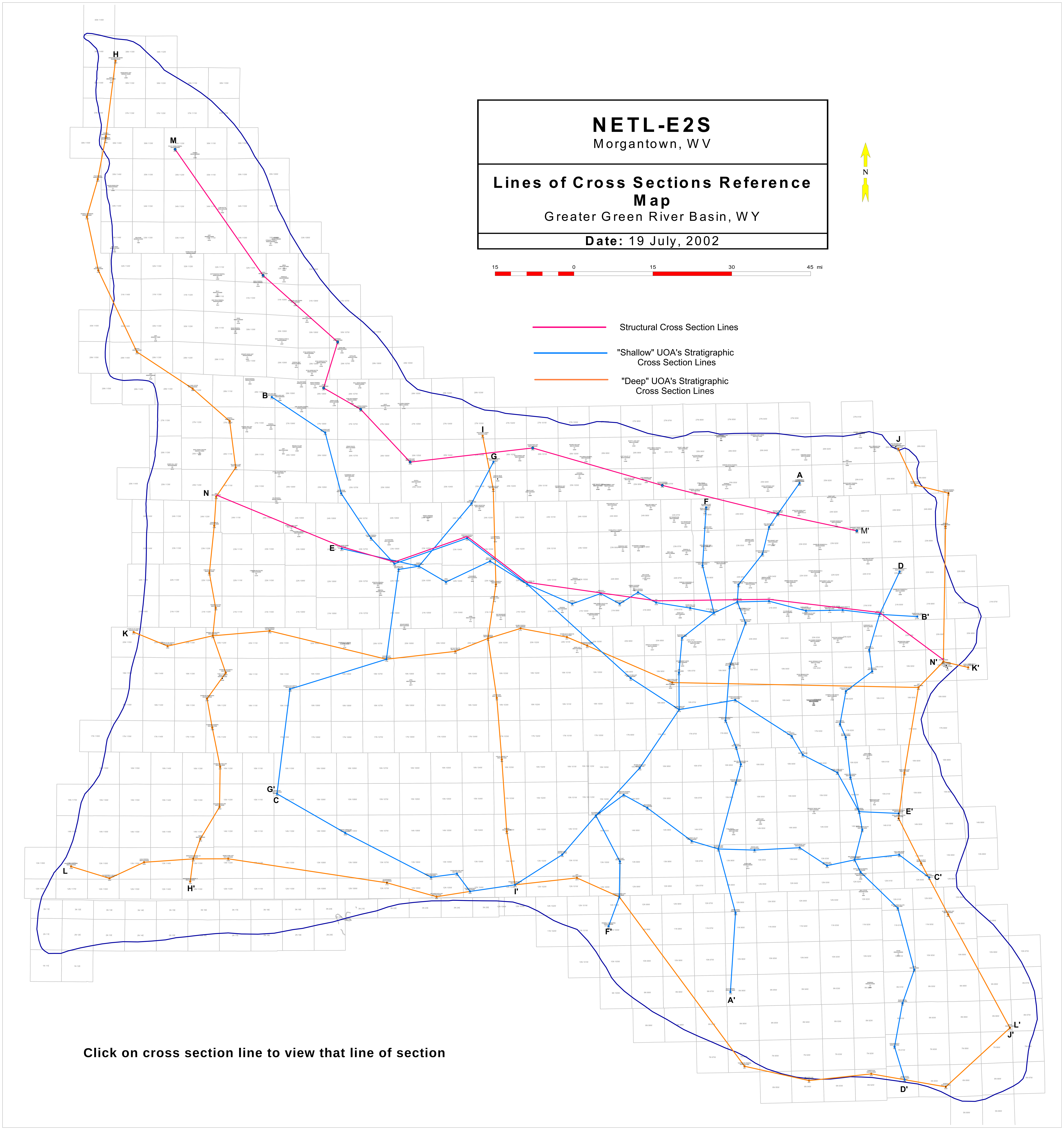

LMVRDW-E
49037206500000 KANSAS NEB NAT GAS FEDERAL-SANDY BEND 1 TWP: 23N - Range: 108W - Sec. 14
79478 ft
49037203770000 HUSKY OIL LTD FEDERAL 7-5 TWP: 22N - Range: 105W - Sec. 5
31489 ft
49037227950000 BUTTONWOOD PET INC UPRC 19-4 TWP: 22N - Range: 104W - Sec. 19
49027 ft
49037226930000 PACIFIC ENTPR OIL CO PINE CANYON 10-34 TWP: 23N - Range: 103W - Sec. 34
43869 ft
49037235670000 BASIN EXPL CO TABLE WASH CREEK UN 14-23 TWP: 22N - Range: 102W - Sec. 23
140328 ft
49037238000000 UNION PACIFIC RES CO SAGE FLAT FED UNIT 5 TWP: 19N - Range: 99W - Sec. 27
58018 ft
49037218010000 TEXACO INCORPORATED DELANEY RIM UNIT 7 TWP: 18N - Range: 97W - Sec. 30
57064 ft
49037208350000 AMOCO PROD CO CHAMPLIN267AMOCO-A 1 TWP: 18N - Range: 96W - Sec. 13
67462 ft
49037207130000 LADD PETROLEUM CORP FEDERAL 1-22-74 TWP: 17N - Range: 94W - Sec. 22
21755 ft
49037217980000 GULF OIL CORP UNIT 12-1 TWP: 16N - Range: 94W - Sec. 12
39012 ft
49007204820000 KEMMERER COAL CO BARREL SPRS UNIT II 25-1 TWP: 16N - Range: 93W - Sec. 25
44847 ft
49007203750000 SINCLAIR OIL CORP FAIR-FEDERAL 3-1 TWP: 14N - Range: 92W - Sec. 3
39747 ft
49007209780000 TRIGG DRLG CO INC BROWNING-FEDERAL 1-1 TWP: 14N - Range: 91W - Sec. 1
LMVRDW-E'
E
E'
Correlation
Depth
GR
GAPI
1500
1000
500
0
-500
-1000
Lower Mesaverde UOA
Lower Mesaverde Shoreline Sands



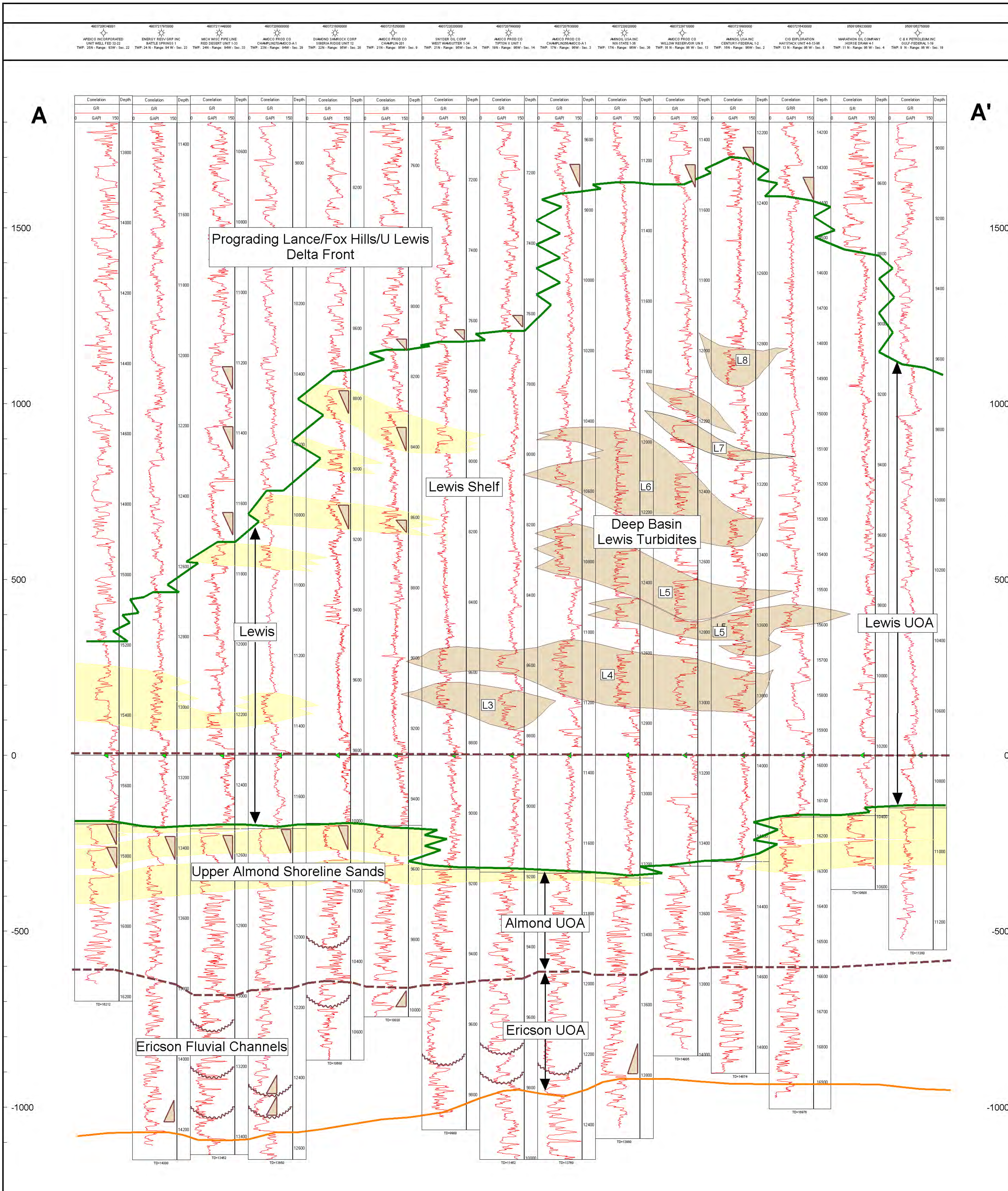
NETL – E2S
Morgantown, WV
Lance UOA Net Sandstone Isolith Map
Greater Green River Basin, WY
C.I. = 200'
Date: 27 September, 2002
N
10 0 10 20 mi
Erosional Downcut into U. Cretaceous
Rock Springs Uplift
~Boundary Lance Outcrop
~Boundary Lance Outcrop
1400'+ Nt Ss
1200' to 1400' Nt Ss
1000' to 1200' Nt Ss

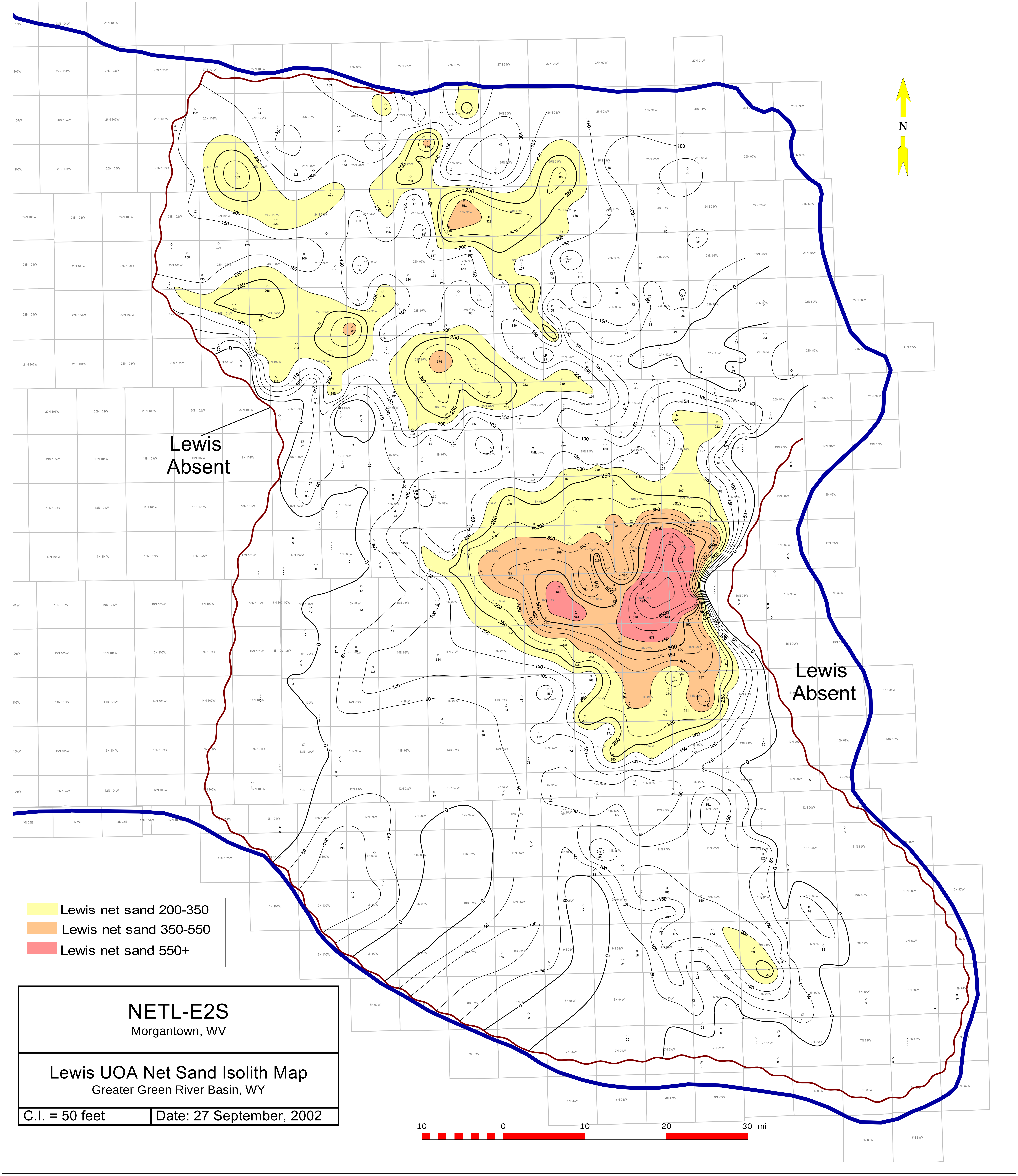
Lance Formation - Northern Greater Green River Basin
Structural Cross Section M-M'

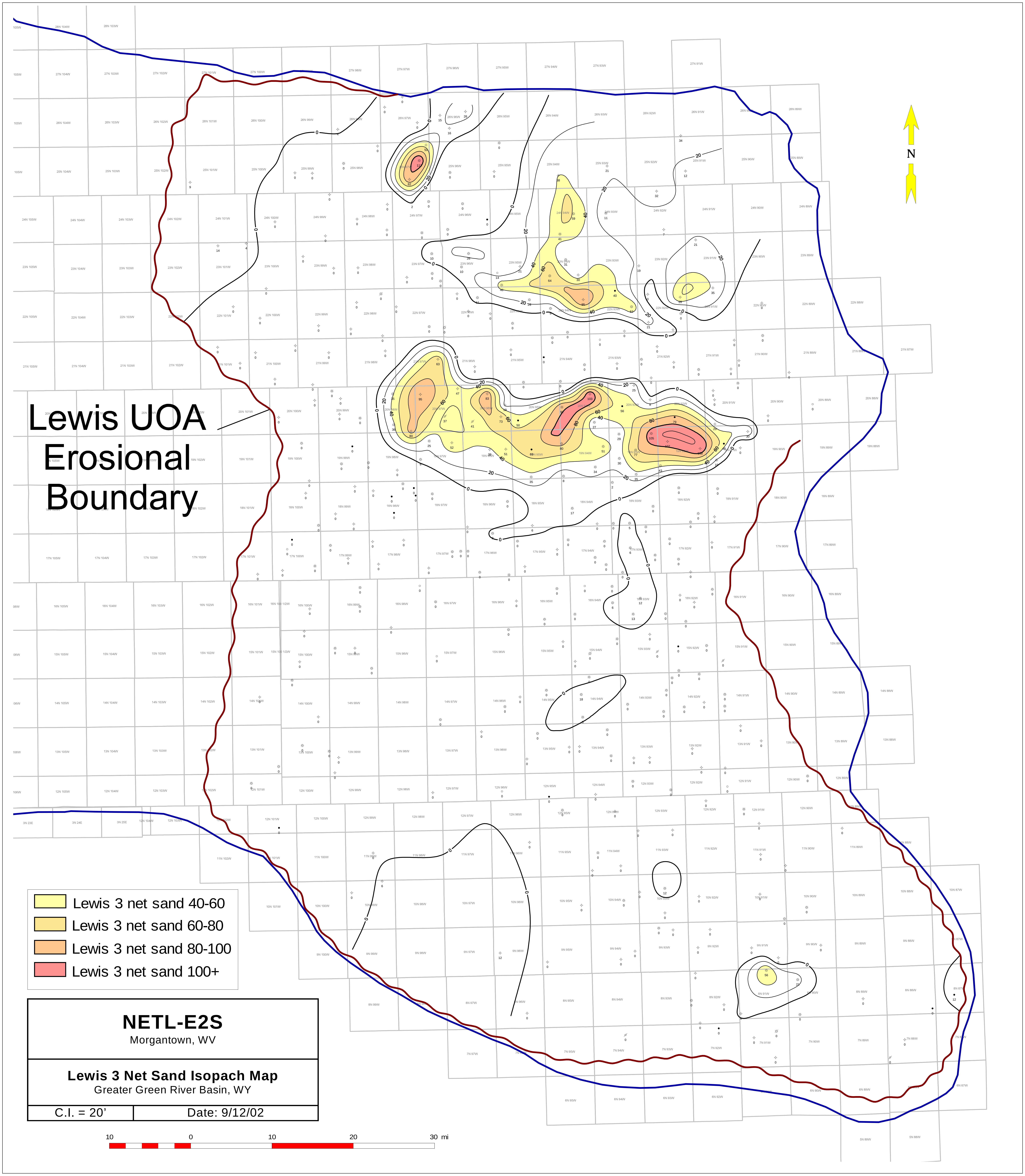




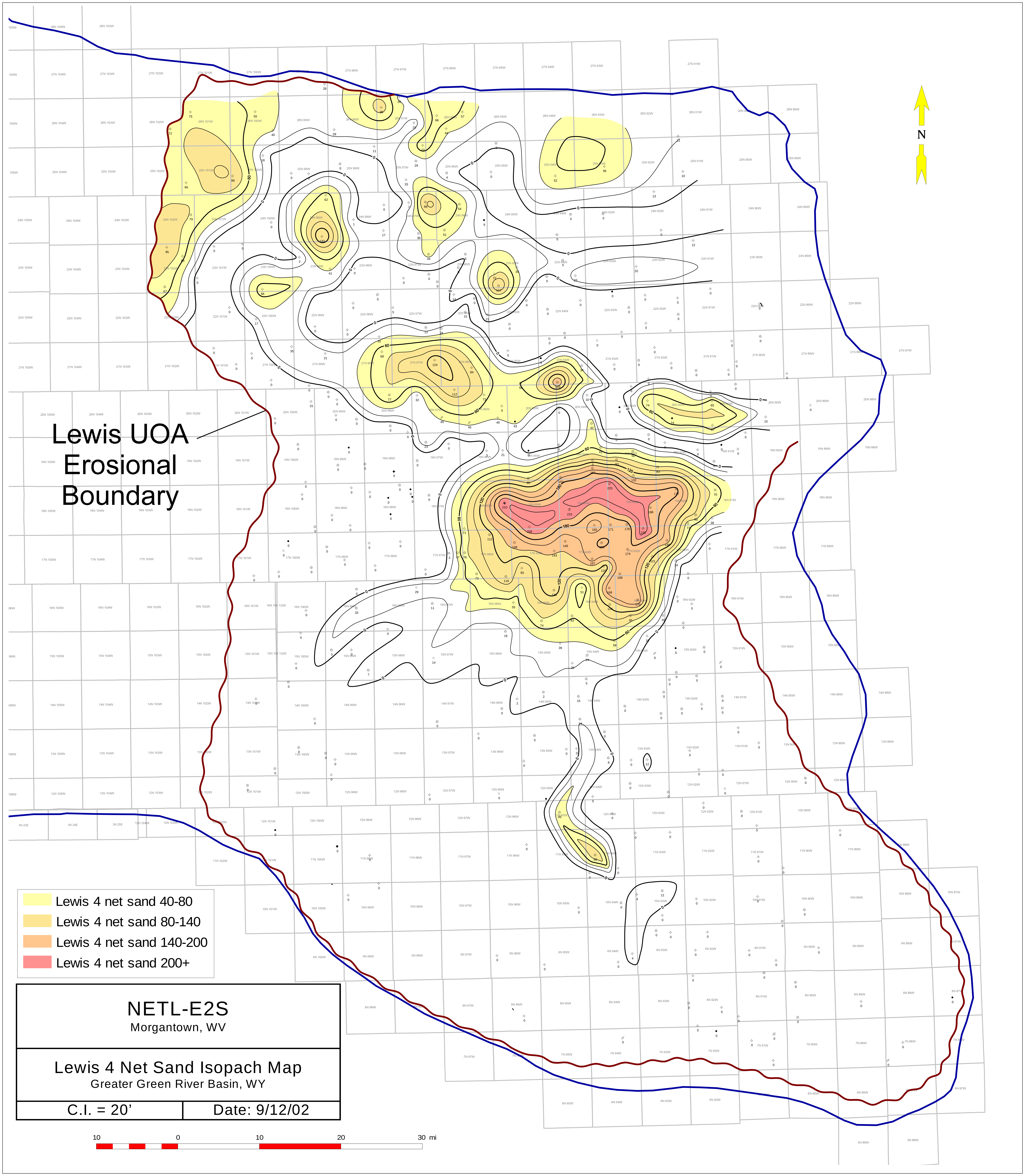
Click on cross section line to view that line of section


A
A'
Prograding Lance/Fox Hills/U Lewis
Delta Front
Lewis Shelf
Deep Basin
Lewis Turbidites
L8
L7
L6
L5
L4
L3
Lewis
Lewis UOA
Upper Almond Shoreline Sands
Almond UOA
Ericson UOA
Ericson Fluvial Channels
1500
1000
500
0
-500
-1000

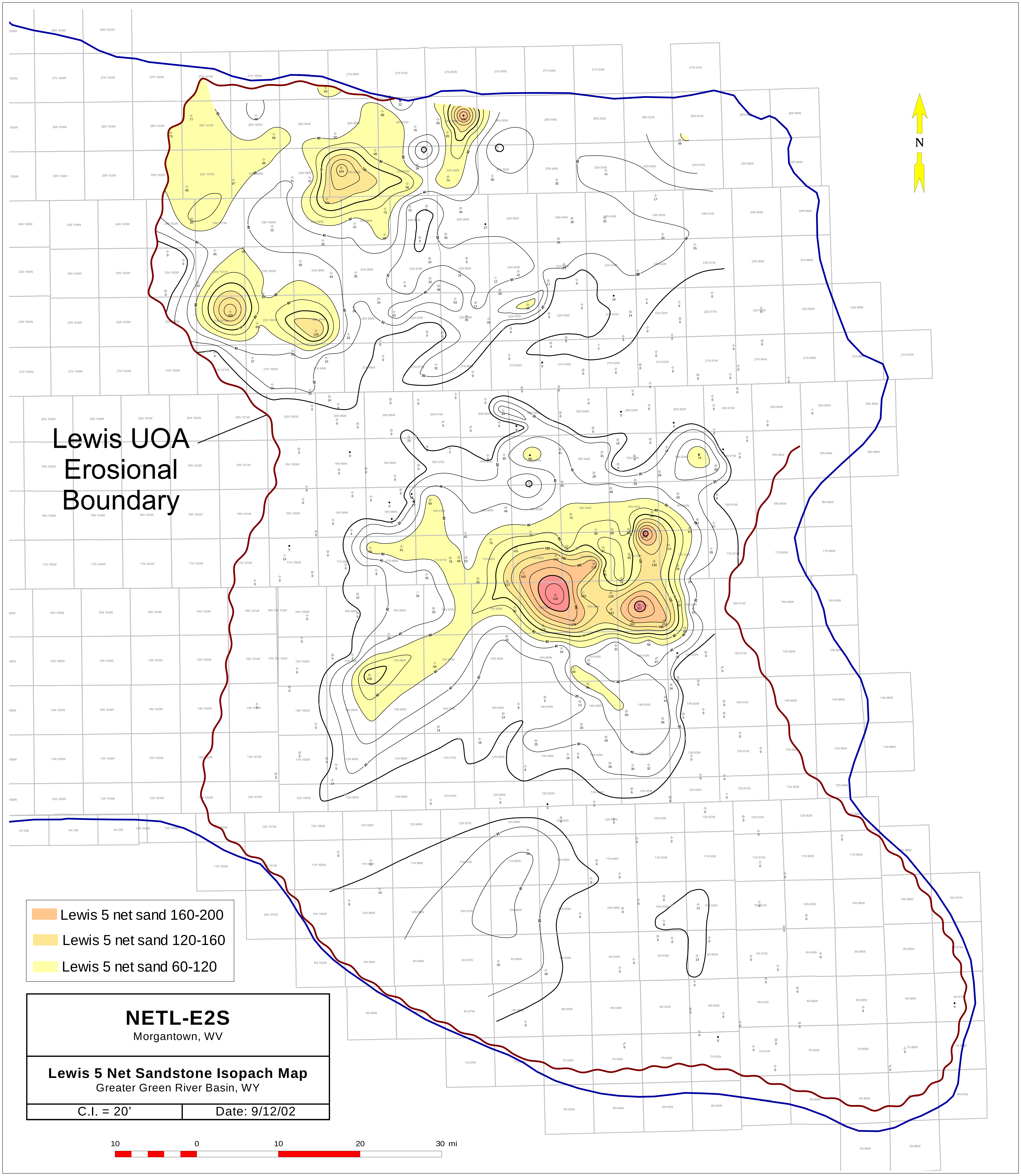

N
Lewis
Absent
Lewis
Absent
Lewis net sand 200-350
Lewis net sand 350-550
Lewis net sand 550+
NETL-E2S
Morgantown, WV
Lewis UOA Net Sand Isolith Map
Greater Green River Basin, WY
C.I. = 50 feet
Date: 27 September, 2002
10 0 10 20 30 mi



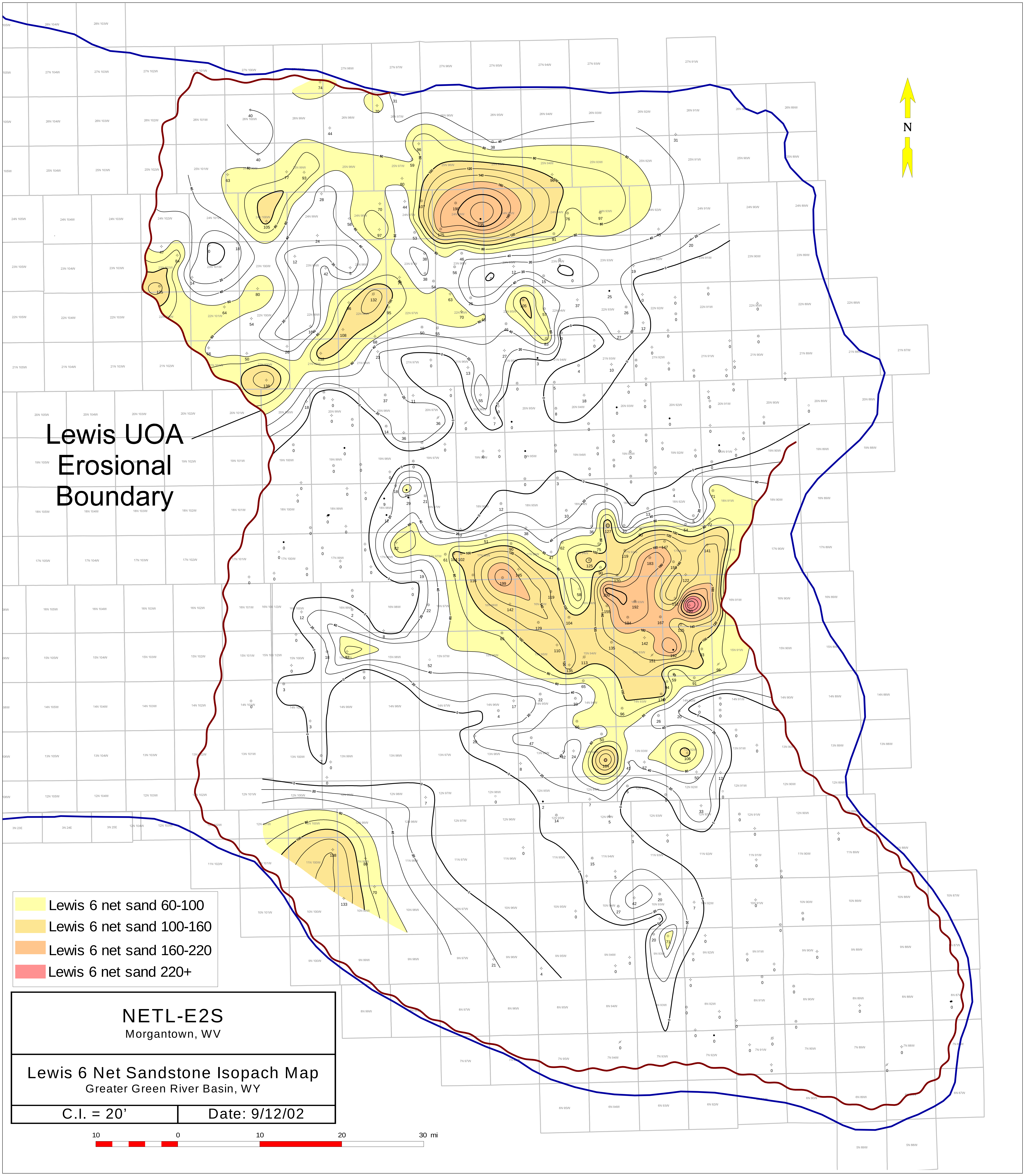
N
Lewis UOA Erosional Boundary
Lewis 3 net sand 40-60
Lewis 3 net sand 60-80
Lewis 3 net sand 80-100
Lewis 3 net sand 100+
NETL-E2S
Morgantown, WV
Lewis 3 Net Sand Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/12/02
10 0 10 20 30 mi



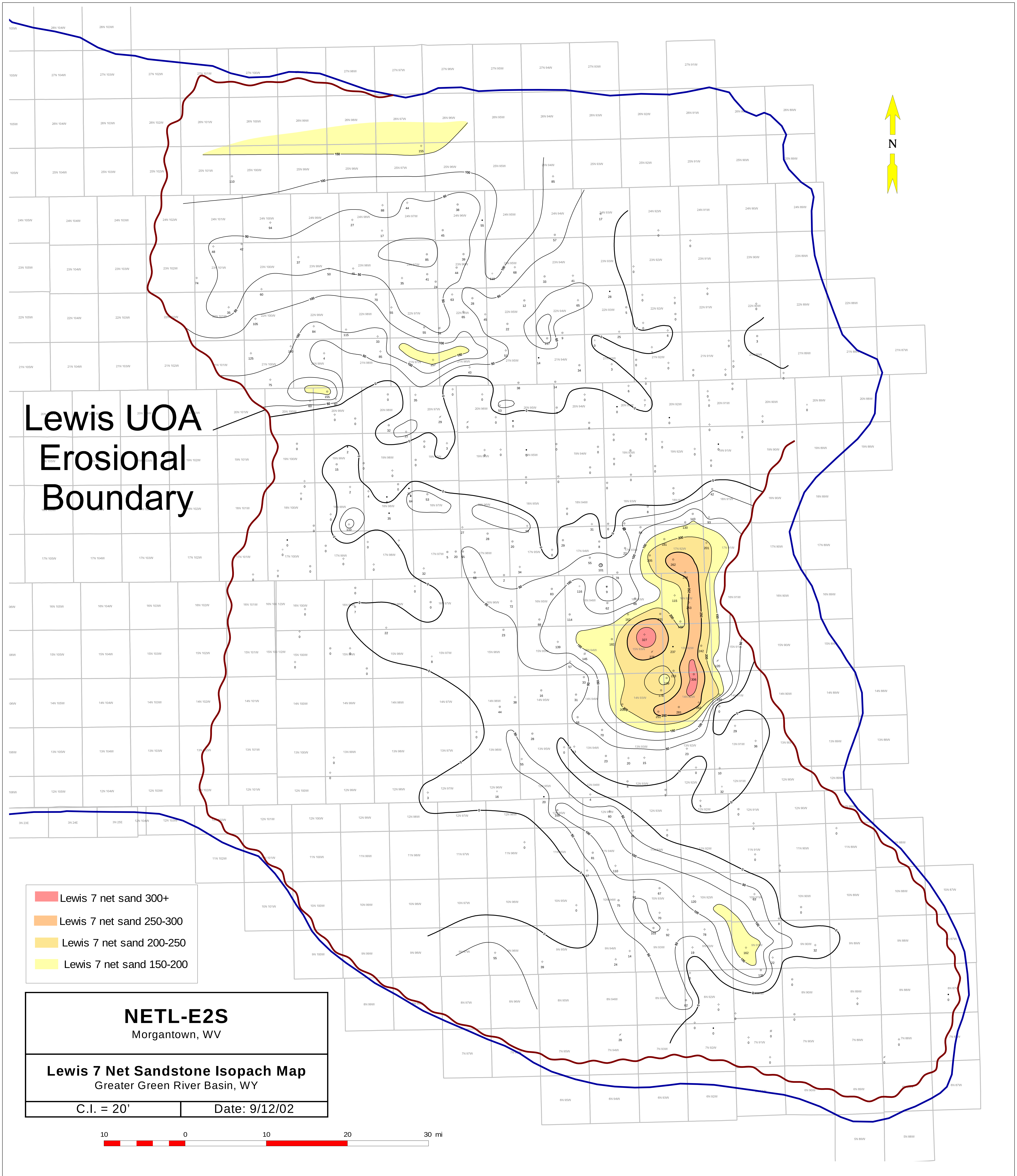
N
Lewis UOA Erosional Boundary
Lewis 4 net sand 40-80
Lewis 4 net sand 80-140
Lewis 4 net sand 140-200
Lewis 4 net sand 200+
NETL-E2S
Morgantown, WV
Lewis 4 Net Sand Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/12/02
10 0 10 20 30 mi

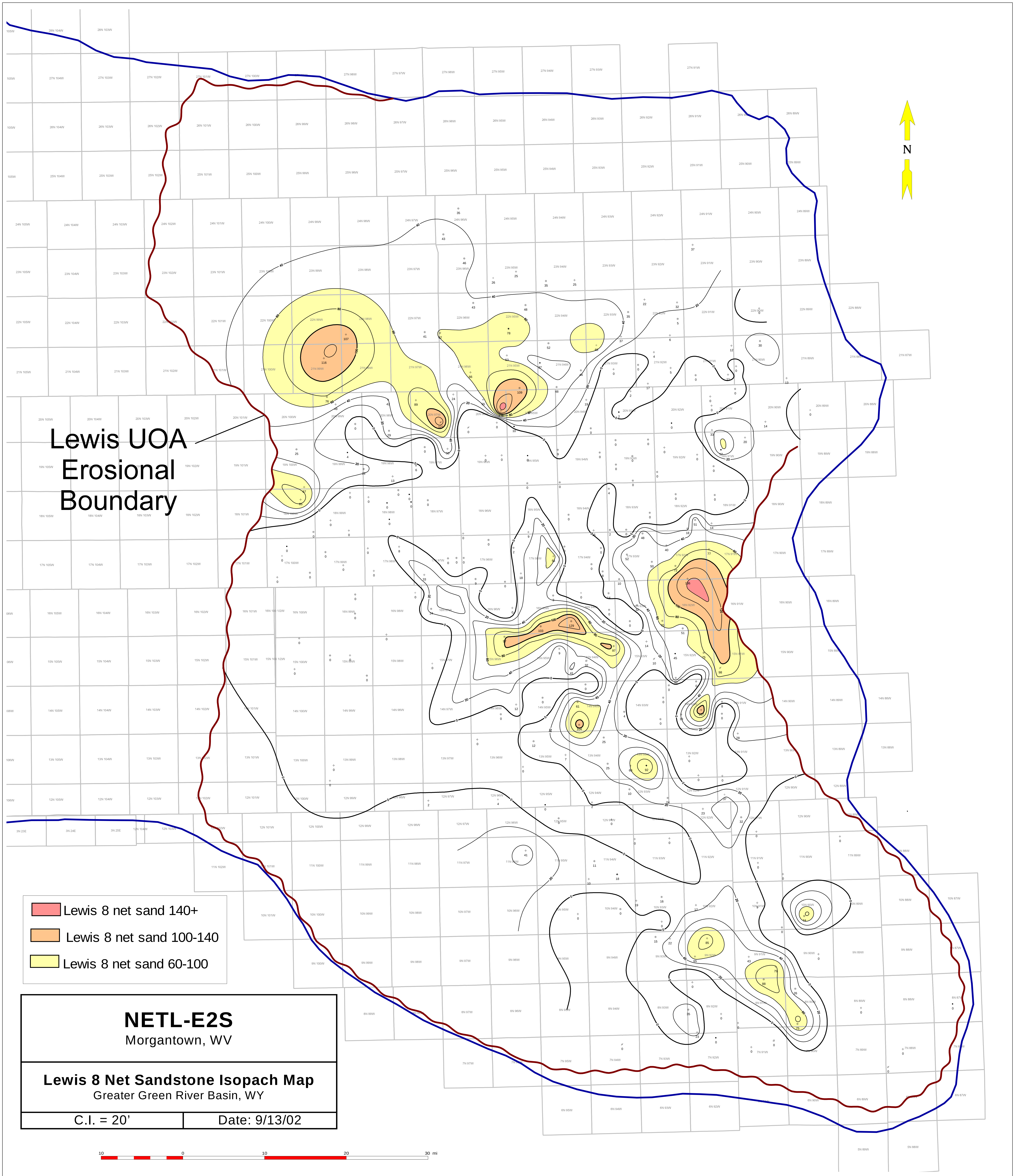


Lewis UOA
Erosional
Boundary
N
Lewis 5 net sand 160-200
Lewis 5 net sand 120-160
Lewis 5 net sand 60-120
NETL-E2S
Morgantown, WV
Lewis 5 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/12/02
10
0
10
20
30 mi

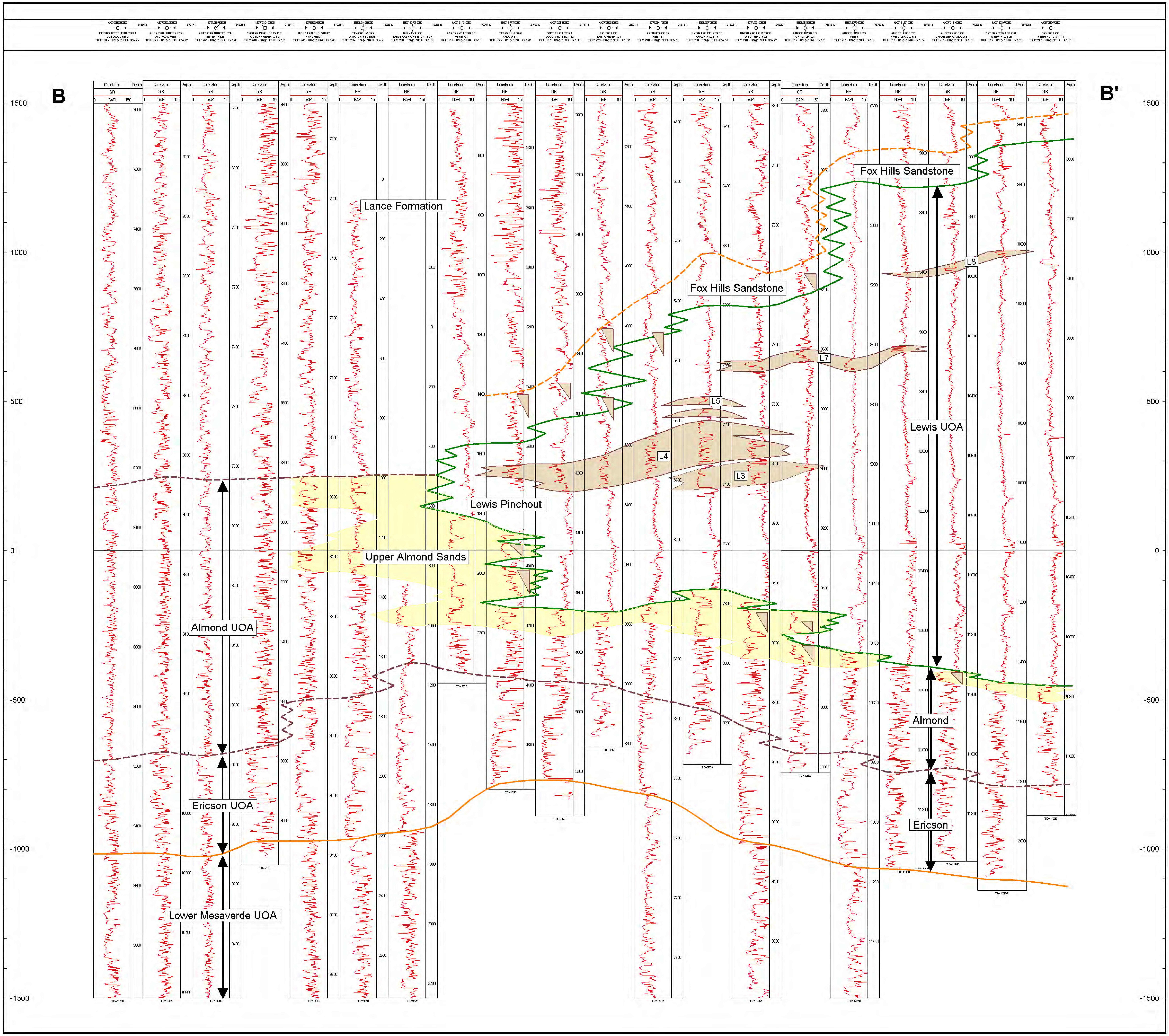


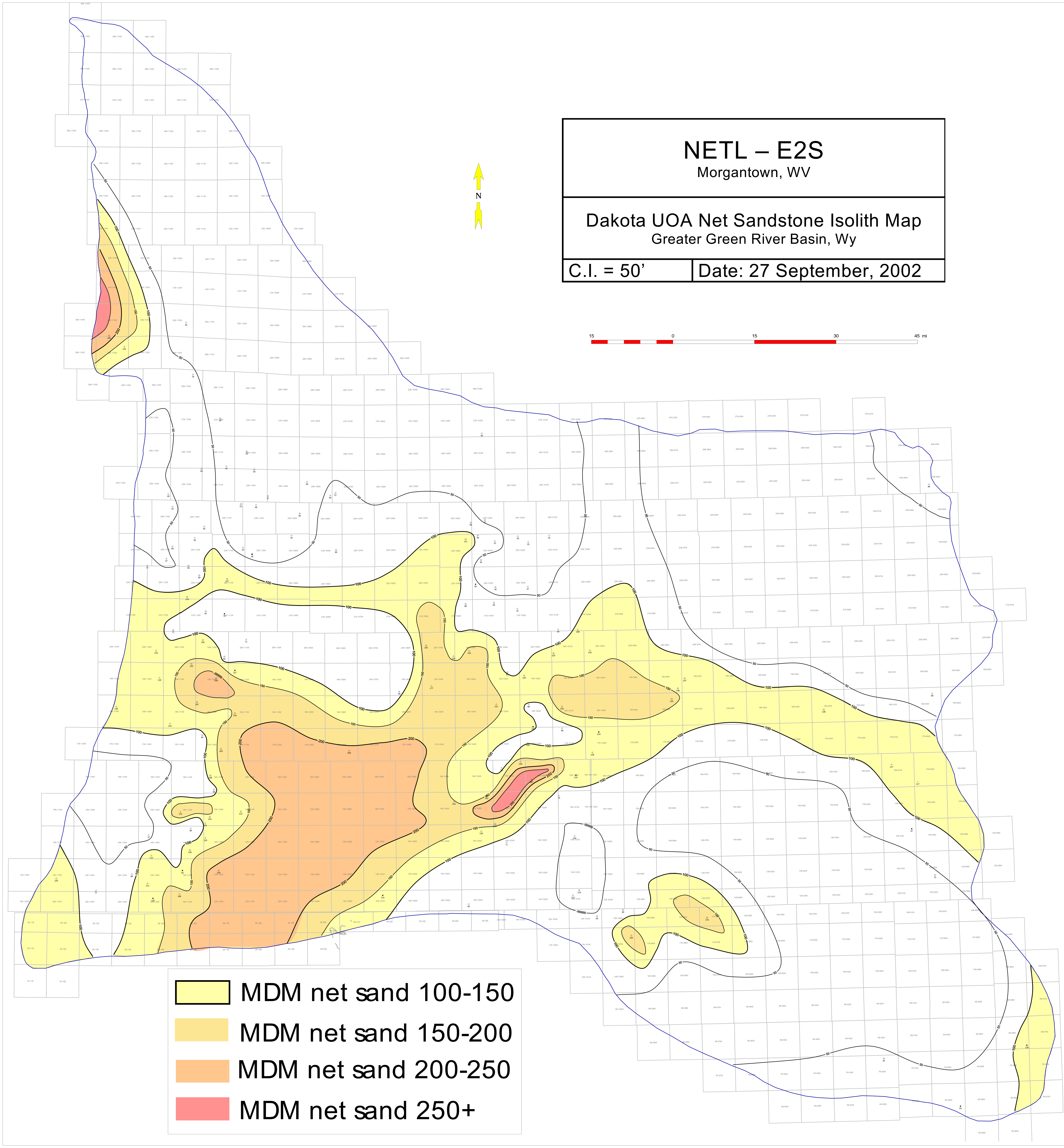
N
Lewis UOA Erosional Boundary
Lewis 6 net sand 60-100
Lewis 6 net sand 100-160
Lewis 6 net sand 160-220
Lewis 6 net sand 220+
NETL-E2S
Morgantown, WV
Lewis 6 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20’
Date: 9/12/02
10
0
10
20
30 mi


Lewis UOA Erosional Boundary
N
Lewis 7 net sand 300+
Lewis 7 net sand 250-300
Lewis 7 net sand 200-250
Lewis 7 net sand 150-200
NETL-E2S
Morgantown, WV
Lewis 7 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/12/02
10
0
10
20
30 mi

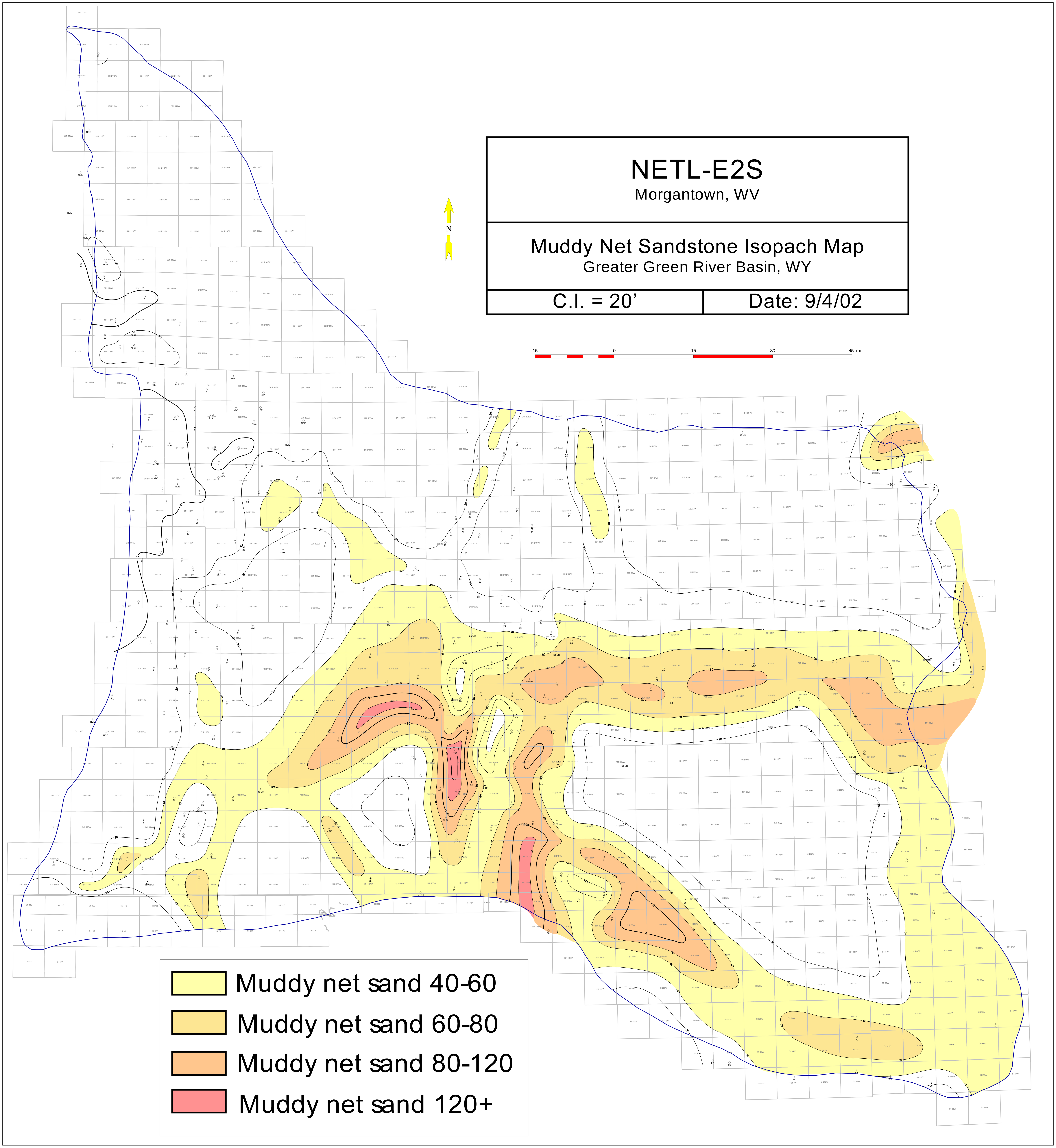


N
Lewis UOA
Erosional
Boundary
Lewis 8 net sand 140+
Lewis 8 net sand 100-140
Lewis 8 net sand 60-100
NETL-E2S
Morgantown, WV
Lewis 8 Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/13/02

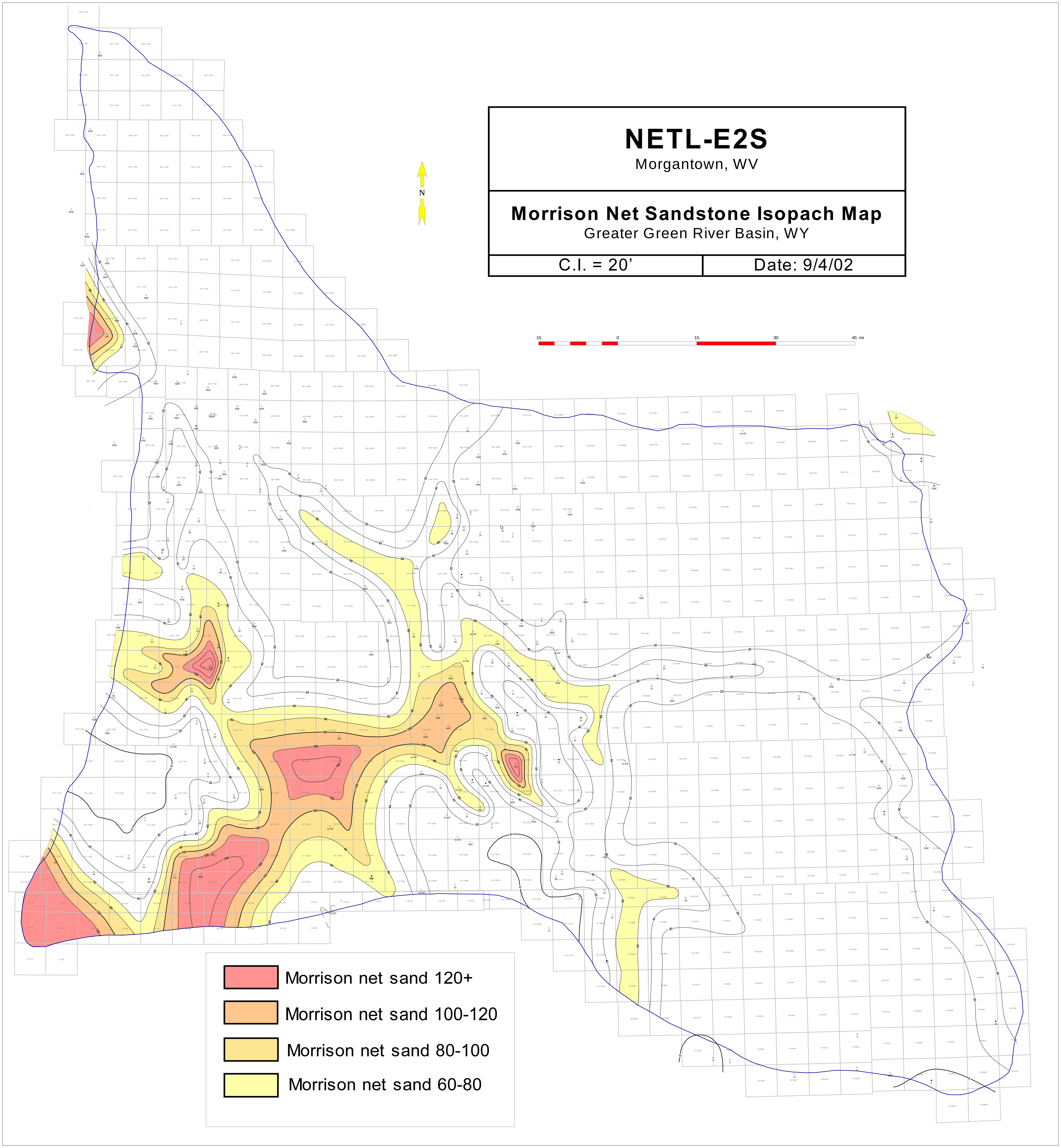

B
B'
1500
1000
500
0
-500
-1000
-1500
Lance Formation
Fox Hills Sandstone
Fox Hills Sandstone
L8
L7
L5
L4
L3
Lewis UOA
Lewis Pinchout
Upper Almond Sands
Almond UOA
Ericson UOA
Lower Mesaverde UOA
Almond
Ericson



NETL – E2S
Morgantown, WV
Dakota UOA Net Sandstone Isolith Map
Greater Green River Basin, Wy
C.I. = 50’
Date: 27 September, 2002
N
15
0
15
30
45 mi
MDM net sand 100-150
MDM net sand 150-200
MDM net sand 200-250
MDM net sand 250+



NETL-E2S
Morgantown, WV
Muddy Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20’
Date: 9/4/02
N
15 0 15 30 45 mi
Muddy net sand 40-60
Muddy net sand 60-80
Muddy net sand 80-120
Muddy net sand 120+

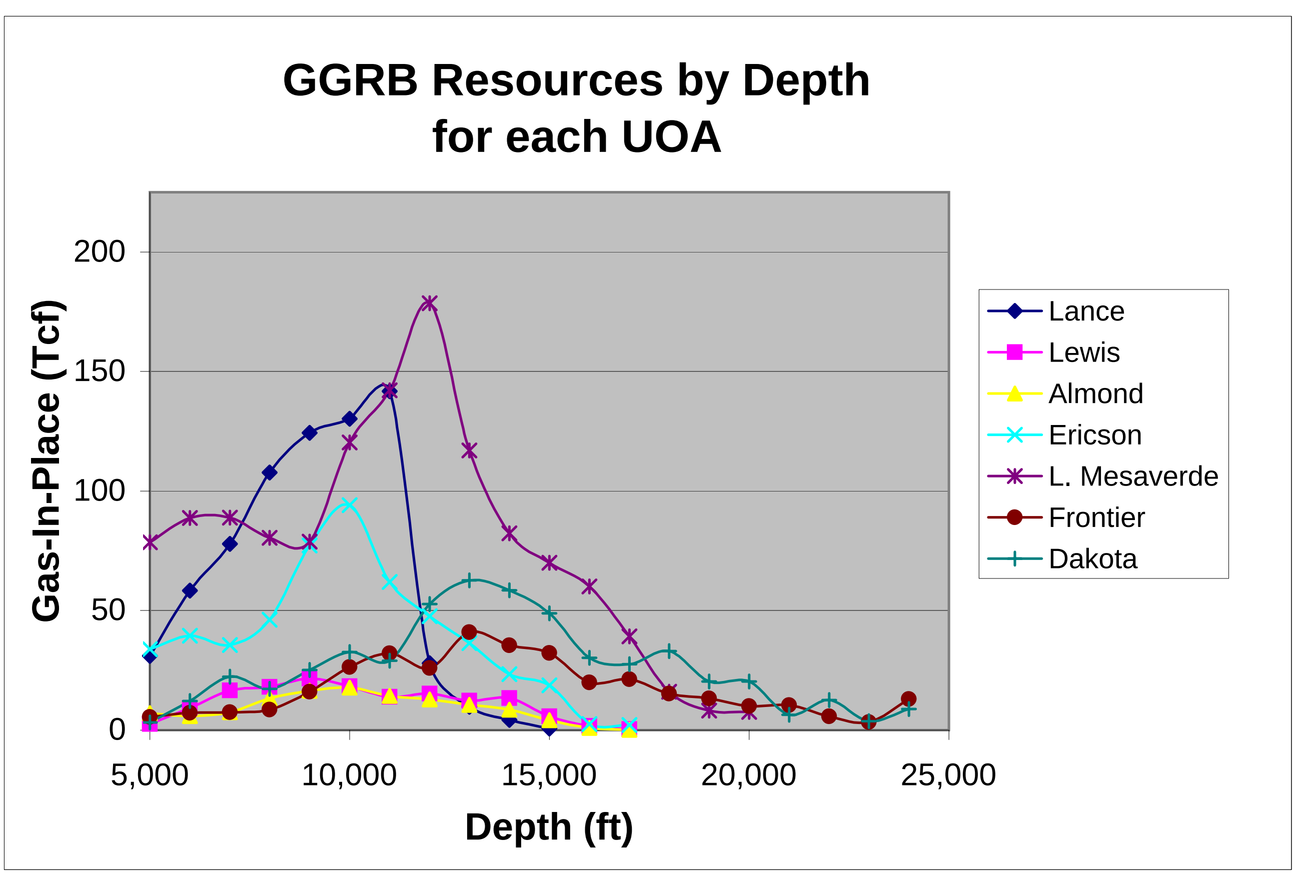


NETL-E2S
Morgantown, WV
Morrison Net Sandstone Isopach Map
Greater Green River Basin, WY
C.I. = 20'
Date: 9/4/02
N
15 0 15 30 45 mi
Morrison net sand 120+
Morrison net sand 100-120
Morrison net sand 80-100
Morrison net sand 60-80

GGRB - Summary

		Lance	Lewis	Almond	Ericson	Lower Mesaverde	Frontier	Dakota
UOA Averages	Acreage	5,247,060	4,331,520	8,363,520	8,484,480	9,066,240	11,128,320	11,796,480
	Potential Pay (ft)	341	82	27	119	305	46	55
	Porosity (%)	8	7	9	9	8	8	8
	Sw (%)	58	61	62	53	58	39	35
	Drilling Depth (ft)	8,628	10,104	9,882	9,729	10,778	14,511	14,629
	Pressure (psi)	4,322	5,232	5,430	5,322	5,739	8,498	9,592
	Temperature (oF)	164	181	179	177	189	249	250
	Assigned Rw	0.1	0.173	0.23	0.7	0.23	0.046	0.046
	GIP (Tcf)	714.4	149	119.5	519.4	1257	350.5	527.7
	GIP > 15,000' (Tcf)	0.7	7.8	5.2	23.5	201.1	144.7	211.9
	No. wells used	209	399	369	301	153	266	192
	No. full log suites	88	370	345	231	118	240	146
			GIP (Tcf)					
Gas Resource (Tcf) by 1000-ft Depth Range	5,000	31.1	2.5	7.1	33.9	78.6	5.5	3.2
	6,000	58.4	9.2	5.9	39.5	88.8	7.2	12.2
	7,000	77.9	16.6	7.5	35.6	88.9	7.5	22.3
	8,000	107.8	18.1	13.2	46.2	80.4	8.6	17.3
	9,000	124.4	21.6	16.5	77.2	78.9	16.1	25.2
	10,000	130.2	18.3	17.8	94.1	120.3	26.4	32.7
	11,000	141.8	13.9	14.3	62.0	142.2	32.1	29.0
	12,000	28.0	15.3	12.9	47.6	178.5	26.0	52.8
	13,000	9.8	12.3	10.6	36.4	117.0	40.9	62.6
	14,000	4.3	13.4	8.5	23.4	82.3	35.5	58.5
	15,000	0.7	5.7	4.1	18.7	70.0	32.2	48.8
	16,000		1.7	0.9	2.6	60.1	20.0	30.3
	17,000		0.4	0.2	2.2	39.2	21.3	27.6
	18,000					16.1	15.3	33.0
	19,000					8.1	13.2	20.3
	20,000					7.6	10.1	20.3
	21,000						10.4	6.4
	22,000						5.8	12.6
	23,000						3.4	3.7
	24,000						13.0	8.9
	25,000							
	26,000							
	27,000							
	28,000							
	29,000							
	30,000							
	31,000							
	32,000							

Grey cells indicate depth the formation is not present in the GGRB



GGRB - Lance

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	558720	31.1	216	10.0%	58%	5510	2614	126
6,000	800640	58.3	228	9.4%	60%	3507	3114	138
7,000	869460	77.8	264	8.3%	61%	7536	3695	150
8,000	887040	107.8	331	8.0%	56%	8472	4215	161
9,000	645120	124.4	432	7.6%	54%	9473	4765	173
10,000	696960	130.2	493	7.4%	55%	10518	5391	186
11,000	529920	141.0	508	7.3%	58%	11440	5926	197
12,000	132480	28.0	339	7.4%	59%	12466	6456	209
13,000	69120	9.7	255	7.4%	52%	13409	6980	221
14,000	46080	4.3	137	6.1%	38%	14377	7497	232
15,000	11520	0.7	114	5.2%	30%	15191	7947	242
16,000	0	0	0	0	0	0	0	0
17,000	0	0	0	0	0	0	0	0
18,000	0	0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
22,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
24,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

GGRB - Lewis

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	357120	2.5	25	7.8%	77%	5421	2502	125
6,000	368640	9.2	72	8.4%	72%	6492	3072	138
7,000	426240	16.6	104	7.5%	67%	7527	3739	150
8,000	552960	18.1	81	7.0%	63%	8521	4302	162
9,000	558720	21.6	94	6.5%	62%	9514	5024	174
10,000	426240	18.3	88	6.0%	59%	10492	5531	186
11,000	380160	13.9	104	5.1%	60%	11458	6024	197
12,000	316800	15.3	91	5.8%	54%	12550	6846	211
13,000	316800	12.3	90	5.8%	53%	13482	7104	222
14,000	432000	13.4	66	5.7%	48%	14510	7319	234
15,000	155520	5.7	69	5.9%	40%	15369	8523	244
16,000	28800	1.7	59	6.9%	25%	16530	10428	258
17,000	11520	0.4	39	6.3%	17%	17050	11270	265
18,000	0	0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
22,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
24,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

GGRB - Almond

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	645120	7.1	31	10.2%	62%	5490	2658	126
6,000	760320	5.9	17	10.0%	64%	6447	3240	137
7,000	852480	7.5	22	9.6%	63%	7513	3851	150
8,000	1203840	13.2	24	8.6%	63%	8509	4261	162
9,000	1198080	16.5	27	8.9%	62%	9456	4958	173
10,000	1198080	17.8	28	8.1%	61%	10483	5911	186
11,000	656640	14.3	33	7.2%	62%	11421	6534	197
12,000	403200	12.9	55	8.2%	57%	12534	7311	210
13,000	432000	10.6	34	7.8%	58%	13527	7894	222
14,000	472320	8.5	27	8.0%	60%	14502	8397	234
15,000	403200	4.1	18	6.5%	59%	15510	9124	246
16,000	103680	0.9	12	6.8%	63%	16327	10860	256
17,000	34560	0.2	18	5.3%	65%	17714	13834	272
18,000	0	0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
22,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
24,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

GGRB - Ericson

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	650880	33.9	136	11.7%	60%	5492	2629	126
6,000	904320	39.5	101	10.2%	62%	6539	3256	138
7,000	875520	35.6	95	9.1%	61%	7543	3793	151
8,000	1054080	46.2	107	8.9%	61%	8541	4340	163
9,000	1267200	77.2	155	8.7%	58%	9524	4835	174
10,000	1388160	94.1	115	7.9%	52%	10508	5771	186
11,000	737280	62.0	125	7.7%	42%	11393	6639	197
12,000	374400	47.6	156	8.0%	33%	12487	7386	210
13,000	311040	36.4	141	7.7%	32%	13516	7918	222
14,000	391680	23.4	86	6.8%	42%	14542	8705	235
15,000	391680	18.7	80	5.8%	39%	15446	9379	245
16,000	80640	2.6	113	4.5%	60%	16498	11669	258
17,000	57600	2.2	121	4.3%	58%	17405	13570	269
18,000	0	0.0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
22,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
24,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

GGRB - Lower Mesaverde

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	564480	78.6	306	11.3%	55%	5518	2621	126
6,000	673920	88.8	256	10.8%	56%	6509	3234	138
7,000	685440	88.9	273	9.9%	58%	7482	3715	150
8,000	760320	80.4	244	9.3%	63%	8531	4280	162
9,000	864000	78.9	212	8.7%	66%	9554	4709	175
10,000	1336320	120.3	215	8.3%	66%	10486	5239	186
11,000	1238400	142.2	301	7.8%	60%	11451	6288	197
12,000	794880	178.5	476	7.4%	51%	12463	6817	210
13,000	455040	117.0	454	7.3%	51%	13442	7401	221
14,000	414720	82.3	387	6.4%	53%	14466	8112	234
15,000	432000	70.0	358	5.8%	53%	15490	8856	246
16,000	368640	60.1	377	5.5%	53%	16500	9410	258
17,000	276480	39.2	393	5.2%	53%	17380	9944	269
18,000	97920	16.1	399	5.8%	53%	18415	11003	281
19,000	51840	8.1	410	4.9%	51%	19553	11800	295
20,000	51840	7.6	414	4.4%	50%	20000	12000	300
21,000	0	0	0	0	0	0	0	0
22,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
24,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

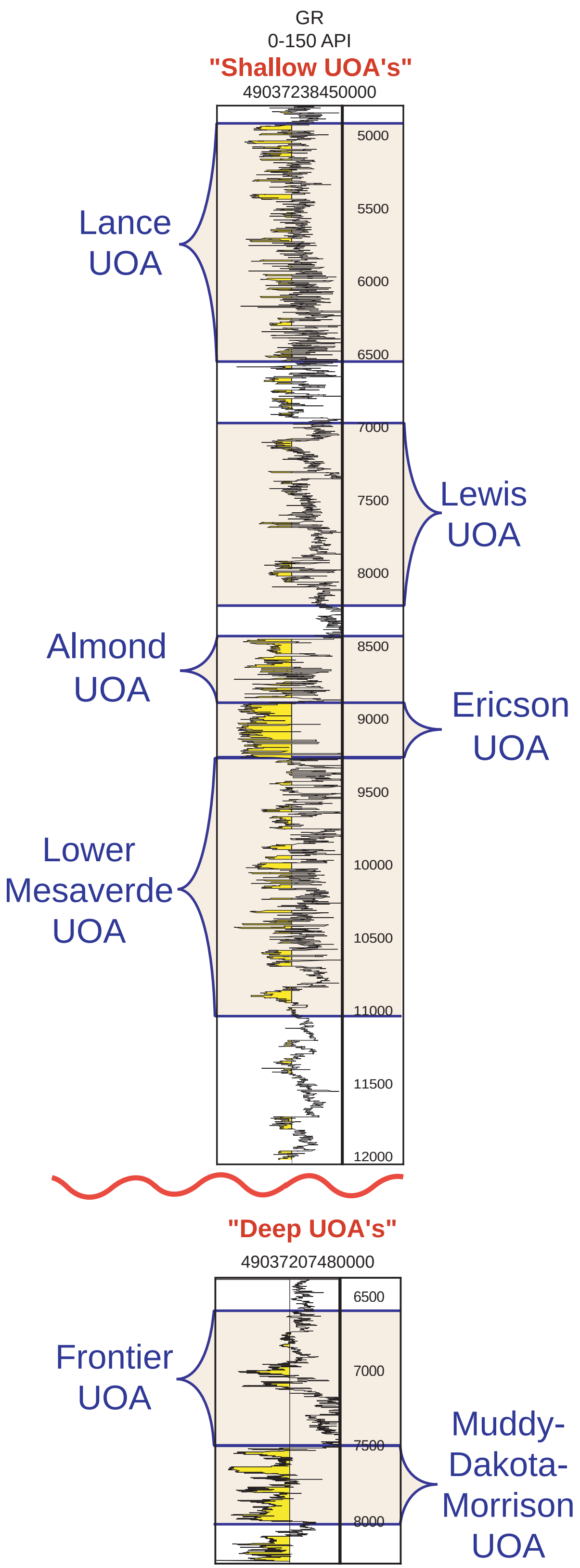
GGRB - Frontier

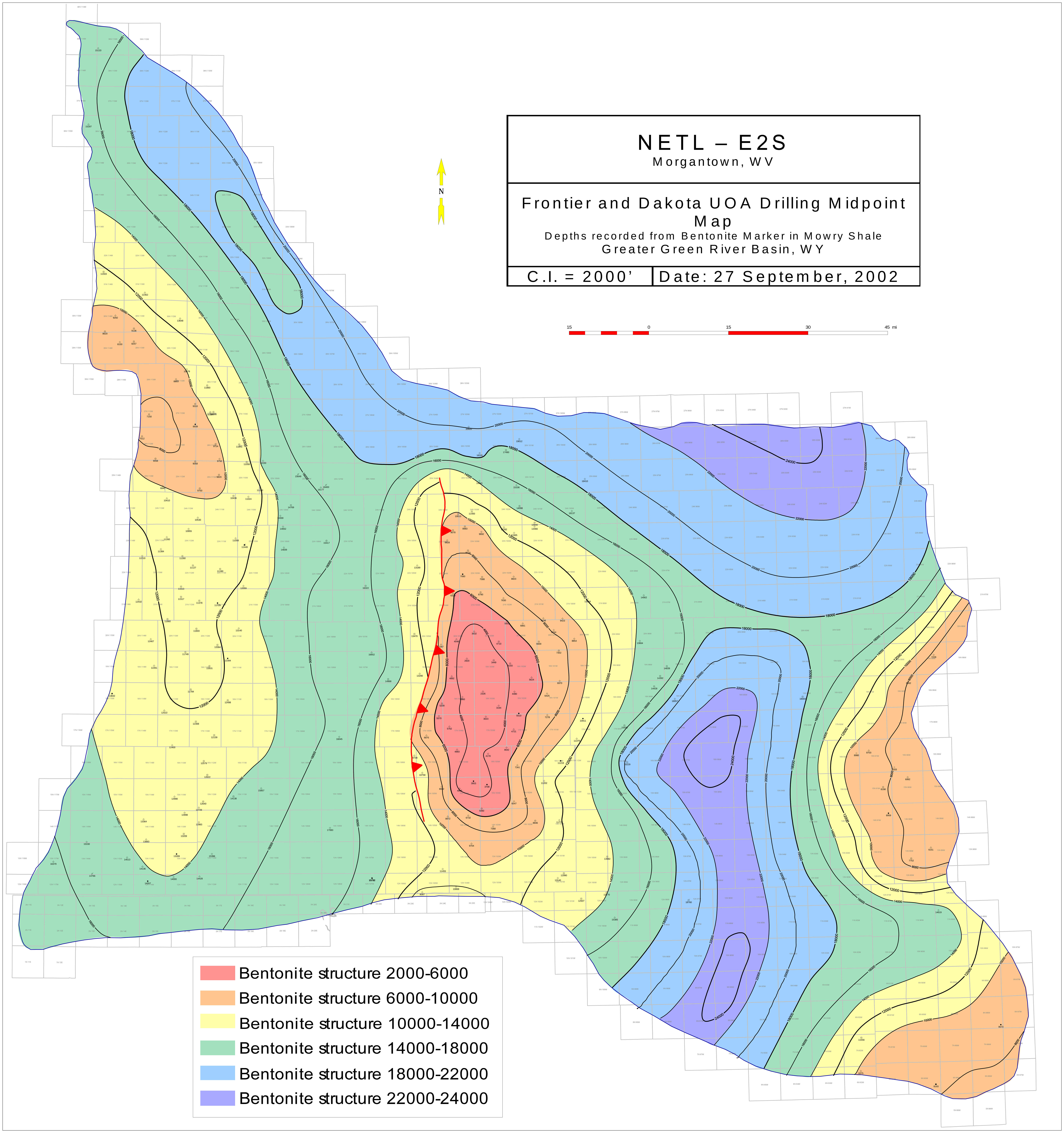
DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	207360	5.5	45	10.4%	42%	5641	3164	133
6,000	276480	7.2	44	10.1%	39%	6437	3573	144
7,000	253440	7.5	47	9.5%	36%	7530	4092	158
8,000	299520	8.6	43	10.1%	34%	8720	4899	173
9,000	414720	16.1	62	9.4%	36%	9533	5321	184
10,000	576000	26.4	64	9.2%	32%	10552	5718	197
11,000	898560	32.1	47	9.5%	36%	11505	6527	210
12,000	967680	26.0	37	9.2%	37%	12463	6959	222
13,000	1221120	40.9	44	8.8%	39%	13498	7762	235
14,000	1175040	35.5	39	8.9%	38%	14449	8549	248
15,000	1036800	32.2	47	7.7%	41%	15520	9143	262
16,000	691200	20.0	44	7.4%	43%	16474	10071	274
17,000	852480	21.3	37	6.6%	42%	17494	10747	287
18,000	622080	15.3	37	6.9%	39%	18547	11587	301
19,000	552960	13.2	38	6.5%	46%	19428	11535	313
20,000	368640	10.1	43	6.5%	44%	20392	12623	325
21,000	253440	10.4	67	6.1%	40%	21522	12139	340
22,000	184320	5.8	49	6.6%	38%	22488	12655	352
23,000	69120	3.4	77	5.9%	33%	23558	13107	366
24,000	207360	13.0	101	5.4%	28%	24462	13845	378
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

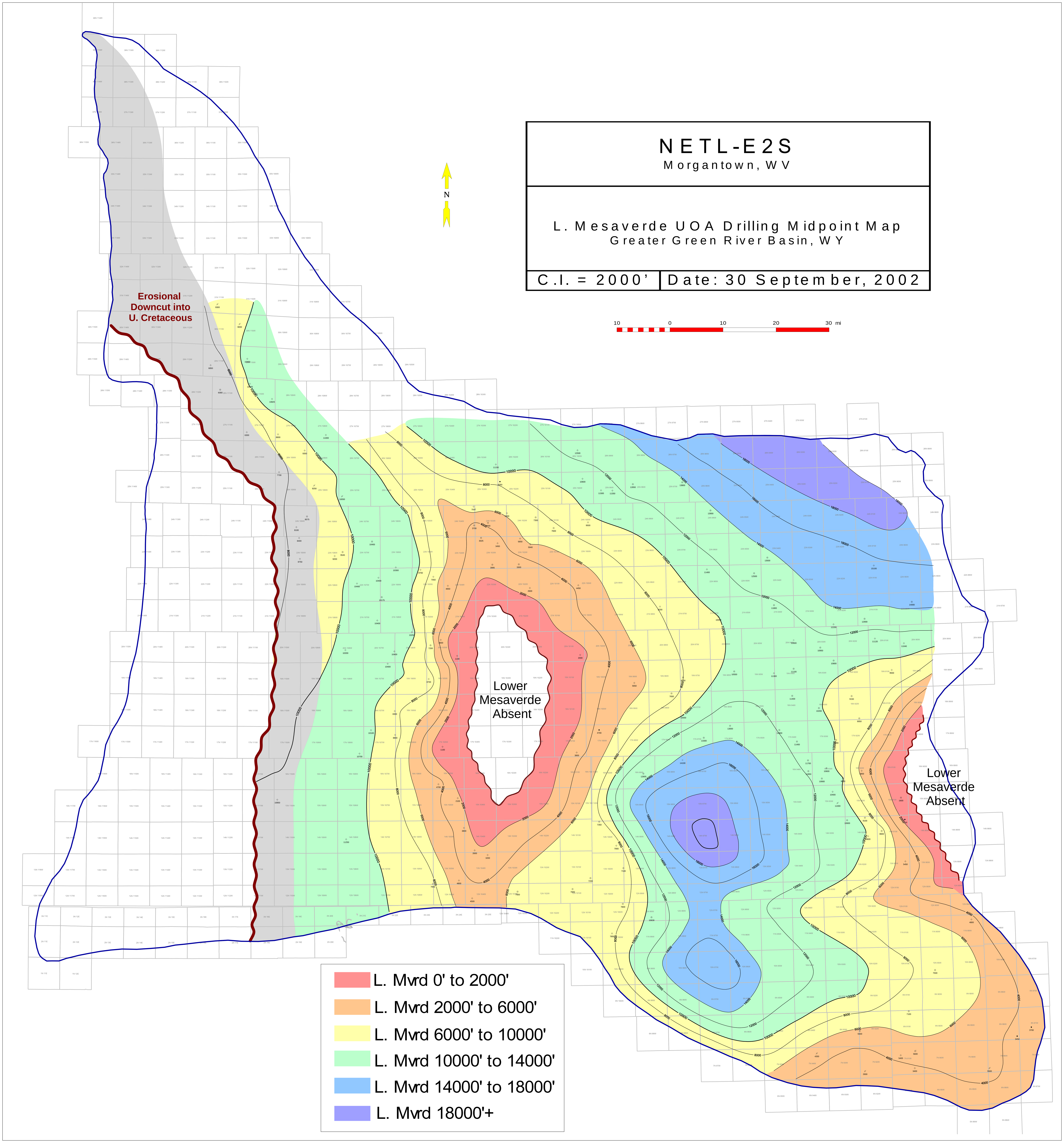
GGRB - Dakota

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	115200	3.2	71	10.2%	33%	5363	2197	130
6,000	345600	12.2	63	9.8%	43%	6624	3539	146
7,000	437760	22.3	67	10.0%	37%	7401	3926	156
8,000	391680	17.3	57	9.2%	36%	8479	4596	170
9,000	506880	25.2	63	9.5%	34%	9521	5468	184
10,000	529920	32.7	62	9.9%	31%	10473	5956	196
11,000	645120	29.0	54	9.2%	32%	11535	6439	210
12,000	990720	52.8	63	9.3%	34%	12487	7289	222
13,000	1128960	62.6	59	9.5%	32%	13495	8124	235
14,000	1082880	58.5	50	9.8%	26%	14504	8560	249
15,000	1267200	48.8	47	7.9%	35%	15447	9700	261
16,000	944640	30.3	41	7.2%	33%	16484	11011	274
17,000	806400	27.6	52	6.9%	37%	17553	12133	288
18,000	852480	33.0	50	7.3%	38%	18472	13567	300
19,000	483840	20.3	56	7.3%	38%	19456	14325	313
20,000	483840	20.3	54	7.9%	44%	20376	15447	325
21,000	138240	6.4	60	7.0%	37%	21518	16817	340
22,000	299520	12.6	60	6.2%	38%	22445	17734	352
23,000	115200	3.7	55	5.5%	42%	23469	18757	365
24,000	230400	8.9	66	5.5%	43%	24797	19995	383
25,000	0	0	0	0	0	0	0	0
26,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
28,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
30,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
32,000	0	0	0	0	0	0	0	0

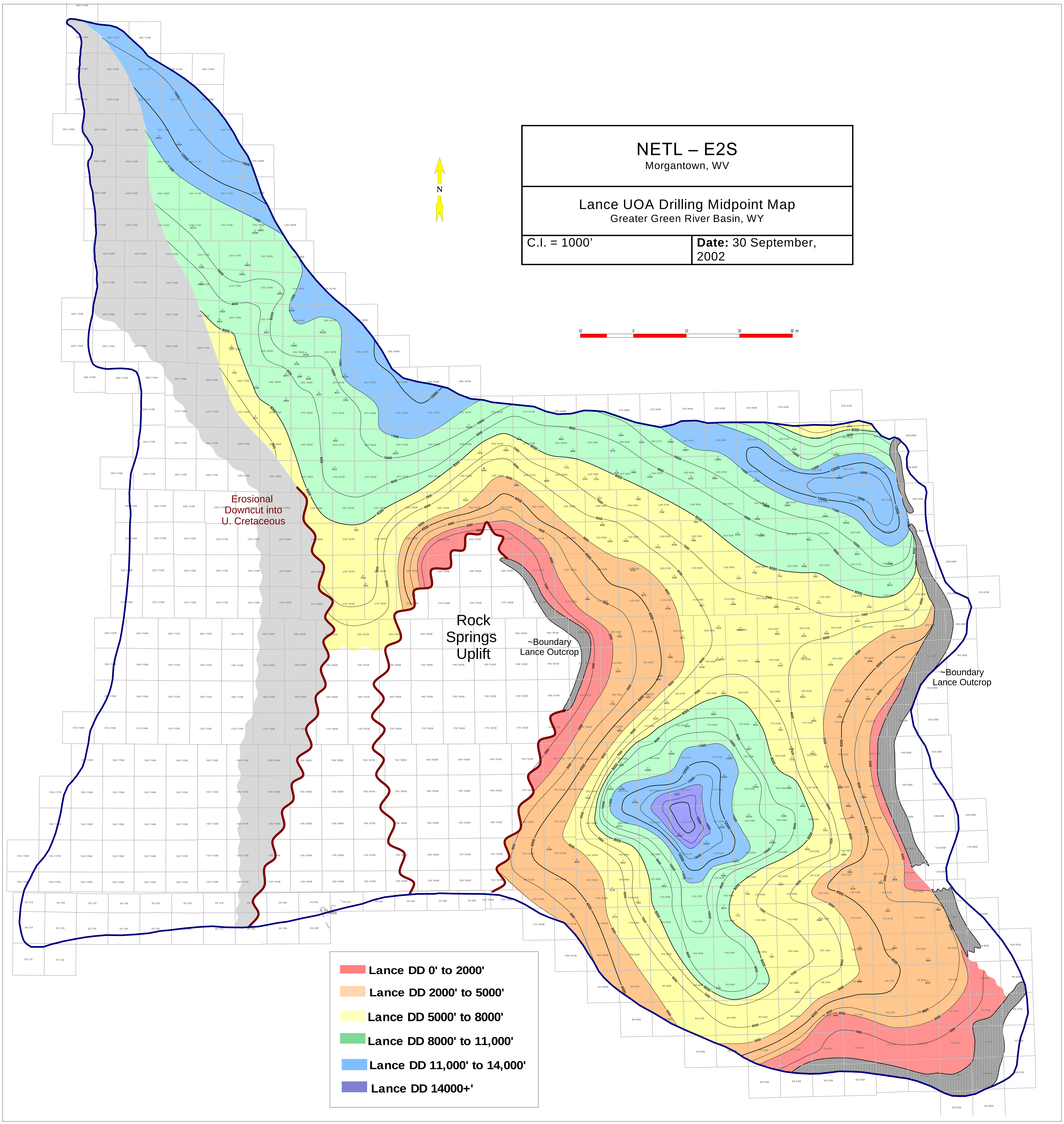
GGRB - Type Log

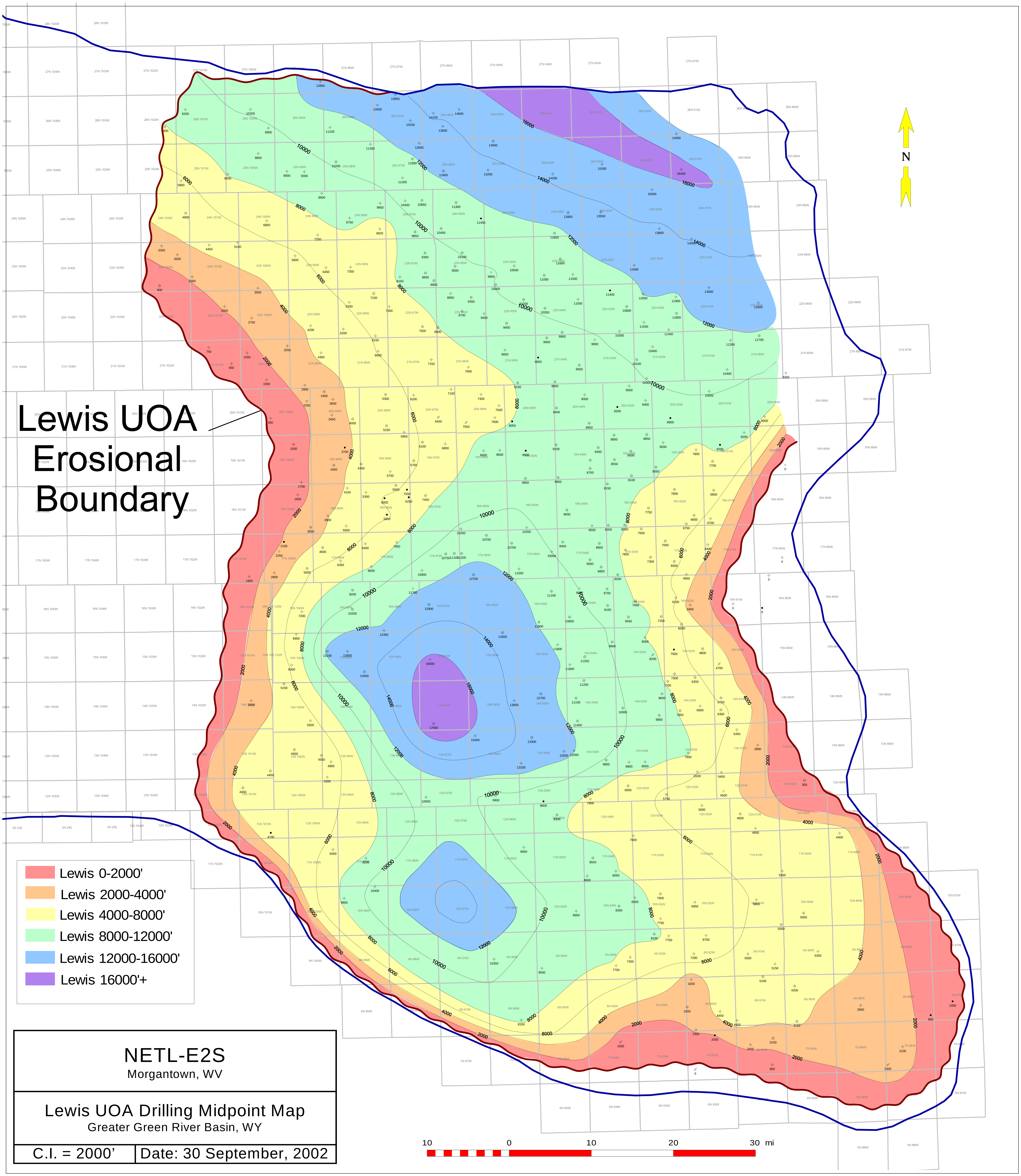



NETL – E2S
Morgantown, WV
Frontier and Dakota UOA Drilling Midpoint Map
Depths recorded from Bentonite Marker in Mowry Shale
Greater Green River Basin, WY
C.I. = 2000'
Date: 27 September, 2002
N
15 0 15 30 45 mi
Bentonite structure 2000-6000
Bentonite structure 6000-10000
Bentonite structure 10000-14000
Bentonite structure 14000-18000
Bentonite structure 18000-22000
Bentonite structure 22000-24000



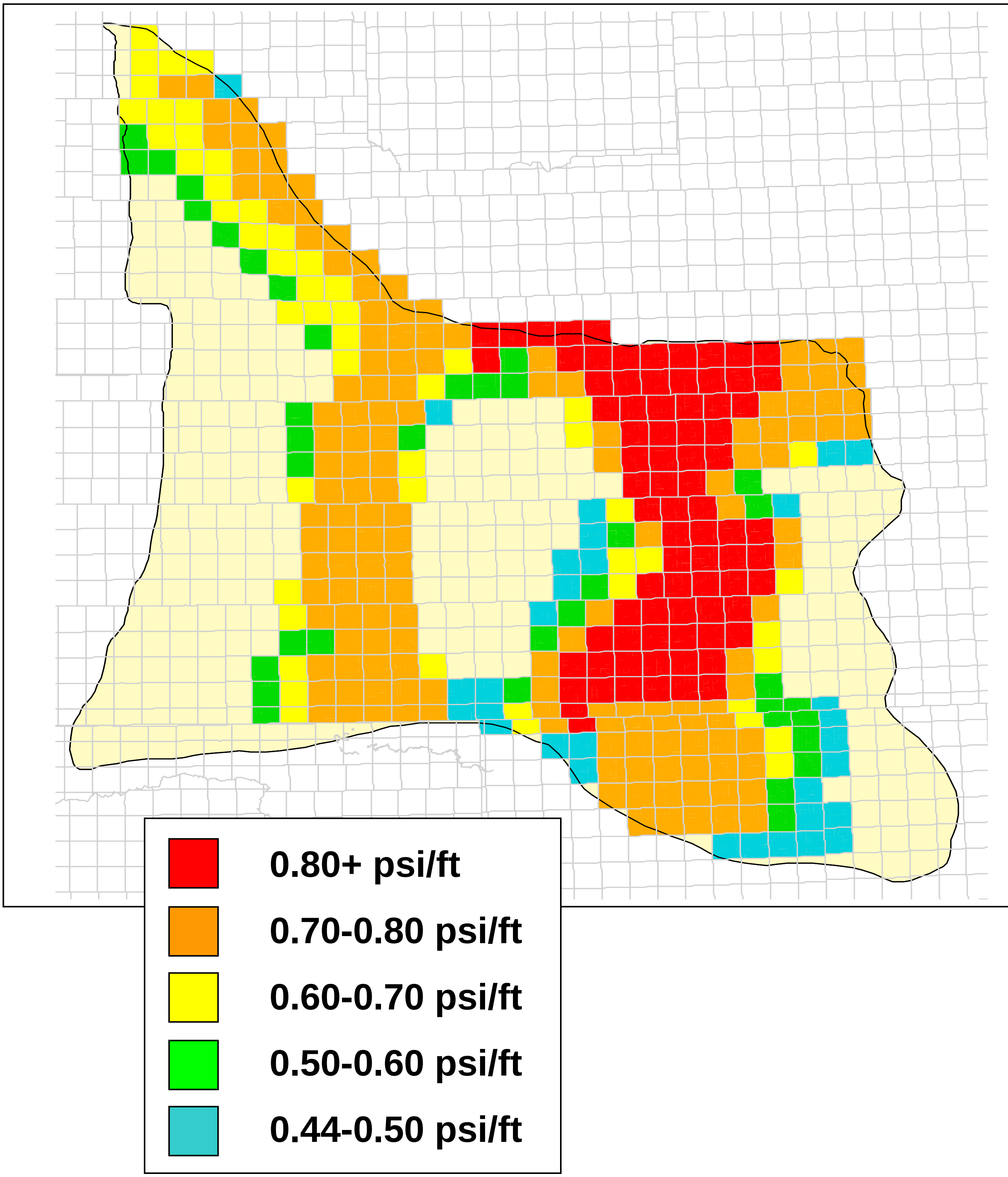
NETL-E2S
Morgantown, WV
L. Mesaverde UOA Drilling Midpoint Map
Greater Green River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
N
10 0 10 20 30 mi
Erosional Downcut into U. Cretaceous
Lower Mesaverde Absent
Lower Mesaverde Absent
L. Mvrd 0' to 2000'
L. Mvrd 2000' to 6000'
L. Mvrd 6000' to 10000'
L. Mvrd 10000' to 14000'
L. Mvrd 14000' to 18000'
L. Mvrd 18000'+


NETL – E2S
Morgantown, WV
Lance UOA Drilling Midpoint Map
Greater Green River Basin, WY
C.I. = 1000’
Date: 30 September, 2002
N
Erosional Downcut into U. Cretaceous
Rock Springs Uplift
~Boundary Lance Outcrop
~Boundary Lance Outcrop
Lance DD 0' to 2000'
Lance DD 2000' to 5000'
Lance DD 5000' to 8000'
Lance DD 8000' to 11,000'
Lance DD 11,000' to 14,000'
Lance DD 14000+'



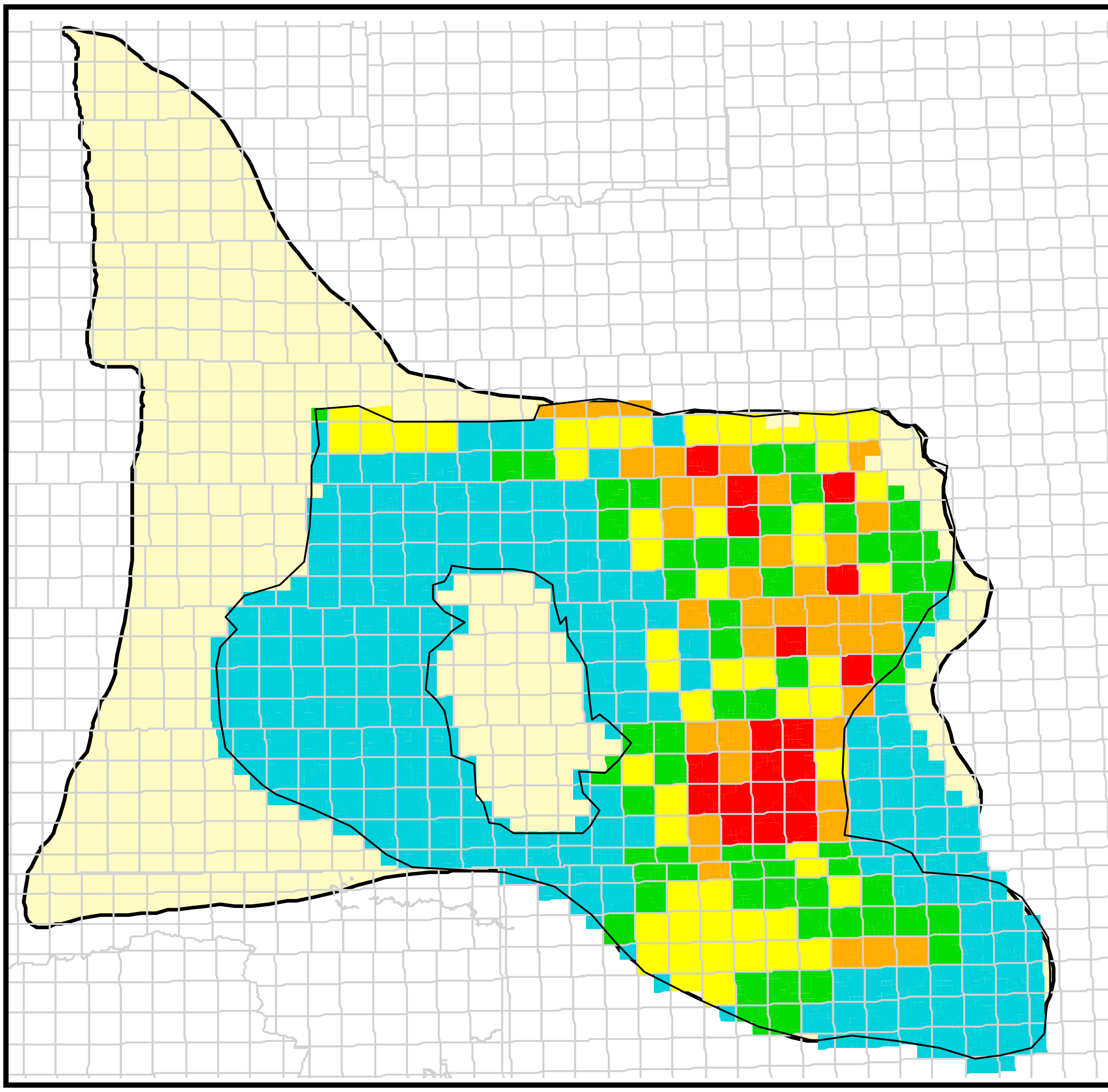
Lewis UOA Erosional Boundary
N
Lewis 0-2000'
Lewis 2000-4000'
Lewis 4000-8000'
Lewis 8000-12000'
Lewis 12000-16000'
Lewis 16000'+
NETL-E2S
Morgantown, WV
Lewis UOA Drilling Midpoint Map
Greater Green River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
10 0 10 20 30 mi

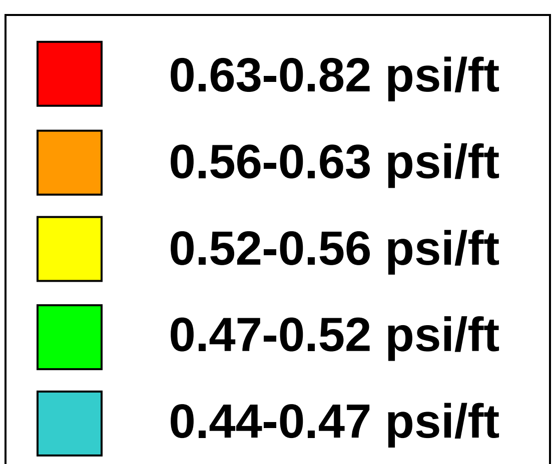
Reservoir Pressure Gradient, Frontier Fm., GGRB



Advanced Resources International

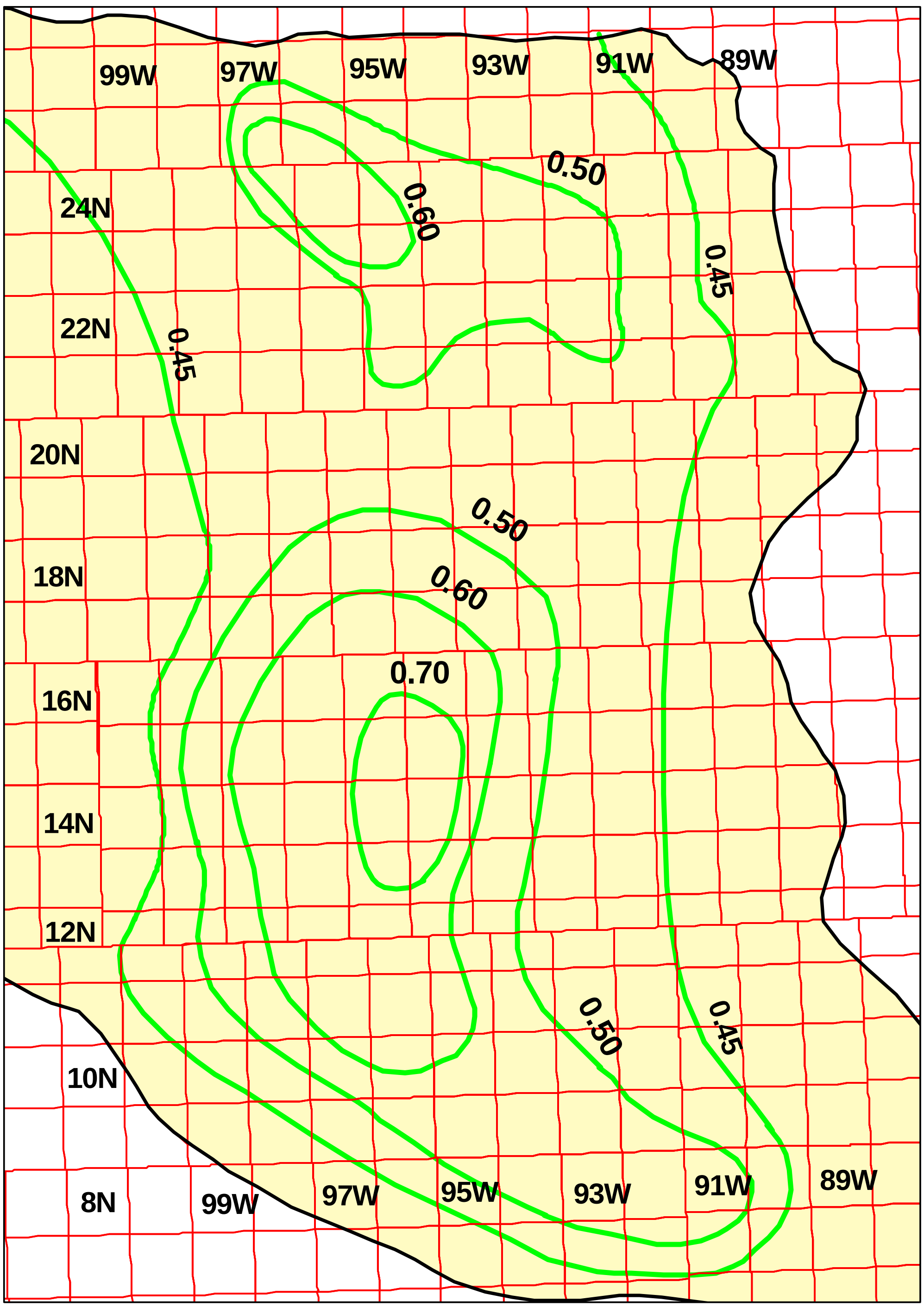
Reservoir Pressure Gradient, Mesaverde Group, GGRB





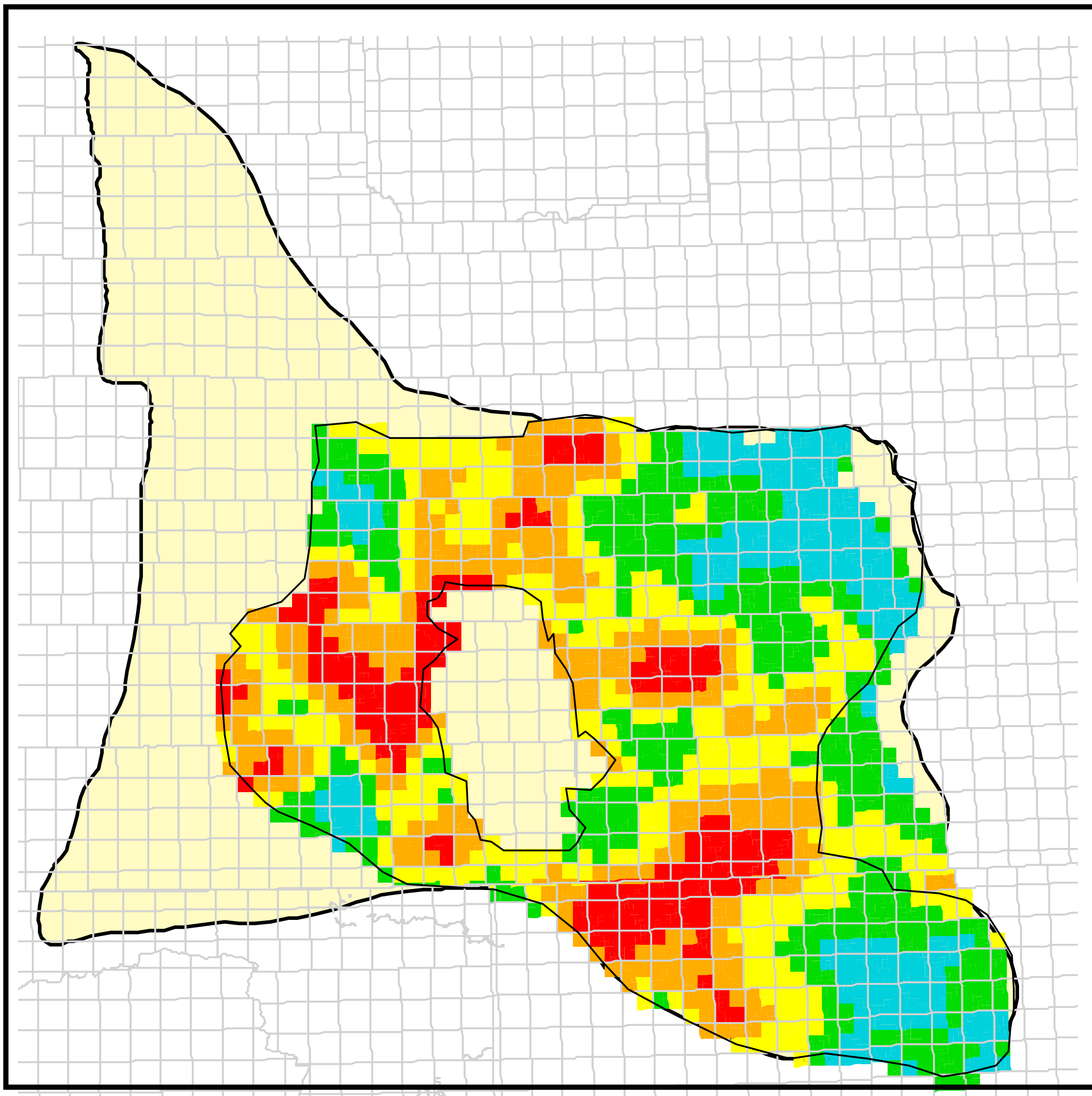
Advanced Resources International

Reservoir Pressure Gradients, Lewis Shale, GGRB



Advanced Resources International

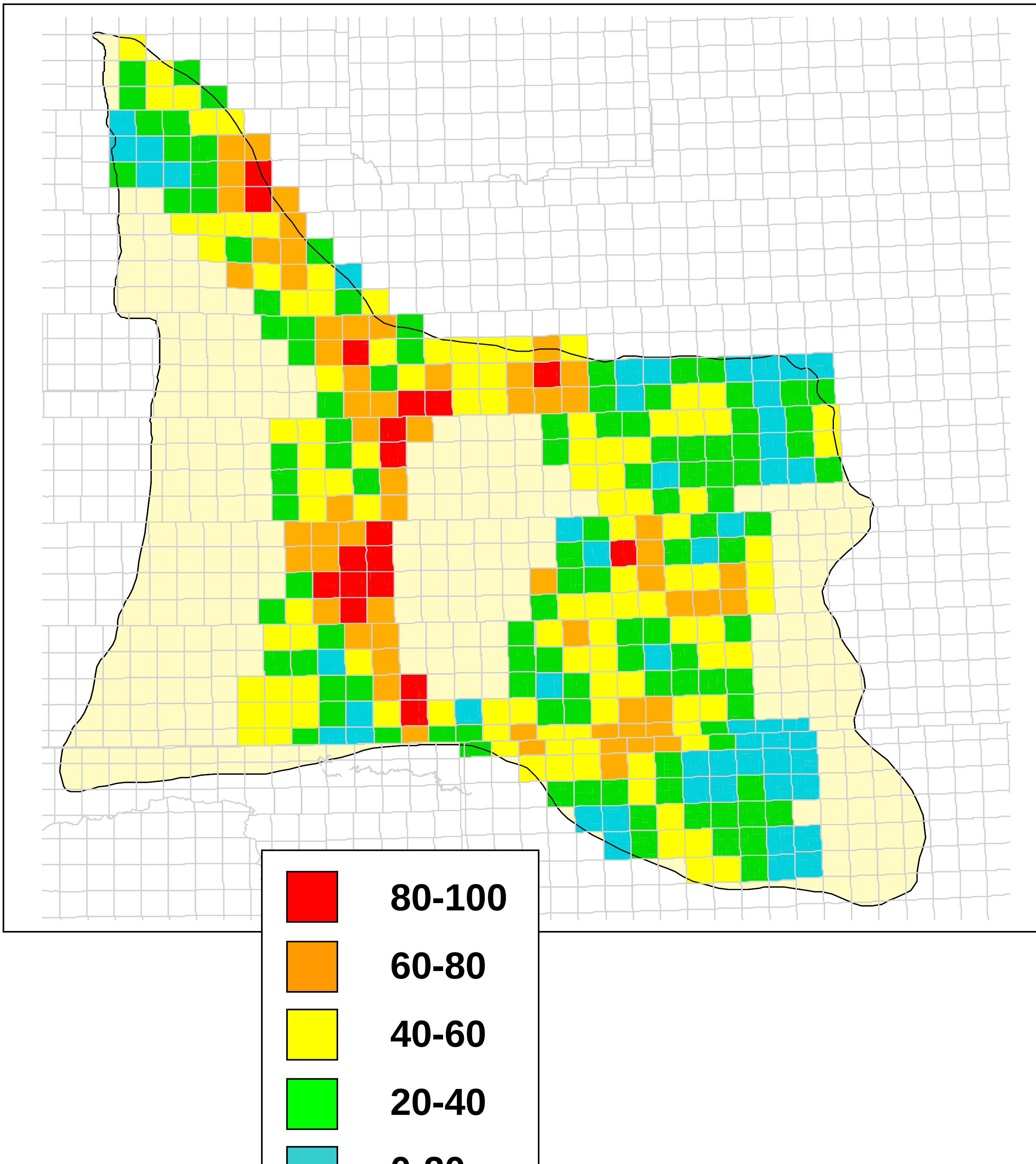
Structural Complexity, Mesaverde Group, GGRB



	69-96
	55-69
	42-55
	30-42
	8-30

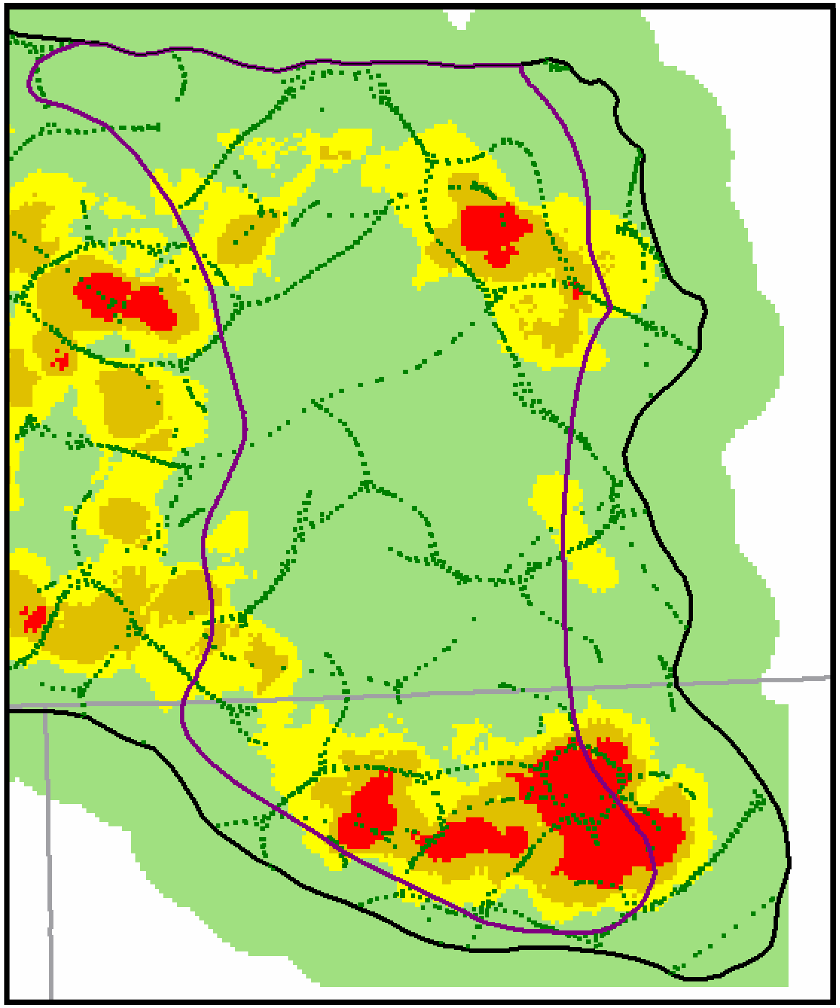
Advanced Resources International

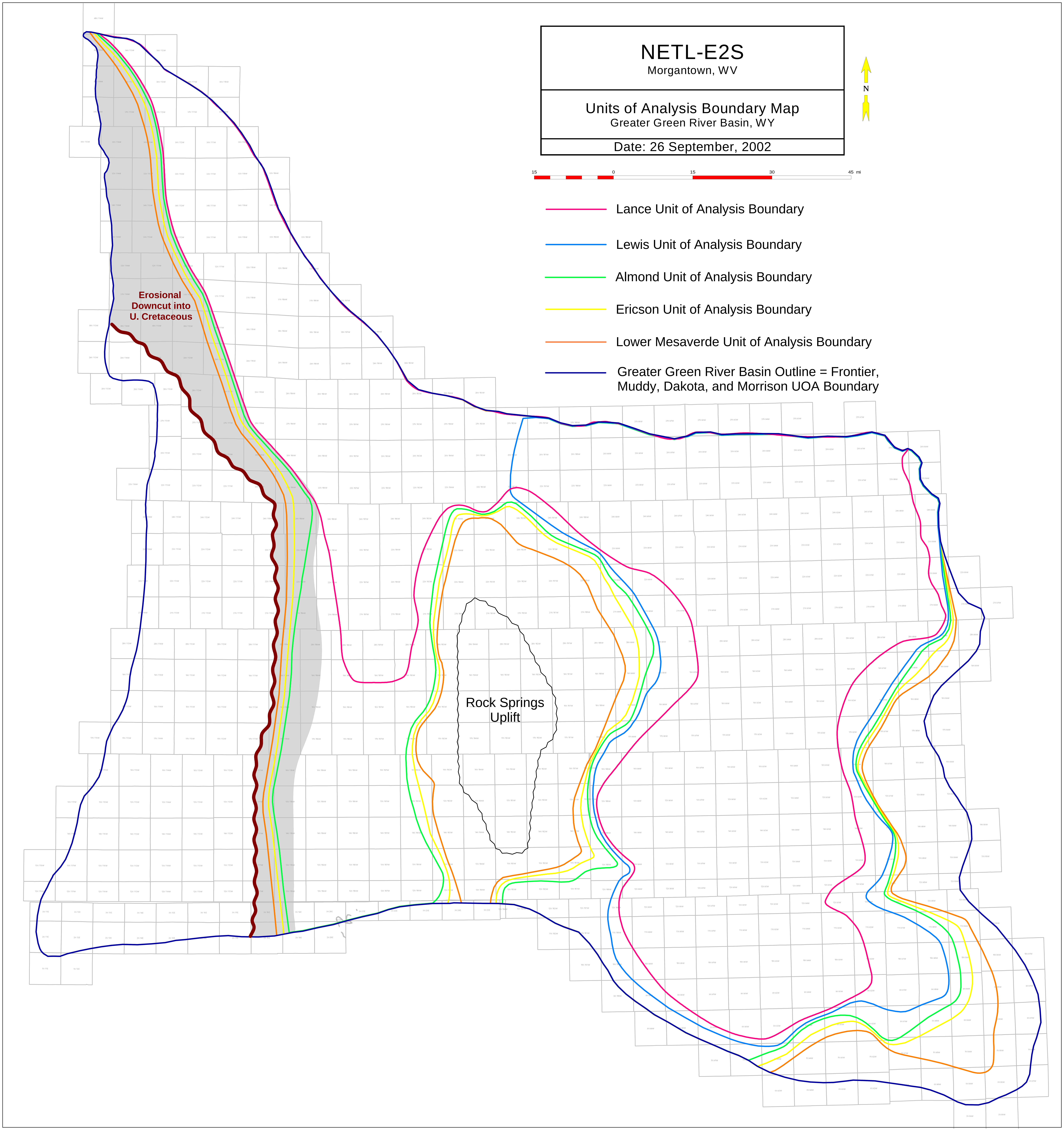
Structural Complexity, Frontier Fm., GGRB



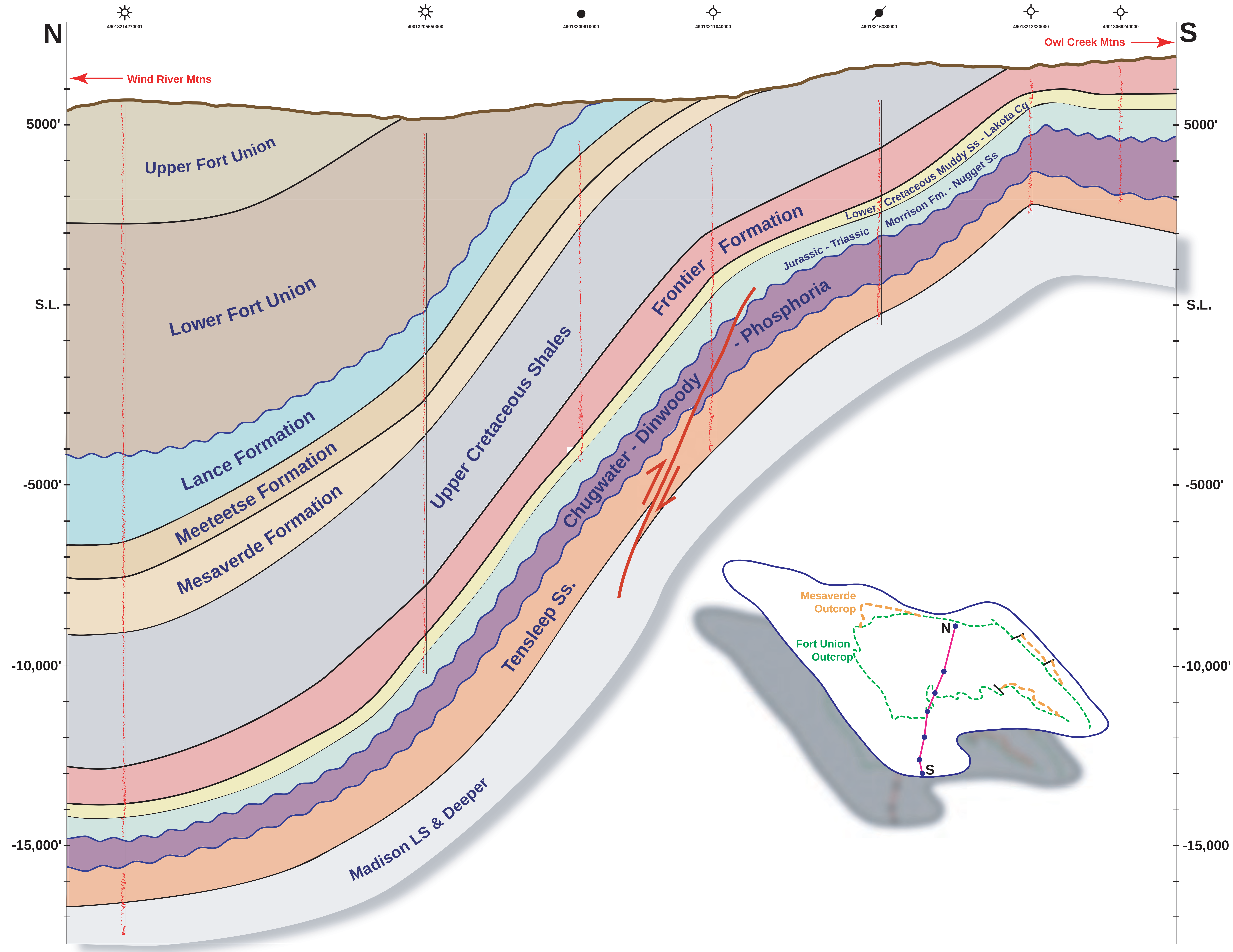
Advanced Resources International

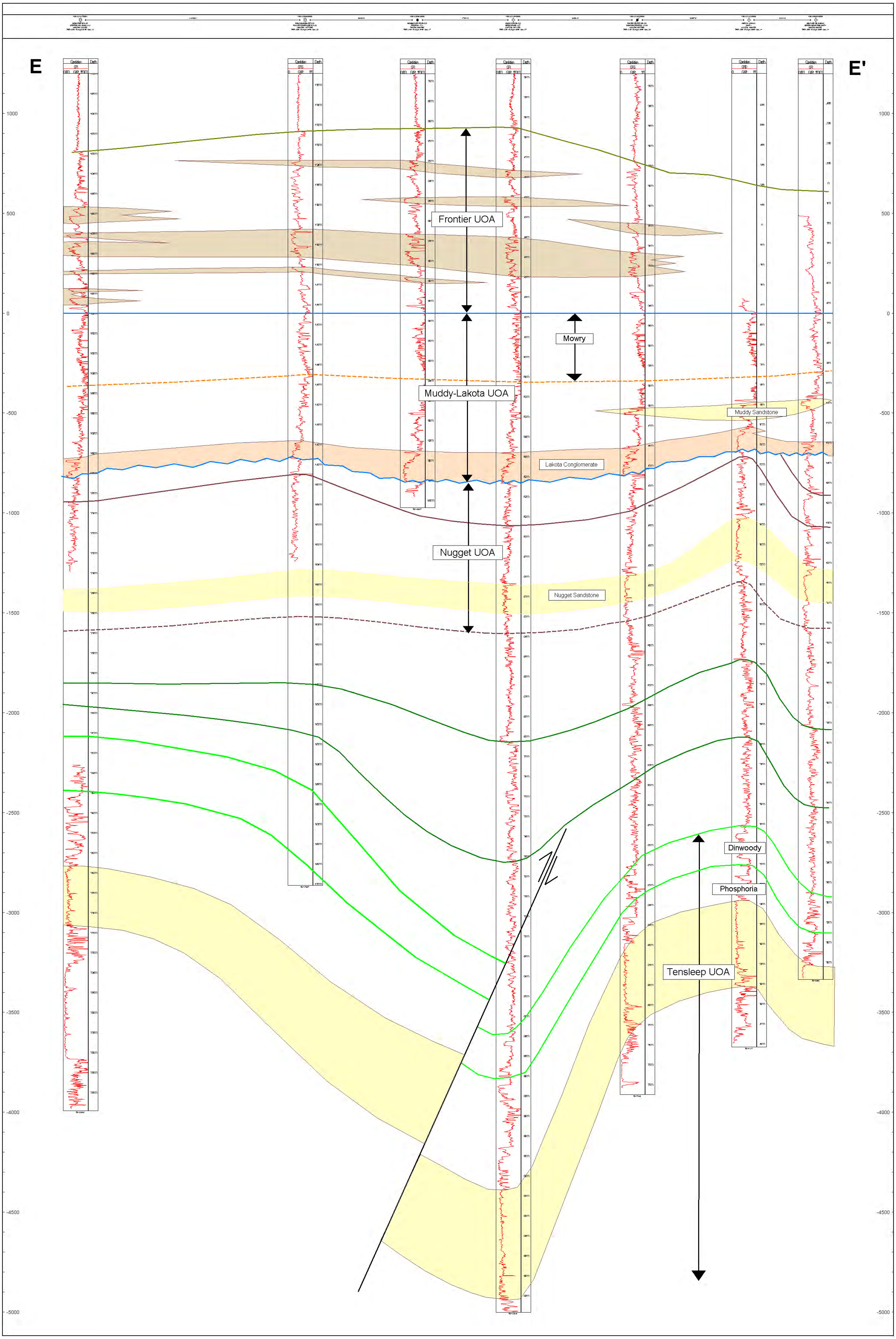
Structural Complexity, Lewis Shale, GGRB

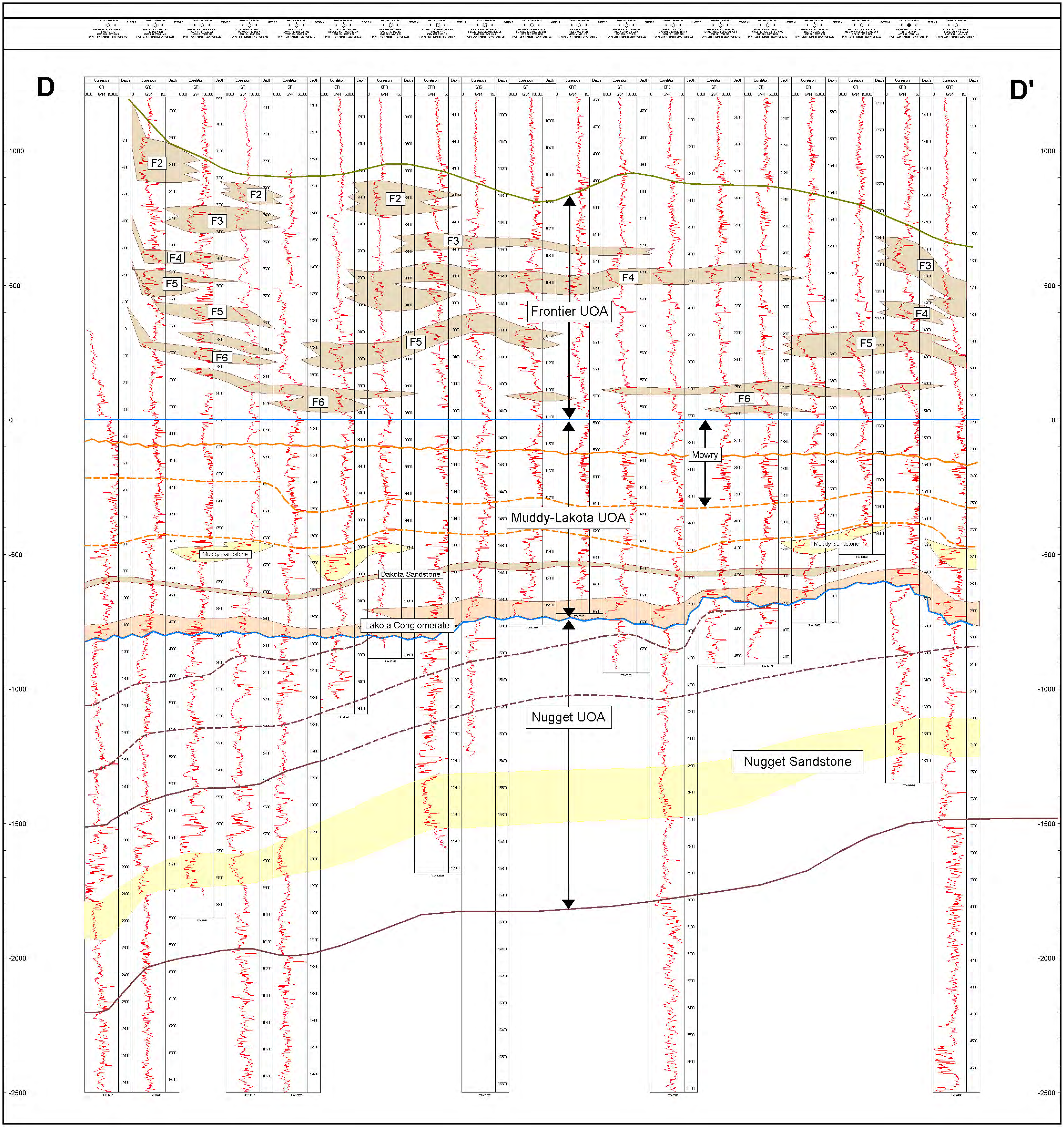


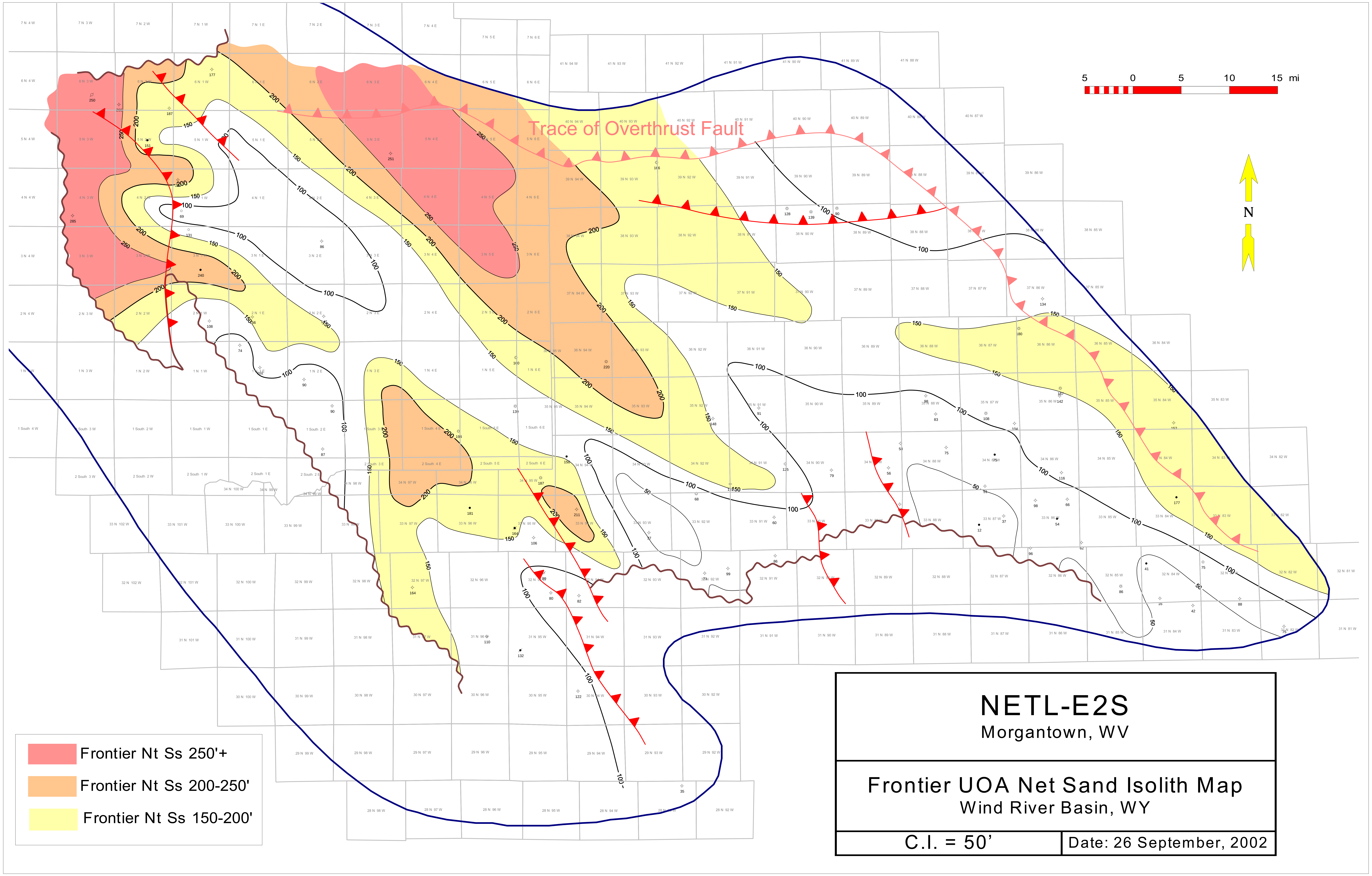

NETL-E2S
Morgantown, WV
Units of Analysis Boundary Map
Greater Green River Basin, WY
Date: 26 September, 2002
N
15 0 15 30 45 mi
Lance Unit of Analysis Boundary
Lewis Unit of Analysis Boundary
Almond Unit of Analysis Boundary
Ericson Unit of Analysis Boundary
Lower Mesaverde Unit of Analysis Boundary
Greater Green River Basin Outline = Frontier, Muddy, Dakota, and Morrison UOA Boundary
Erosional Downcut into U. Cretaceous
Rock Springs Uplift

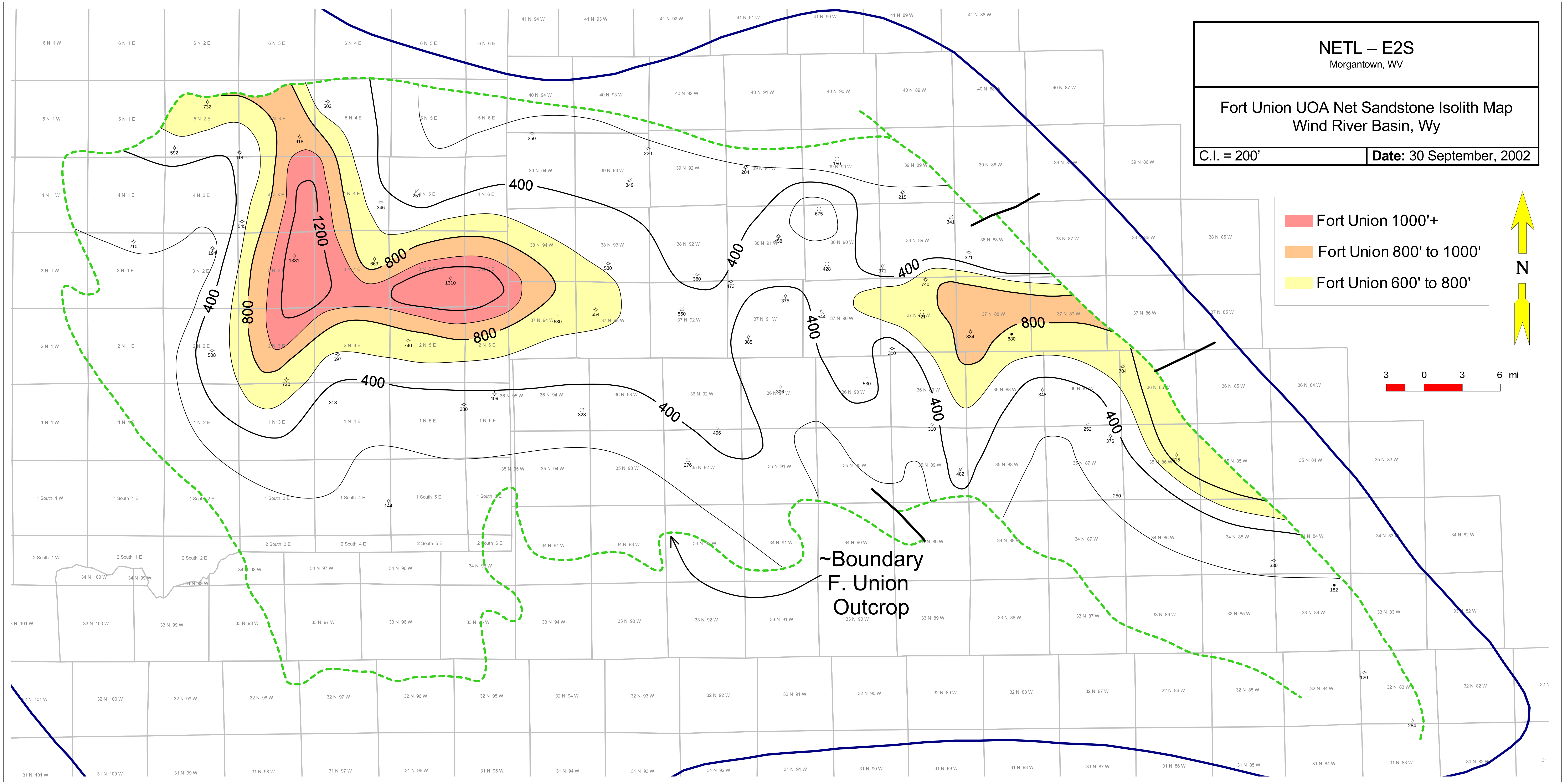
Wind River Basin Structural Cross Section - Vertical Exaggeration - 13x



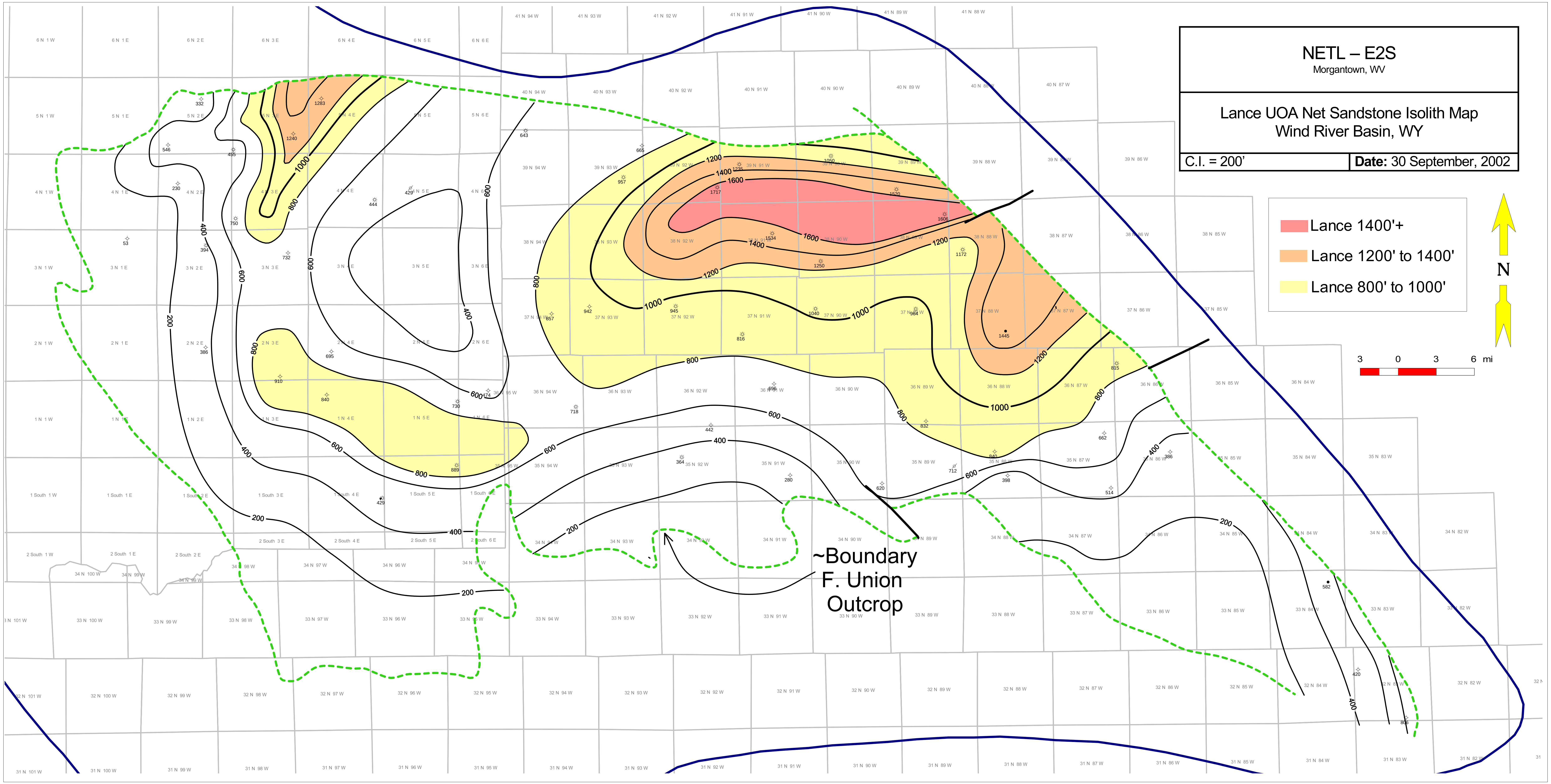

E
E'
Frontier UOA
Mowry
Muddy-Lakota UOA
Muddy Sandstone
Lakota Conglomerate
Nugget UOA
Nugget Sandstone
Dinwoody
Phosphoria
Tensleep UOA
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000


D
D'
1000
500
0
-500
-1000
-1500
-2000
-2500
F2
F3
F4
F5
F6
Frontier UOA
Mowry
Muddy-Lakota UOA
Muddy Sandstone
Dakota Sandstone
Lakota Conglomerate
Nugget UOA
Nugget Sandstone

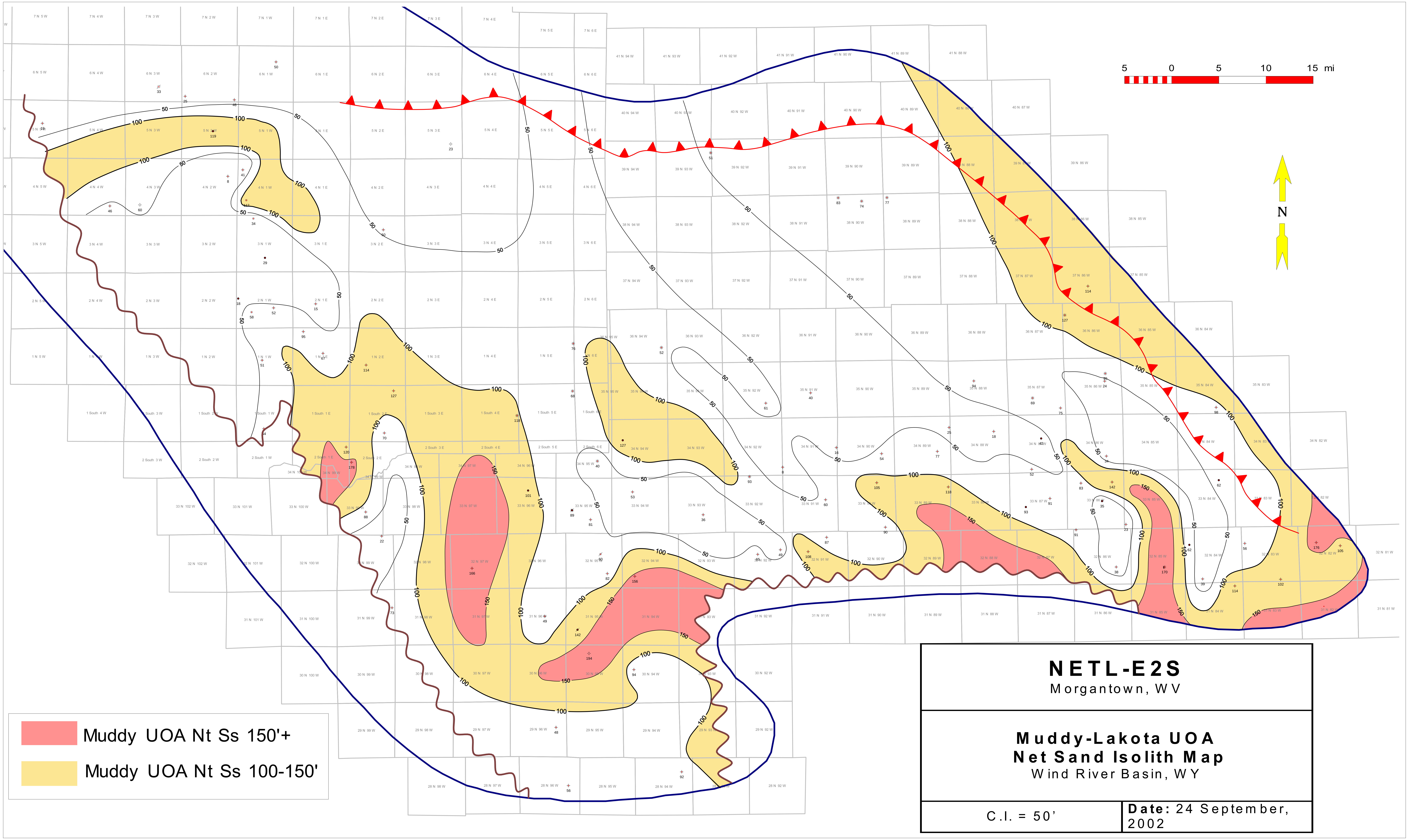

Trace of Overthrust Fault
5 0 5 10 15 mi
N
Frontier Nt Ss 250'+
Frontier Nt Ss 200-250'
Frontier Nt Ss 150-200'
NETL-E2S
Morgantown, WV
Frontier UOA Net Sand Isolith Map
Wind River Basin, WY
C.I. = 50'
Date: 26 September, 2002



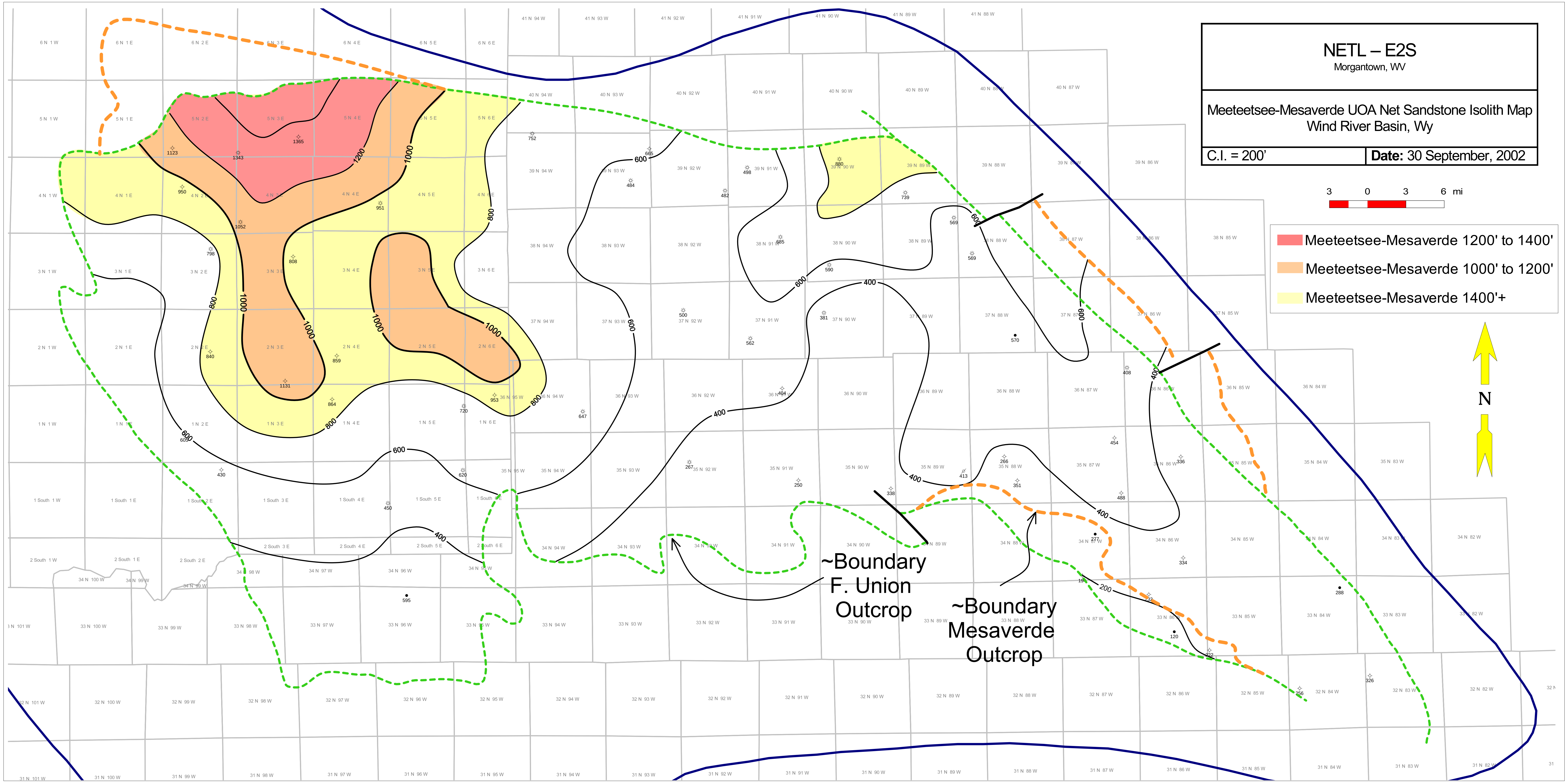
NETL – E2S
Morgantown, WV
Fort Union UOA Net Sandstone Isolith Map
Wind River Basin, Wy
C.I. = 200'
Date: 30 September, 2002
Fort Union 1000'+
Fort Union 800' to 1000'
Fort Union 600' to 800'
N
3 0 3 6 mi
400
800
1200
~Boundary
F. Union
Outcrop


NETL – E2S
Morgantown, WV
Lance UOA Net Sandstone Isolith Map
Wind River Basin, WY
C.I. = 200'
Date: 30 September, 2002
Lance 1400'+
Lance 1200' to 1400'
Lance 800' to 1000'
N
3 0 3 6 mi
~Boundary
F. Union
Outcrop

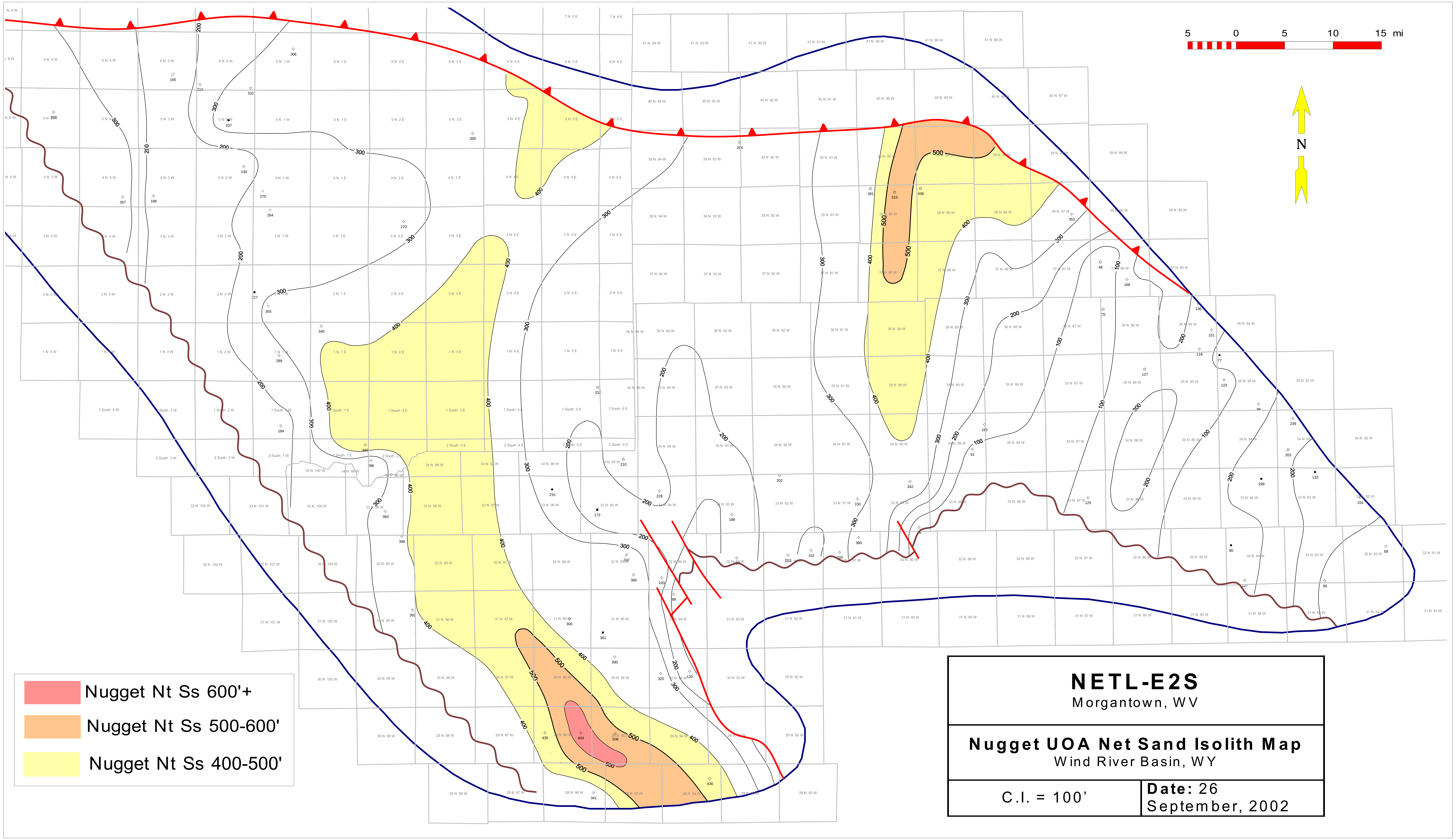
Click on cross section line to view that line of section



5 0 5 10 15 mi
N
Muddy UOA Nt Ss 150'+
Muddy UOA Nt Ss 100-150'
NETL-E2S
Morgantown, WV
Muddy-Lakota UOA
Net Sand Isolith Map
Wind River Basin, WY
C.I. = 50'
Date: 24 September, 2002



NETL – E2S
Morgantown, WV
Meeteetsee-Mesaverde UOA Net Sandstone Isolith Map
Wind River Basin, Wy
C.I. = 200'
Date: 30 September, 2002
3 0 3 6 mi
Meeteetsee-Mesaverde 1200' to 1400'
Meeteetsee-Mesaverde 1000' to 1200'
Meeteetsee-Mesaverde 1400'+
N
~Boundary
F. Union
Outcrop
~Boundary
Mesaverde
Outcrop



5 0 5 10 15 mi
N
Nugget Nt Ss 600'+
Nugget Nt Ss 500-600'
Nugget Nt Ss 400-500'
NETL-E2S
Morgantown, WV
Nugget UOA Net Sand Isolith Map
Wind River Basin, WY
C.I. = 100'
Date: 26 September, 2002

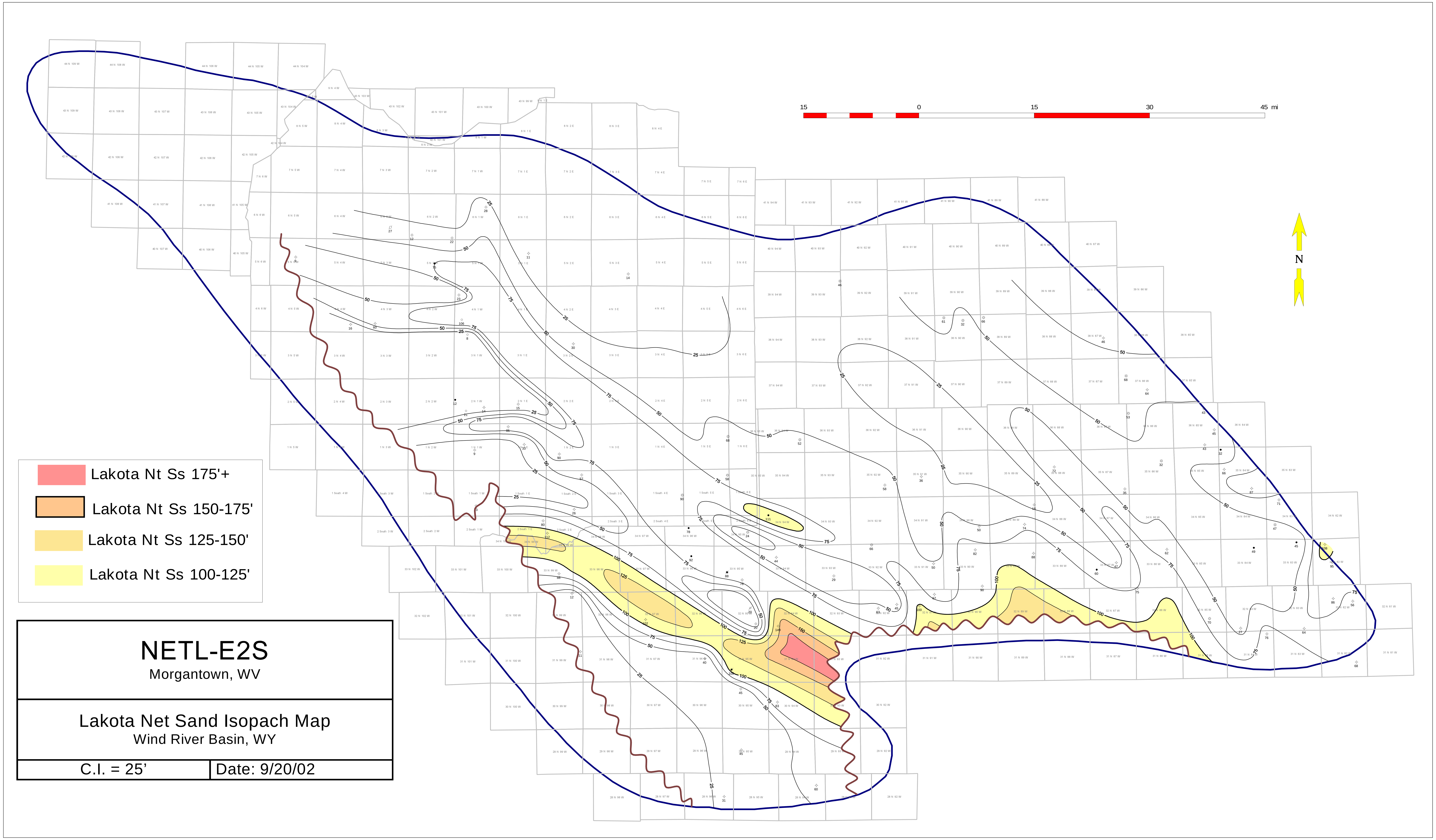
15 0 15 30 45 mi
Trace of Overthrust Fault
N
Frontier 1,2 Nt Ss 120'+
Frontier 1,2 Nt Ss 100-120'
Frontier 1,2 Nt Ss 80-100'
NETL-E2S
Morgantown, WV
Frontier 1-2 Net Sandstone Isopach Map
Wind River Basin, WY
C.I. = 20'
Date: 9/4/02

Trace of Overthrust Fault
15 0 15 30 45 mi
N
Frontier 3 Nt Ss 120'+
Frontier 3 Nt Ss 100-120'
Frontier 3 Nt Ss 80-100'
Frontier 3 Nt Ss 60-80'
NETL-E2S
Morgantown, WV
Frontier 3 Net Sand Isopach Map
Wind River Basin, WY
C.I. = 20'
Date: 9/3/02

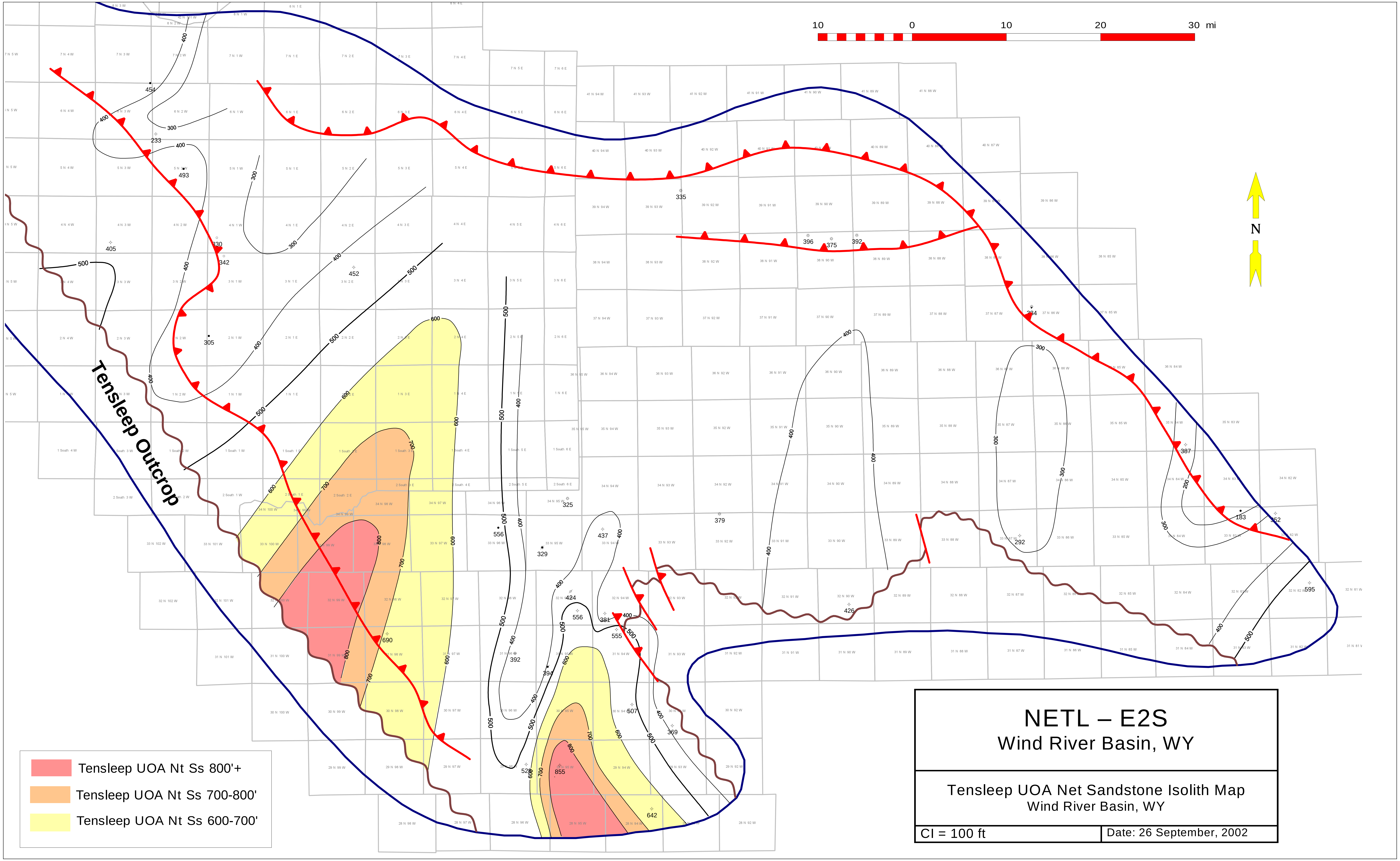

15
0
15
30
45 mi
N
Frontier 4 Nt Ss 120'+
Frontier 4 Nt Ss 100-120'
Frontier 4 Nt Ss 80-100'
NETL-E2S
Morgantown, WV
Frontier 4 Net Sand Isopach Map
Wind River Basin, WY
C.I. = 20'
Date: 9/3/02

15
0
15
30
45 mi
N
Trace of Overthrust Fault
Frontier 5 Nt Ss 125'+
Frontier 5 Nt Ss 100-125'
Frontier 5 Nt Ss 75-100'
NETL-E2S
Morgantown, WV
Frontier 5 Net Sand Isopach Map
Wind River Basin, WY
C.I. = 25'
Date: 9/3/02

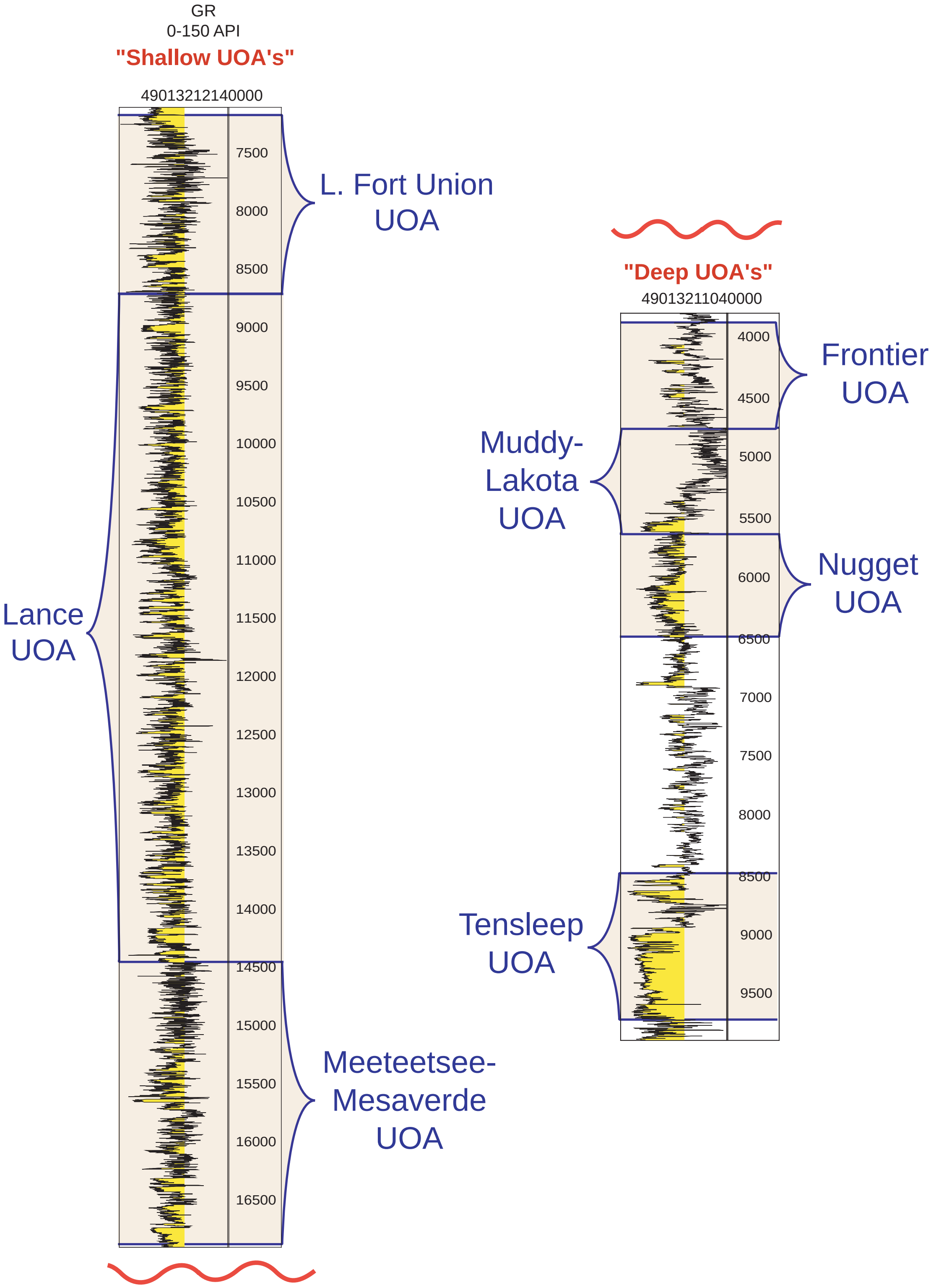

15 0 15 30 45 mi
N
Muddy Nt Ss 75'+
Muddy Nt Ss 50-75'
NETL-E2S
Morgantown, WV
Muddy Net Sand Isopach Map
Wind River Basin, WY
C.I. = 25'
Date: 9/5/02



15
0
15
30
45 mi
N
Lakota Nt Ss 175'+
Lakota Nt Ss 150-175'
Lakota Nt Ss 125-150'
Lakota Nt Ss 100-125'
NETL-E2S
Morgantown, WV
Lakota Net Sand Isopach Map
Wind River Basin, WY
C.I. = 25'
Date: 9/20/02

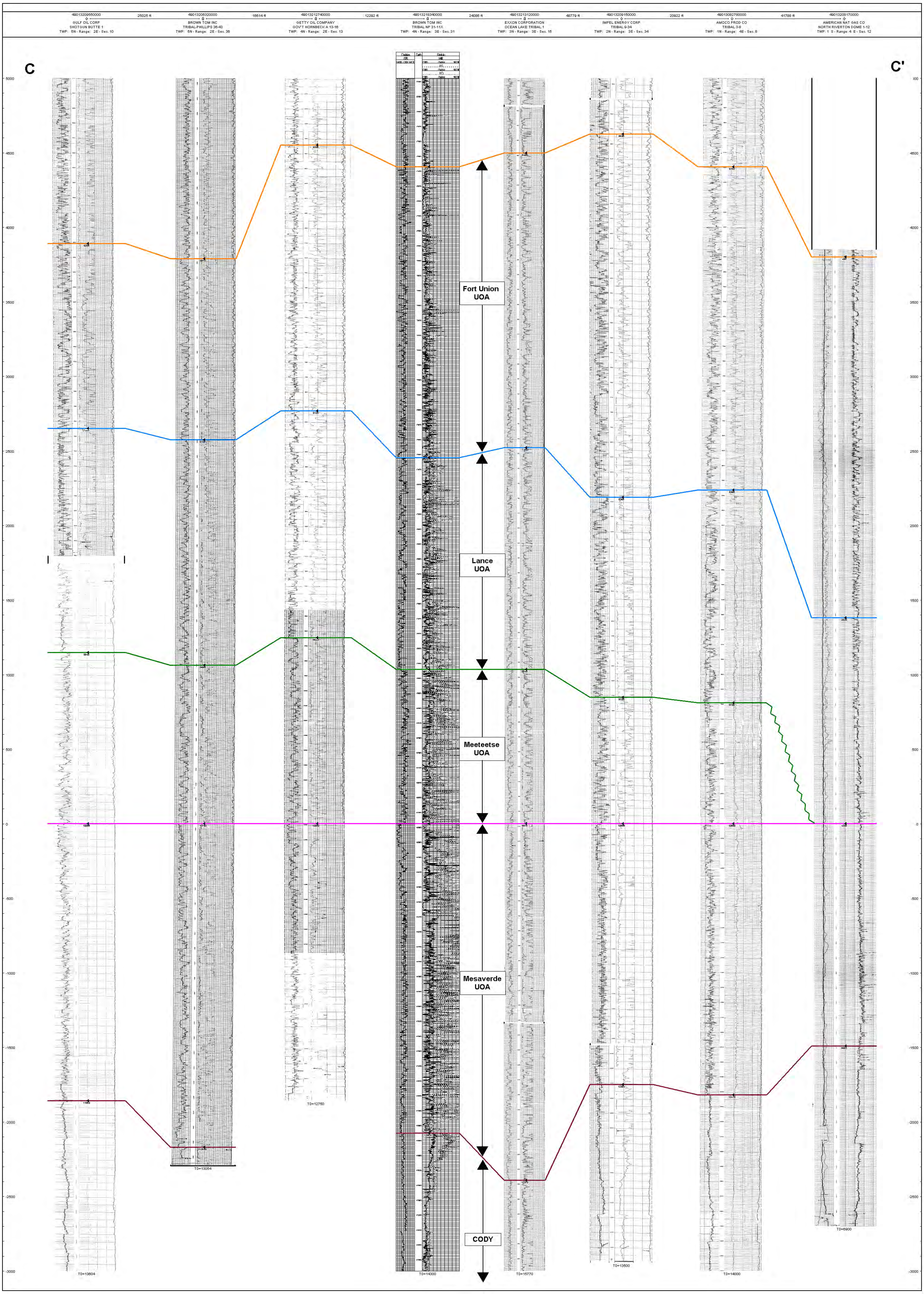

NETL – E2S
Wind River Basin, WY
Tensleep UOA Net Sandstone Isolith Map
Wind River Basin, WY
CI = 100 ft
Date: 26 September, 2002
Tensleep UOA Nt Ss 800'+
Tensleep UOA Nt Ss 700-800'
Tensleep UOA Nt Ss 600-700'
Tensleep Outcrop
N
10 0 10 20 30 mi

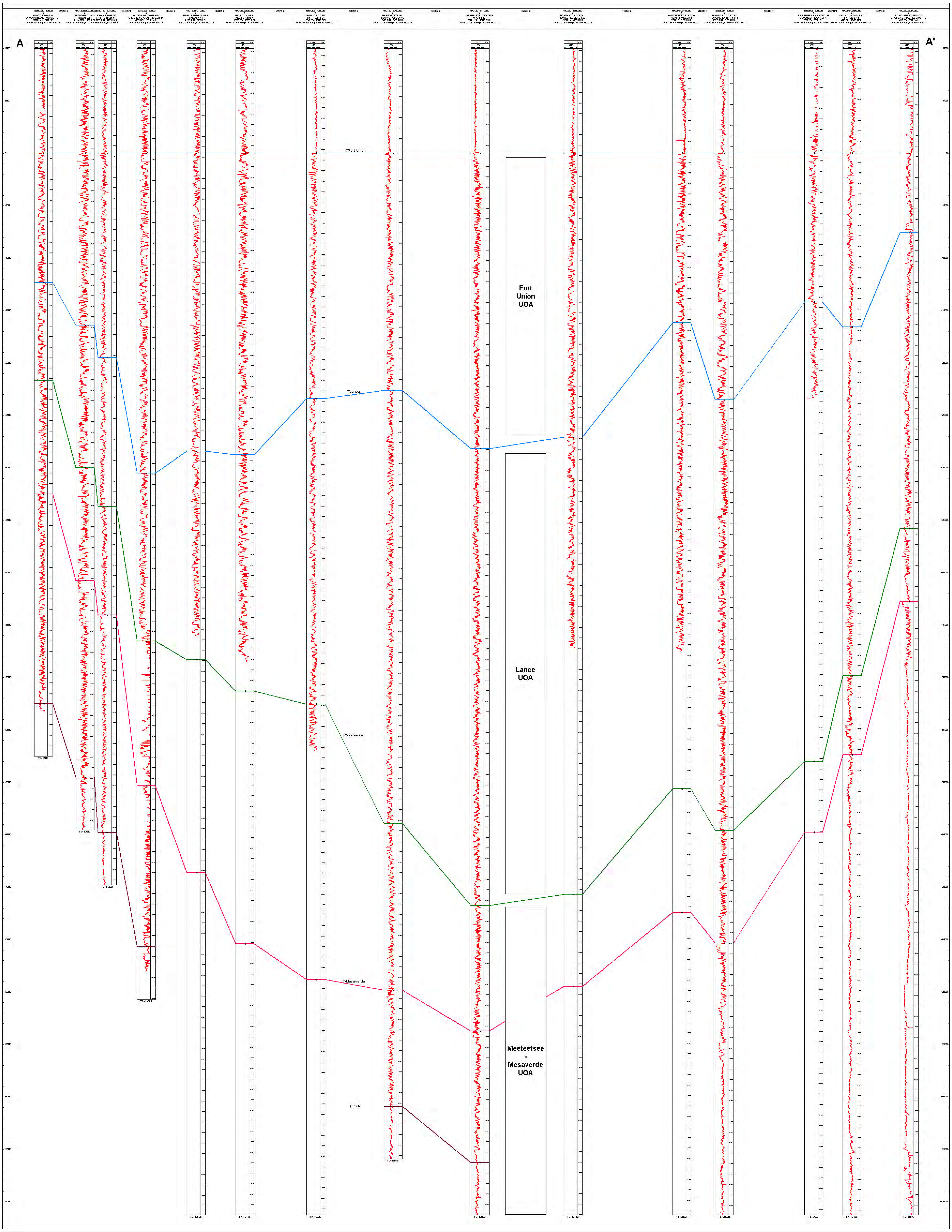
WRB - Type Log

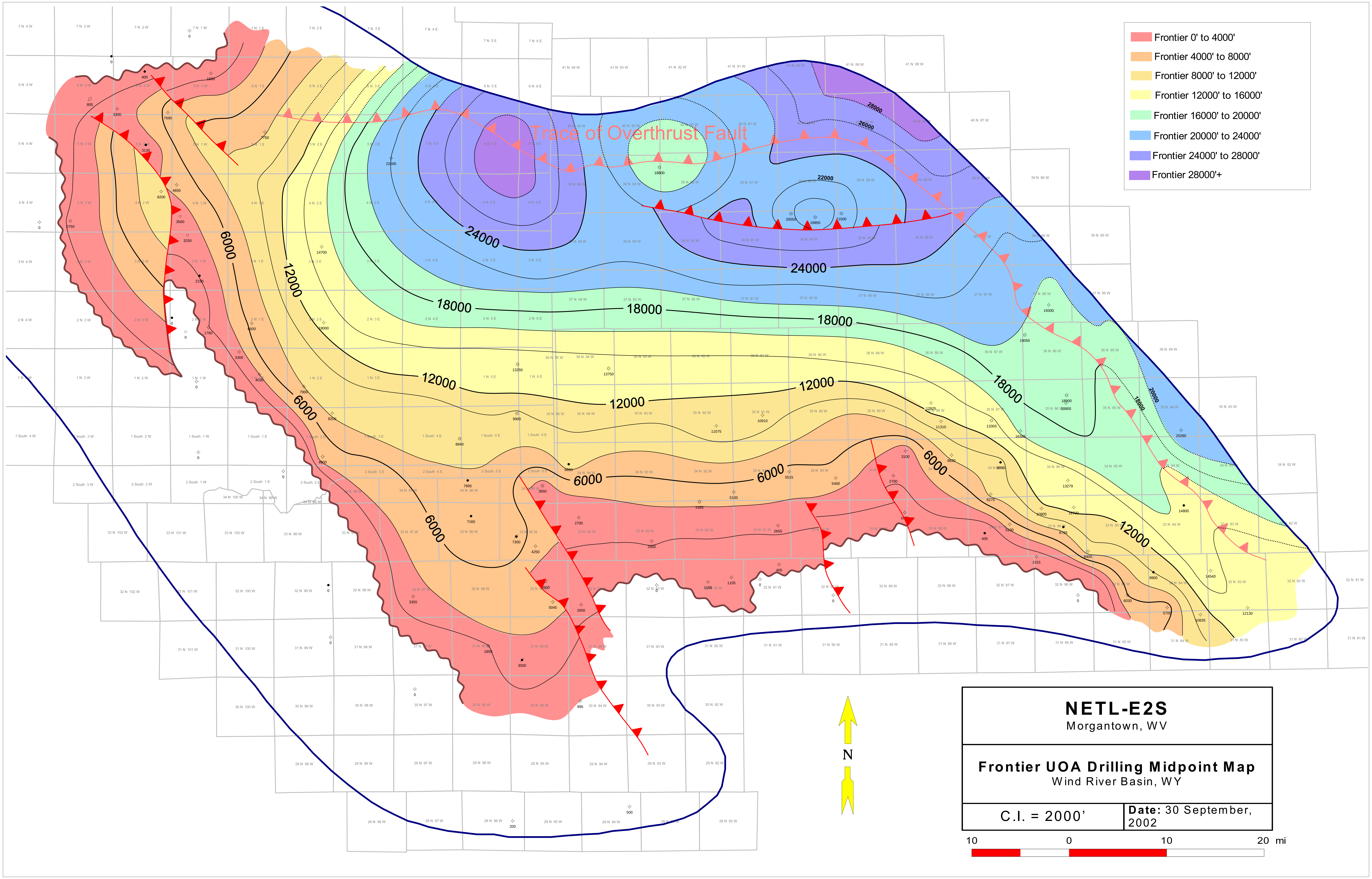


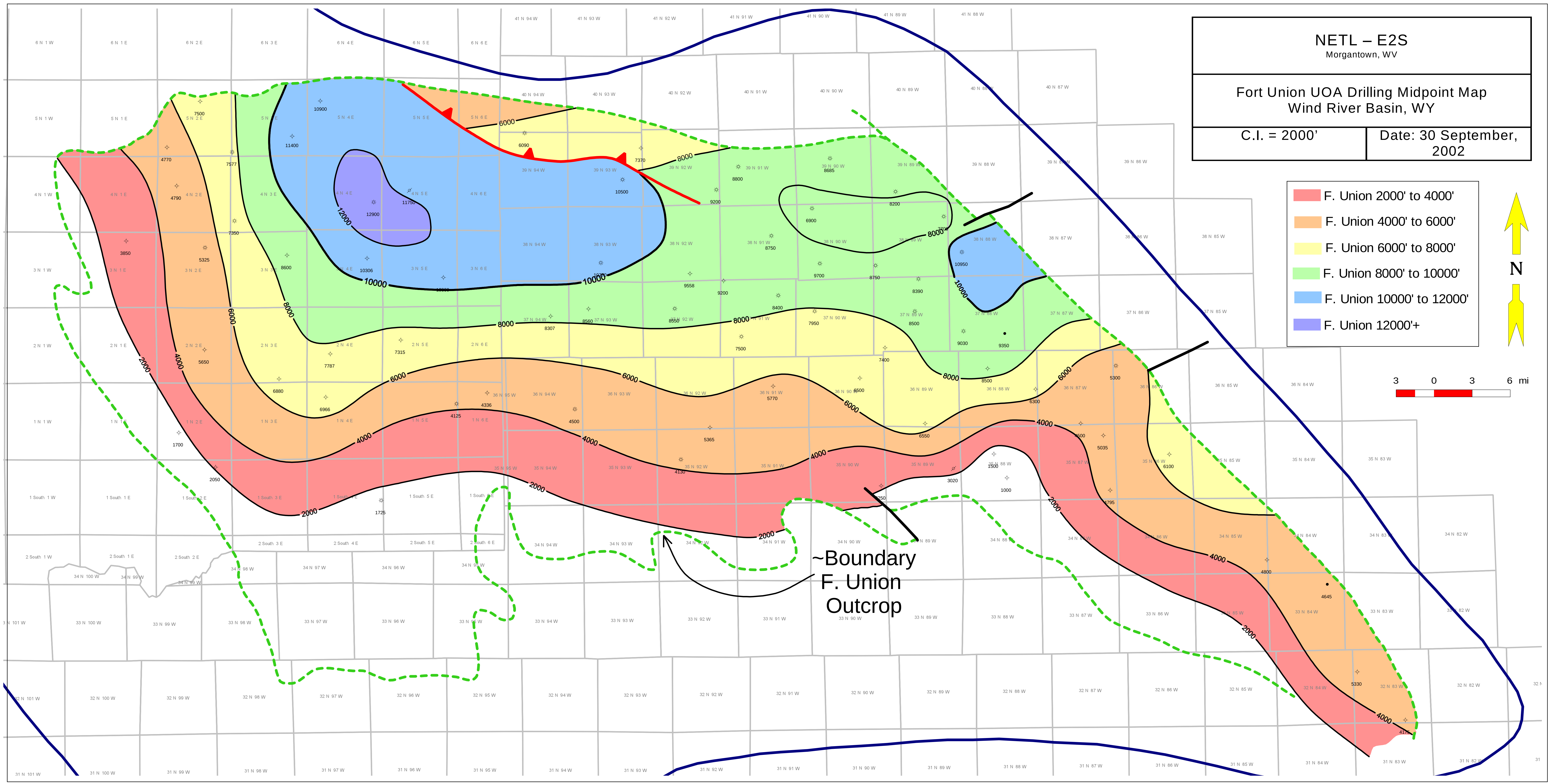
GR
0-150 API
"Shallow UOA's"
49013212140000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
14500
15000
15500
16000
16500
L. Fort Union UOA
Lance UOA
Meeteetsee-Mesaverde UOA
"Deep UOA's"
49013211040000
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
Frontier UOA
Muddy-Lakota UOA
Nugget UOA
Tensleep UOA

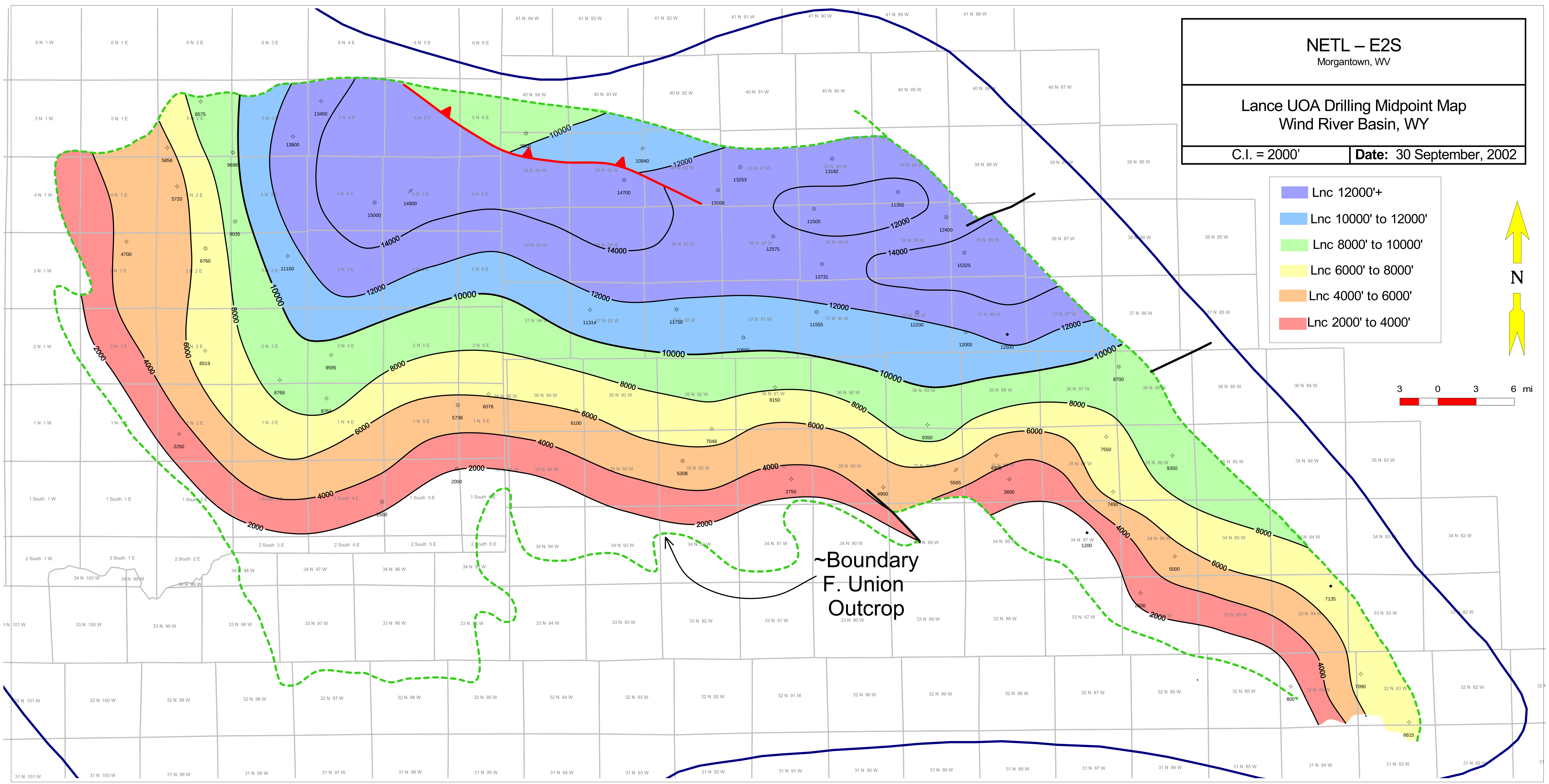

49013207630000
8300 ft
49013209840000
14873 ft
49013213620000
23238 ft
49013208490000
20036 ft
49013212140000
MONSANTO CO ETAL
STATE 1-16
TWP: 39 N - Range: 90 W - Sec. 16
MONSANTO CO ETAL
MEDIAN 1-21
TWP: 39N - Range: 90W - Sec. 21
MONSANTO OIL LTD
BIG HORN 1-5
TWP: 38 N - Range: 90 W - Sec. 5
COLUMBIA GAS DEV CRP
MONETA HILLS 1-29
TWP: 38N - Range: 90W - Sec. 29
ADAMS EXPLORATION
O A B 1-17
TWP: 37N - Range: 90W - Sec. 17
B
B'
11000
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Fort Union
UOA
Lance
UOA
Meeteetse
UOA
Mesaverde
UOA
CODY
TD=18891
TD=19484
TD=24877
TD=20590
TD=18839


49013209550000
GULF OIL CORP
SHOTGUN BUTTE 1
TWP: 5N - Range: 2E - Sec. 10
25025 ft
49013206320000
BROWN TOM INC
TRIBAL-PHILLIPS 36-43
TWP: 5N - Range: 2E - Sec. 36
16614 ft
49013212740000
GETTY OIL COMPANY
GOV'T HORNBECK A 13-16
TWP: 4N - Range: 2E - Sec. 13
12292 ft
49013218340000
BROWN TOM INC
TRIBAL NP 31-11X
TWP: 4N - Range: 3E - Sec. 31
24086 ft
49013213120000
EXXON CORPORATION
OCEAN LAKE TRIBAL 1
TWP: 3N - Range: 3E - Sec. 15
48779 ft
49013209150000
IMPEL ENERGY CORP
TRIBAL 9-34
TWP: 2N - Range: 3E - Sec. 34
20922 ft
49013082780000
AMOCO PROD CO
TRIBAL 3-8
TWP: 1N - Range: 4E - Sec. 8
41788 ft
49013208170000
AMERICAN NAT GAS CO
NORTH RIVERTON DOME 1-12
TWP: 1 S - Range: 4 E - Sec. 12
C
C'
Fort Union
UOA
Lance
UOA
Meeteetse
UOA
Mesaverde
UOA
CODY
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
TD=13604
TD=13054
TD=12750
TD=14000
TD=15770
TD=13500
TD=14000
TD=6900


A
A'
T/Fort Union
Fort
Union
UOA
T/Lance
Lance
UOA
T/Meeteetse
T/Mesaverde
Meeteetsee
-
Mesaverde
UOA
T/Cody


Frontier 0' to 4000'
Frontier 4000' to 8000'
Frontier 8000' to 12000'
Frontier 12000' to 16000'
Frontier 16000' to 20000'
Frontier 20000' to 24000'
Frontier 24000' to 28000'
Frontier 28000'+
Trace of Overthrust Fault
6000
12000
18000
24000
NETL-E2S
Morgantown, WV
Frontier UOA Drilling Midpoint Map
Wind River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
10 0 10 20 mi
N


NETL – E2S
Morgantown, WV
Fort Union UOA Drilling Midpoint Map
Wind River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
F. Union 2000' to 4000'
F. Union 4000' to 6000'
F. Union 6000' to 8000'
F. Union 8000' to 10000'
F. Union 10000' to 12000'
F. Union 12000'+
N
3 0 3 6 mi
~Boundary
F. Union
Outcrop


NETL – E2S
Morgantown, WV
Lance UOA Drilling Midpoint Map
Wind River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
Lnc 12000'+
Lnc 10000' to 12000'
Lnc 8000' to 10000'
Lnc 6000' to 8000'
Lnc 4000' to 6000'
Lnc 2000' to 4000'
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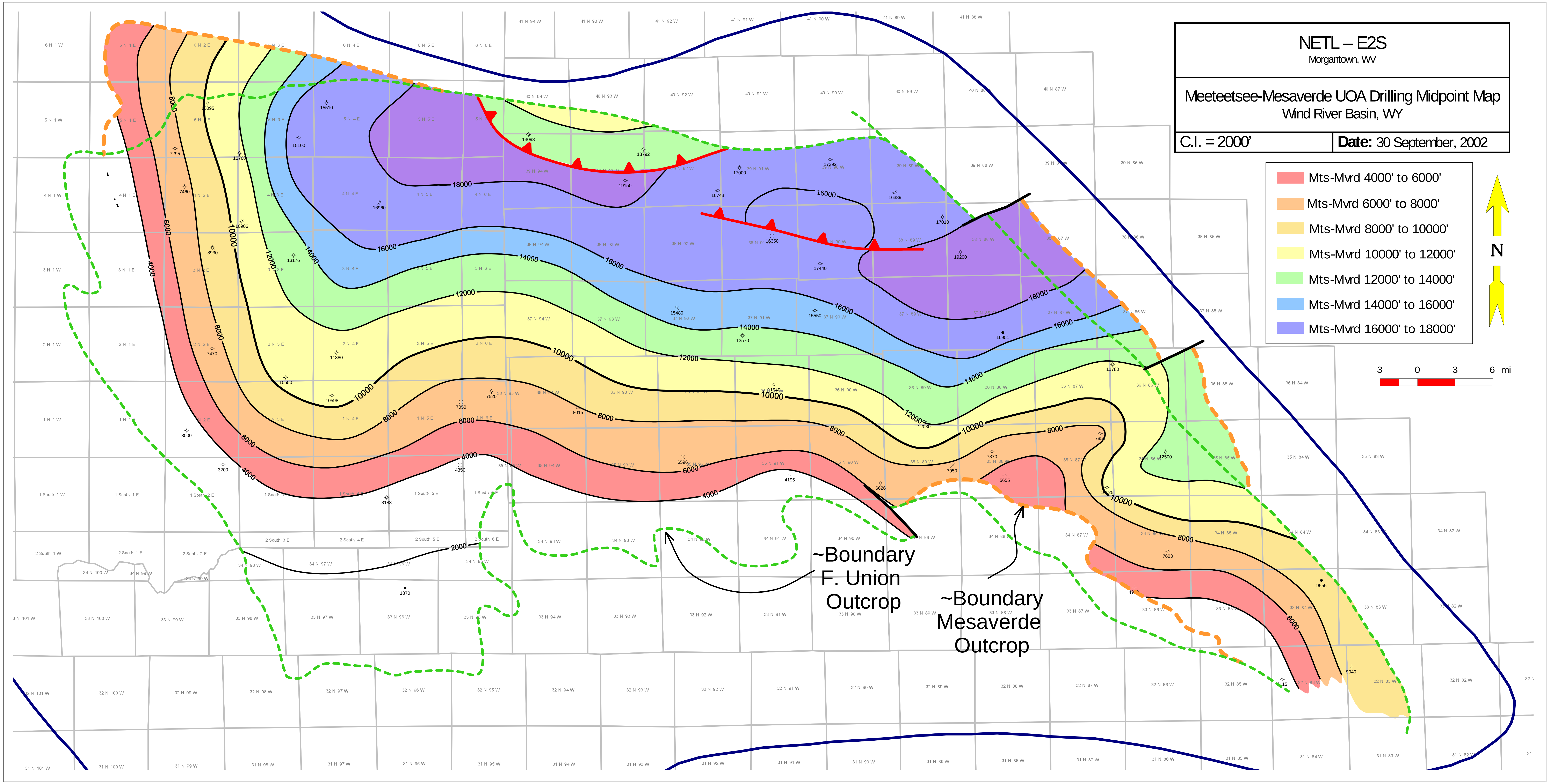
NETL – E2S
Morgantown, WV
Meeteetsee-Mesaverde UOA Drilling Midpoint Map
Wind River Basin, WY
C.I. = 2000'
Date: 30 September, 2002
Mts-Mvrd 4000' to 6000'
Mts-Mvrd 6000' to 8000'
Mts-Mvrd 8000' to 10000'
Mts-Mvrd 10000' to 12000'
Mts-Mvrd 12000' to 14000'
Mts-Mvrd 14000' to 16000'
Mts-Mvrd 16000' to 18000'
N
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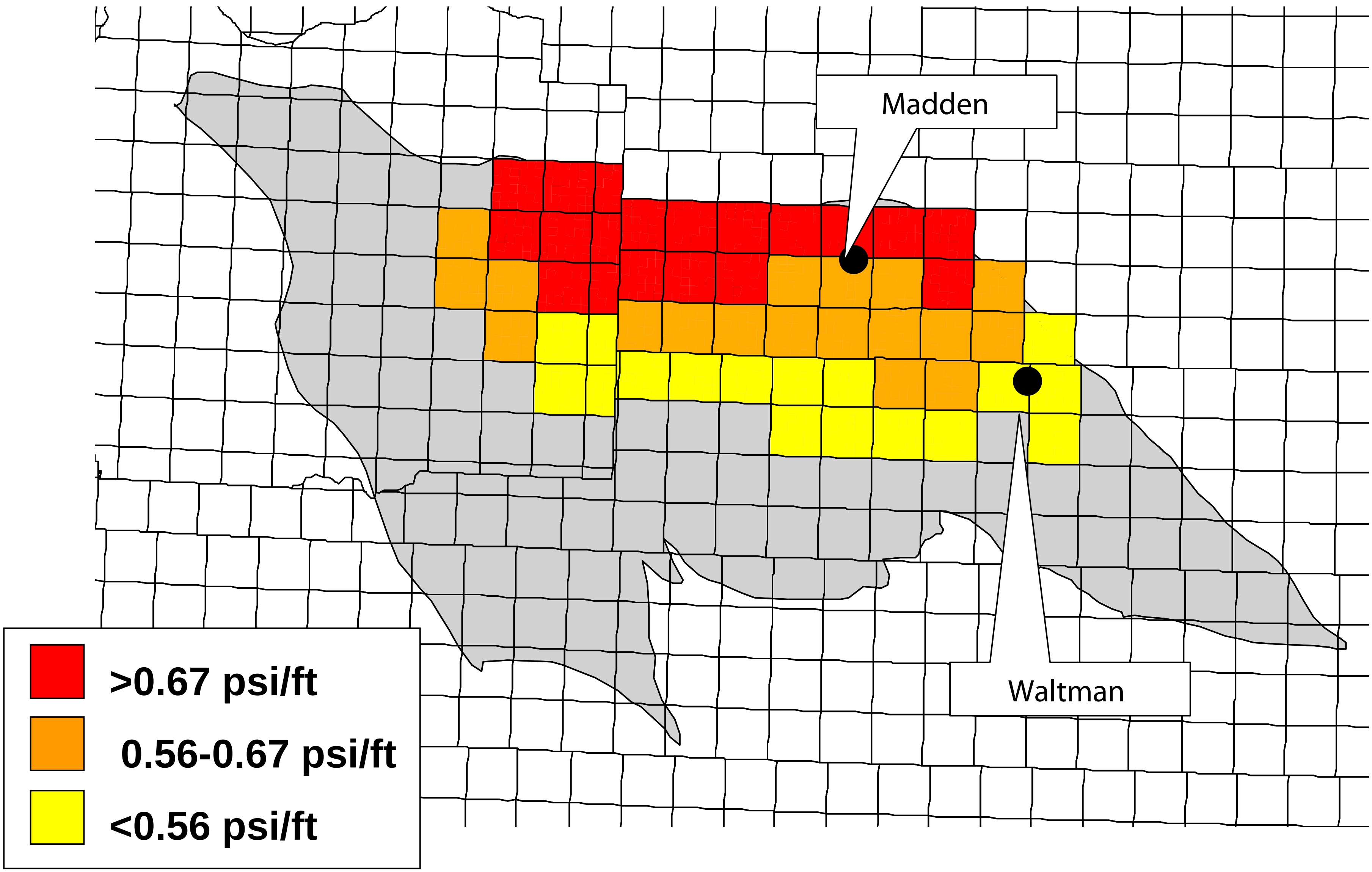
F. Union
Outcrop
~Boundary
Mesaverde
Outcrop

WRB Frontier Formation – Pressure Gradient Map



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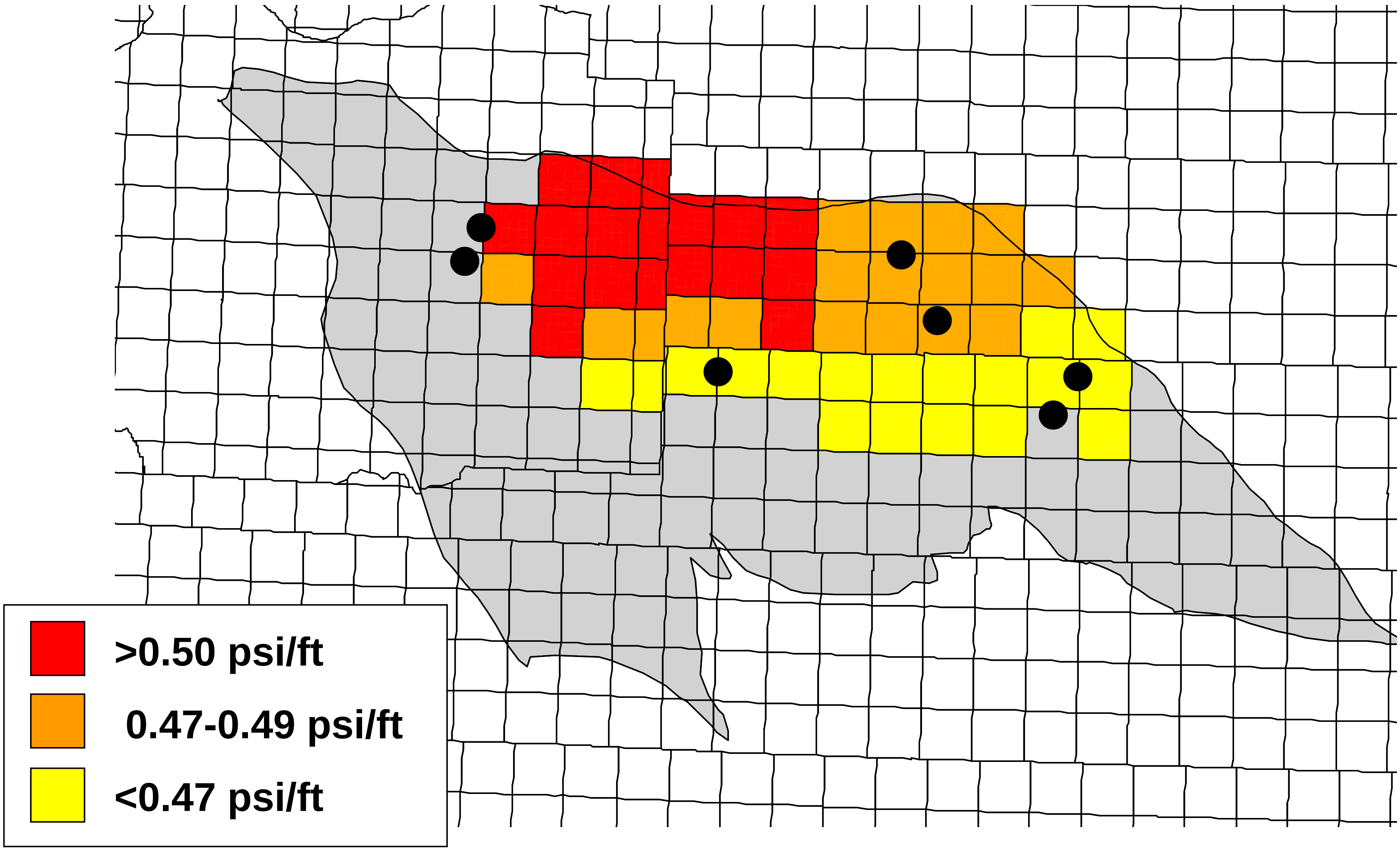
WRB Fort Union Formation – Pressure Gradient



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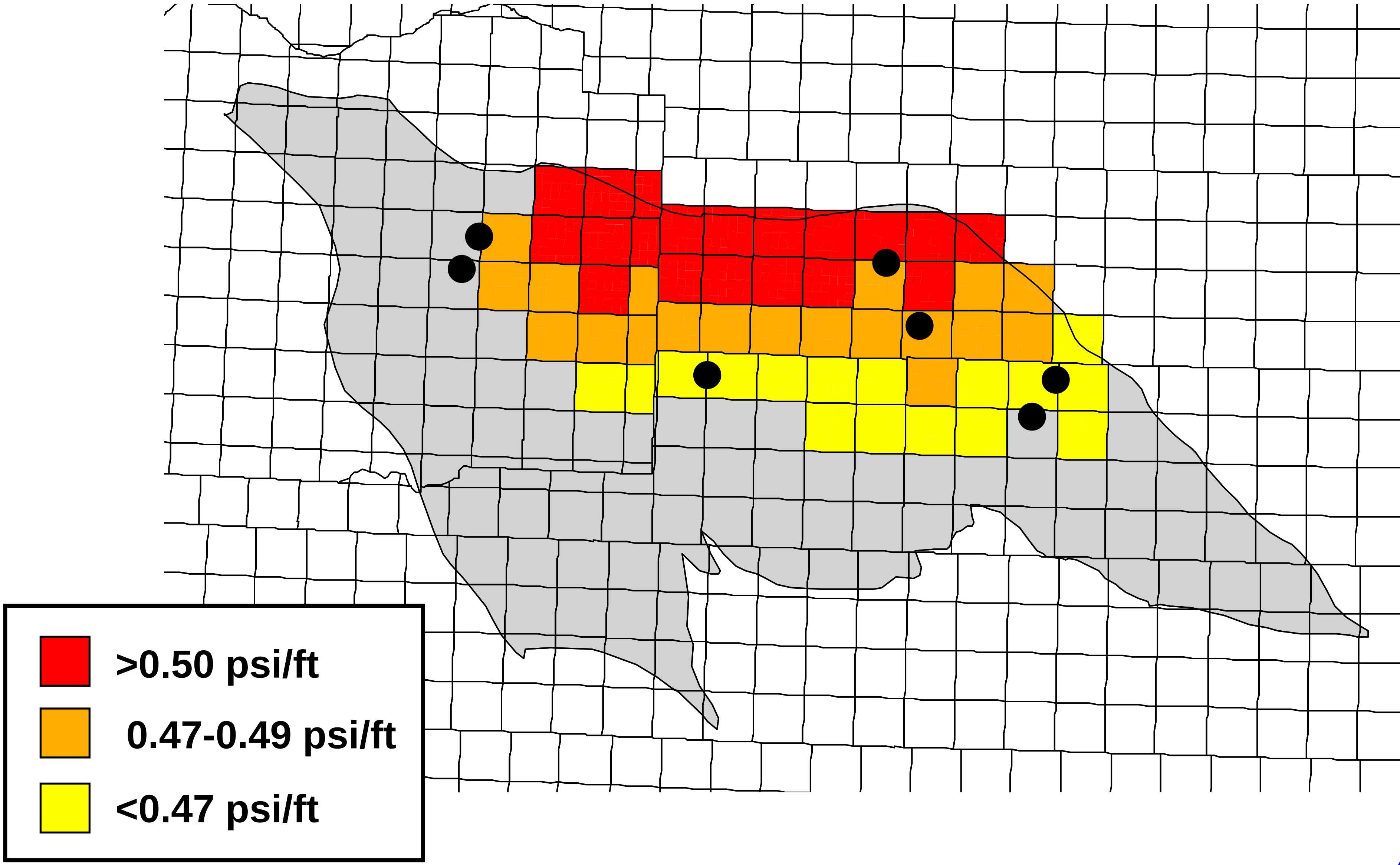
WRB Lance Formation – Pressure Gradient



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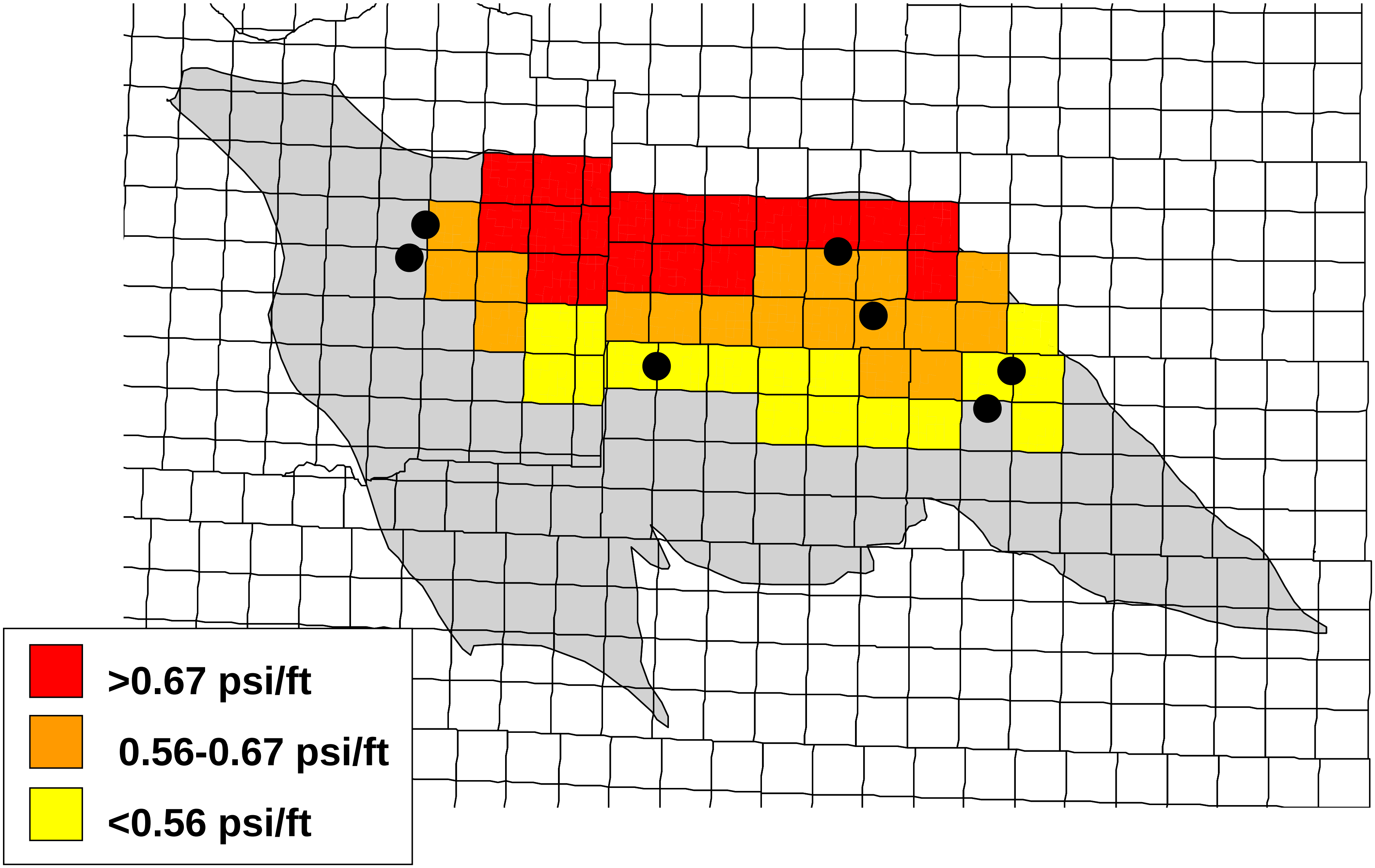
WRB Mesaverde Formation – Pressure Gradient Map



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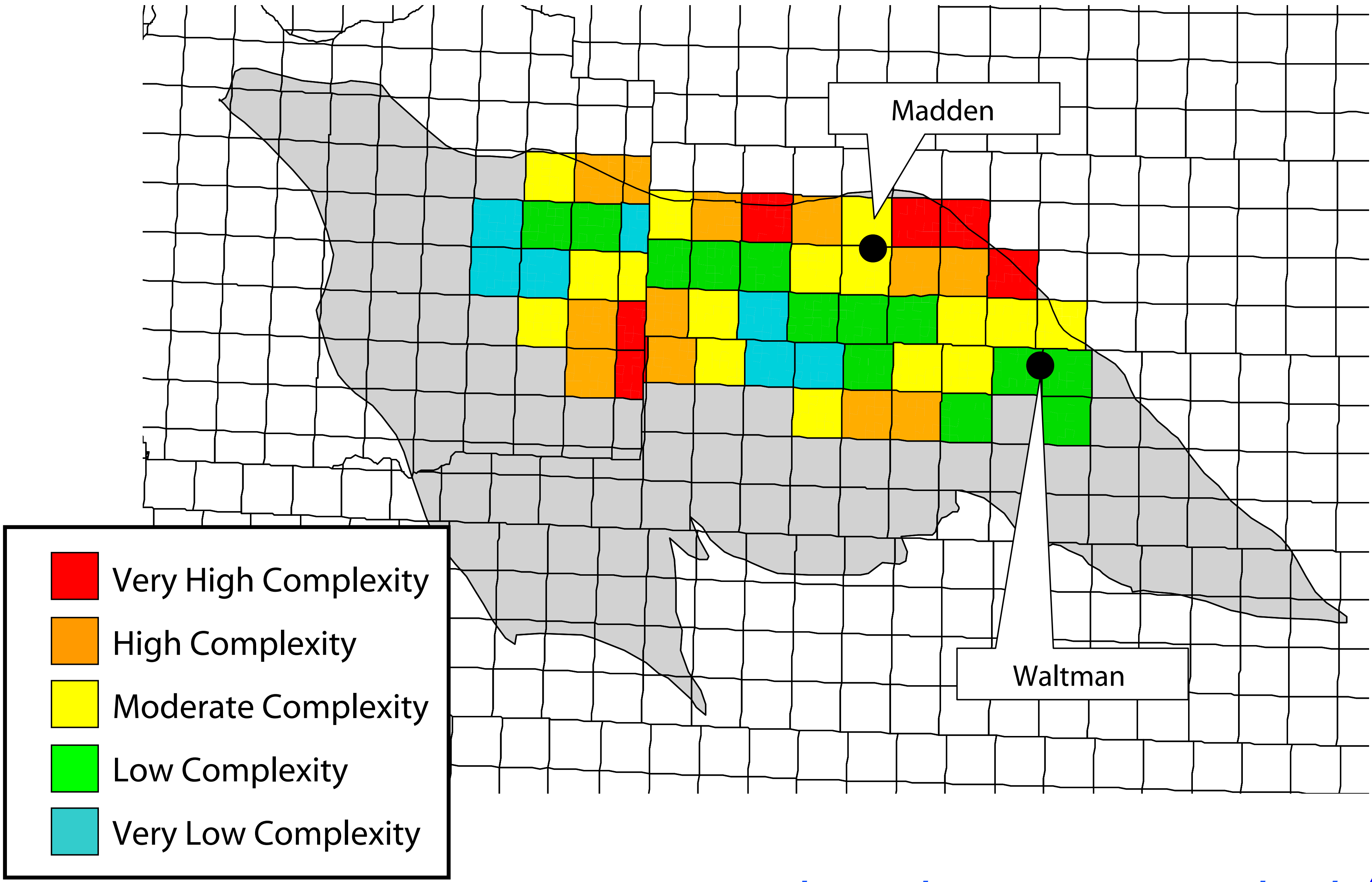
WRB Frontier Formation – Structural Complexity Map



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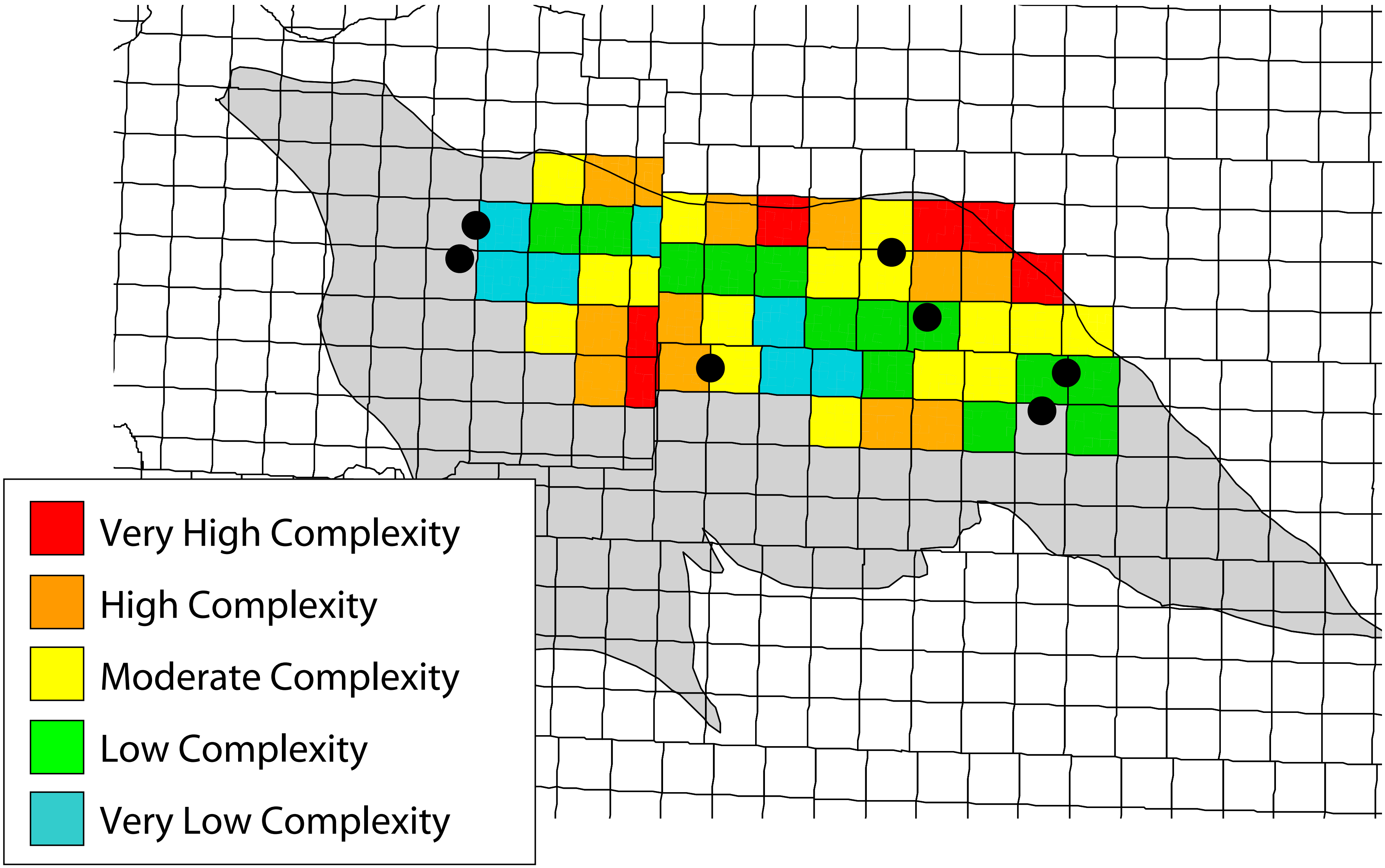
WRB Fort Union Formation – Structural Complexity



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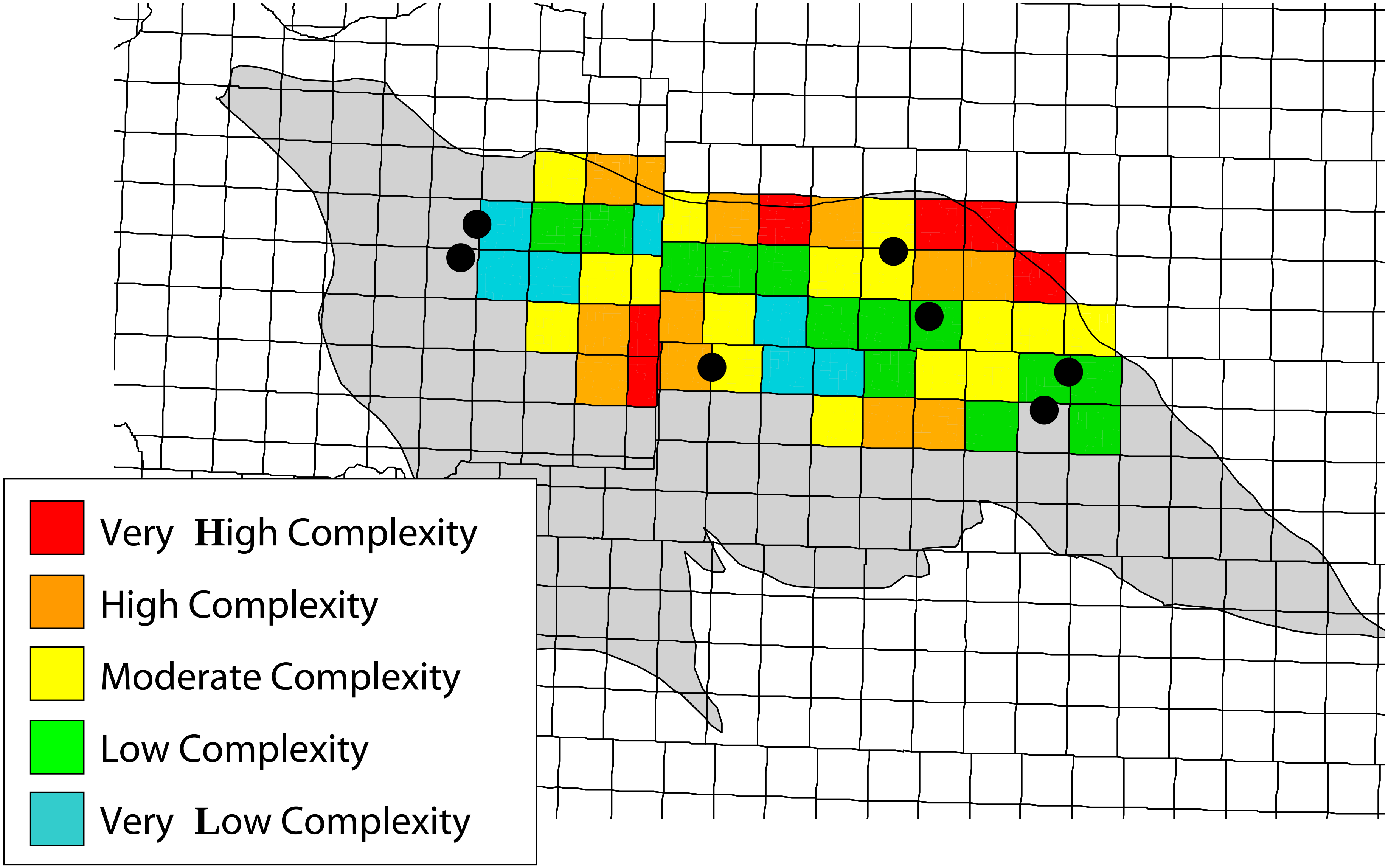
WRB Lance Formation – Structural Complexity Map



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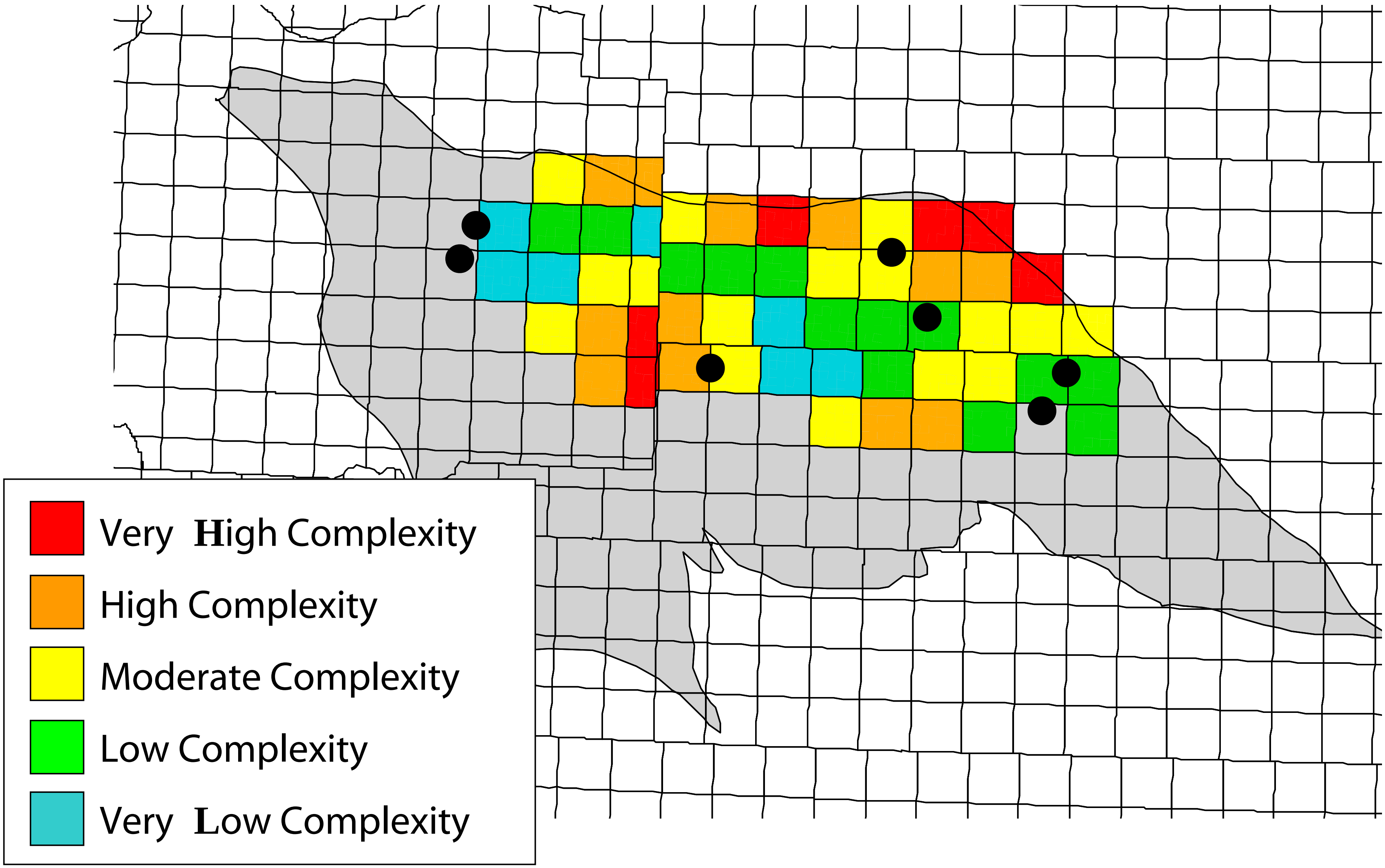
WRB Mesaverde Formation - Structural Complexity Map



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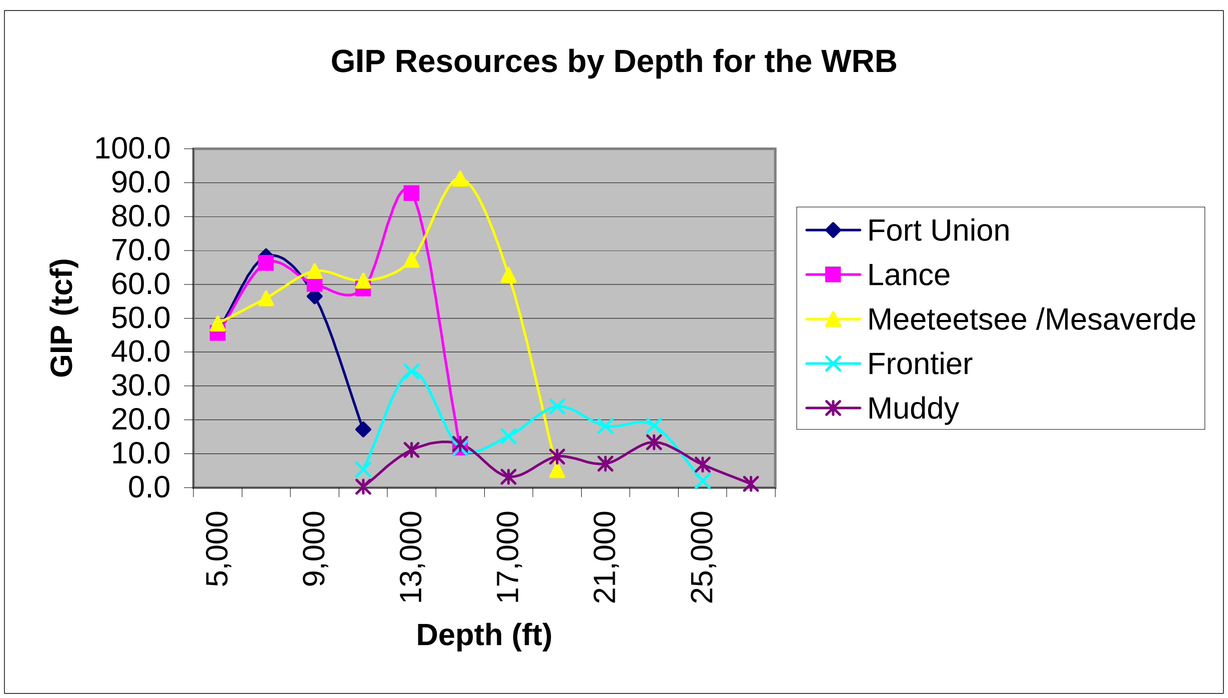
WRB - Summary

		Fort Union	Lance	Meeteetsee /Mesaverde	Frontier	Muddy
UOA Averages	Acreage	1,094,400	1,267,200	1,480,320	1,612,800	1,866,240
	Potential Pay (ft)	408	560	524	135	53
	Porosity (%)	10	9	8	6	6
	Sw (%)	56	50	42	41	35
	Drilling Depth (ft)	8,240	10,003	12,021	18,931	20,058
	Pressure (psi)	3,663	4,736	7,410	12,219	13,585
	Temperature (oF)	175	200	228	325	340
	Assigned Rw	0.445	0.217	0.16	0.48	0.5
	GIP (Tcf)	190.0	329.3	455.7	129.1	64.9
	GIP > 15,000' (Tcf)	0	11.8	159.2	89.3	53.8
	No. wells used	75	63	60	136	123
	No. full log suites	67	56	58	106	87
				GIP (Tcf)		
Gas Resource (Tcf) by 2000-ft Depth Range	5,000	46.2	45.6	48.4		
	7,000	68.3	66.3	55.9		
	9,000	56.5	60.1	63.9		
	11,000	17.2	58.7	61.1	5.4	0.3
	13,000		86.9	67.2	34.3	11.1
	15,000		11.8	91.2	11.7	12.9
	17,000			62.8	15.2	3.2
	19,000			5.2	24.0	9.2
	21,000				18.2	7.1
	23,000				18.3	13.4
	25,000				2.0	6.8
	27,000					1.1
	29,000					
	31,000					
	33,000					

Blue cells indicate depths where mostly oil is present

Grey cells indicate depth the formation is not present in the WRB



WRB - Fort Union

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	276480	46.2	440	10.8%	52%	5934	2519	172
7,000	374400	68.3	382	9.8%	56%	8104	3570	184
9,000	322560	56.5	418	8.8%	59%	9880	4463	172
11,000	12960	17.2	372	7.9%	57%	11449	5390	161
13,000	0	0	0	0	0	0	0	0
15,000	0	0	0	0	0	0	0	0
17,000	0	0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
33,000	0	0	0	0	0	0	0	0

WRB - Lance

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	230400	45.6	418	11.1%	47%	5935	2650	143
7,000	253440	66.3	493	9.9%	47%	7968	3645	172
9,000	224640	60.1	526	8.7%	46%	9923	4703	199
11,000	218880	58.7	644	7.8%	53%	12005	5791	228
13,000	293760	86.9	721	7.1%	58%	13674	6649	252
15,000	46080	11.8	578	6.9%	52%	15542	7464	278
17,000	0	0	0	0	0	0	0	0
19,000	0	0	0	0	0	0	0	0
21,000	0	0	0	0	0	0	0	0
23,000	0	0	0	0	0	0	0	0
25,000	0	0	0	0	0	0	0	0
27,000	0	0	0	0	0	0	0	0
29,000	0	0	0	0	0	0	0	0
31,000	0	0	0	0	0	0	0	0
33,000	0	0	0	0	0	0	0	0

WRB - Meeteetsee-Mesaverde

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)
5,000	213120	48.4	502	10.6%	44%	5968	2600	144
7,000	207360	55.9	486	9.5%	42%	7994	3873	172
9,000	207360	63.9	528	8.3%	40%	10113	5768	202
11,000	178560	61.1	498	7.3%	39%	12182	7569	231
13,000	172800	67.2	602	7.2%	41%	14104	9271	258
15,000	264960	91.2	544	6.8%	41%	16164	10919	285
17,000	224640	62.8	509	6.3%	48%	17604	11822	306
19,000	11520	5.2	510	6.2%	42%	19079	13306	327
21,000	0	0.0	0	0	0	0	0	0
23,000	0	0.0	0	0	0	0	0	0
25,000	0	0.0	0	0	0	0	0	0
27,000	0	0.0	0	0	0	0	0	0
29,000	0	0.0	0	0	0	0	0	0
31,000	0	0.0	0	0	0	0	0	0
33,000	0	0.0	0	0	0	0	0	0

WRB - Frontier

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)	
5,000	0	0	0	0	0	0	0	0	Hydrocarbons Most Likely Oil
7,000	0	0	0	0	0	0	0	0	
9,000	0	0	0	0	0	0	0	0	
11,000	0	0	0	0	0	0	0	0	
12,000	69120	5.4	128	8.1%	46%	12736	6774	238	
13,000	345600	34.3	127	9.0%	41%	14143	8224	258	
15,000	161280	11.7	119	7.0%	42%	15156	8959	272	
17,000	184320	15.2	140	6.4%	41%	18238	11795	314	
19,000	345600	24.0	112	5.7%	40%	19970	13018	338	
21,000	230400	18.2	170	4.6%	39%	22061	15009	369	
23,000	299520	18.3	151	4.0%	41%	23927	16382	395	
25,000	46080	2.0	121	3.7%	41%	25082	17058	411	
27,000	0	0	0	0	0	0	0	0	
29,000	0	0	0	0	0	0	0	0	
31,000	0	0	0	0	0	0	0	0	
33,000	0	0	0	0	0	0	0	0	

WRB - Muddy

DEPTH RANGE	TOTAL AREA (acres)	GAS-IN-PLACE (Tcf)	AVERAGE POTENTIAL PAY THICKNESS (Ft.)	AVERAGE POROSITY (%)	AVERAGE WATER SATURATION (%)	AVERAGE DRILLING DEPTH (Ft.)	AVERAGE PRESSURE (psi)	AVERAGE TEMPERATURE (oF)	
5,000	0	0	0	0	0	0	0	0	Hydrocarbons Most Likely Oil
7,000	0	0	0	0	0	0	0	0	
9,000	0	0	0	0	0	0	0	0	
11,000	0	0	0	0	0	0	0	0	
12,000	23040	0.3	24	7.5%	52%	12283	6456	232	
13,000	207360	11.1	68	8.4%	33%	14234	8420	259	
15,000	368640	12.9	45	6.9%	39%	15663	9698	280	
17,000	69120	3.2	59	7.2%	32%	18409	12876	318	
19,000	345600	9.2	43	5.8%	37%	19978	13993	339	
21,000	230400	7.1	53	5.0%	32%	22330	15552	372	
23,000	414720	13.4	57	5.3%	34%	24151	16994	397	
25,000	161280	6.8	58	4.0%	32%	25389	17801	415	
27,000	46080	1.1	54	4.0%	34%	28036	19617	453	
29,000	0	0	0	0	0	0	0	0	
31,000	0	0	0	0	0	0	0	0	
33,000	0	0	0	0	0	0	0	0	


Fort Union Unit of Analysis Boundary
Lance Unit of Analysis Boundary
Meeteetsee/ Mesaverde Unit of Analysis Boundary
Frontier Unit of Analysis Boundary
Muddy Unit of Analysis Boundary
Nugget Unit of Analysis Boundary
Tensleep Unit of Analysis Boundary
NETL-E2S
Morgantown, WV
Unit of Analysis Boundary Map
Wind River Basin, WY
Date:27 September, 2002
N
15 0 15 30 45 mi

Assessing the Technology Needs of Unconventional and Marginal Resources

Phase I: The Greater Green and Wind River basins

Prepared by

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Under US DOE Contract DE-AM26-99FT40575
Task No. 01NT20205

Prepared for

Jim Ammer
The Strategic Center for Natural Gas
National Energy Technology Laboratory
U.S. Department of Energy

October 31, 2002

Executive Summary

One of the most difficult challenges in designing a natural gas exploration and production research and development (R&D) program is quantifying the potential benefits associated with a particular suite of research projects. Understanding and estimating how the development of a new technology will affect the recovery of a particular segment of the nation's gas resource requires sophisticated computer models accessing a highly-detailed characterization of the resource. The better our models and characterizations become, the better our ability to relate specific technology advancements to specific quantities of new resources, increases in productivity, or reductions in operating costs. This ability is important when making decisions about how to spend research dollars, whether public or private.

The goal of the Department of Energy's natural gas program is to assure the long-term sustainability of affordable domestic natural gas supply through a steady expansion of the nation's economically-recoverable gas resource base. To do this, the National Energy Technology Laboratory's Strategic Center for Natural Gas implements a portfolio of R&D projects designed to enable and accelerate the transition of unconventional and marginal resources into recoverable resources, and ultimately, into reserves.

In response to recommendations presented by the National Petroleum Council in their 1999 report, *"Meeting the Challenges of the Nation's Growing Natural Gas Demand"* the National Energy Technology Laboratory has undertaken a coordinated program combining resource assessment, industry tracking, and technology modeling. The assessment work is unique in that it is focused primarily on resources that are currently sub-economic and unrecoverable and uses a log-based, gas-in-place approach with an unprecedented level of geographic and stratigraphic detail. Over ten thousand uniquely characterized cells that reflect the natural variety of key geologic and engineering parameters have been established.

The first phase of this effort has focused on the Greater Green River and Wind River basins of the Rocky Mountains. These basins contain the vast majority of the total low-permeability sandstone resource for the Rocky Mountain region based on a series of past gas-in-place resource assessments conducted for the Department of Energy by the United States Geological Survey (USGS).

Results from this current effort confirm past accounts of vast volumes of natural gas existing in these two basins. In the Greater Green River and Wind River basins, over 3,600 Trillion cubic feet (Tcf) and 1,100 Tcf of gas, respectively, was determined to be remaining in place. In light of these huge volumes, exploitation of these resources will require the development and application of advanced exploration, drilling, completion, stimulation, and production technologies in order to produce gas economically and at reasonable prices.

Using the nation's most sophisticated tool for modeling the impacts of technology on a national scale, the Gas Systems Analysis Model, analyses were conducted to estimate the amount of gas in place that is technically and economically recoverable with current technologies. Roughly 10% of the gas in place in the Greater Green River and Wind River basins (360 Tcf and 120 Tcf, respectively), was determined to be recoverable. GSAM's estimates significantly exceed those

of the USGS (2002) and other organizations, with the difference a result of alternative methodologies, assumptions, and geologic models designed to serve different purposes. USGS estimates are based on extrapolation of current conditions and serve as a basis for predicting the productivity that can expected from select resource elements. In contrast, GSAM estimates what could happen if the entire resource was fully developed using the most current technology as a baseline for identifying the most promising R&D avenues. When calculating a quantity as uncertain as undiscovered recoverable natural gas resource, such differences are to be expected and even encouraged, as they lead to further scientific investigation and interagency cooperation that increases the state of knowledge about our Nation's energy resources.

A key finding of this work is a documentation of the sensitivity of resource recoverability to both technology and price. Our preliminary findings indicate that roughly 11% of the technically recoverable resource is economically recoverable at $2.00/Mcf well head gas price; expanding to 28% economically recoverable at $3.50/Mcf price. Technology sensitivity analyses show that modest reductions in drilling costs or gains in recovery efficiency, which should be obtainable with continued advances in technology, lead to appreciable gains in the recoverable resource. With major technological advances, which could be obtained with an aggressive R&D program, significant amounts of gas in place could be added to the economically recoverable resource base.

This report's findings are also highly relevant to the issue of federal land use policy. Using information available from the Energy Policy and Conservation Act Interagency Team for the Greater Green River Basin, our analysis indicates that roughly 10 percent of the total gas-in-place is off limits for development due to federal land access restrictions. Timing restrictions that reduce the drilling window and could therefore increase drilling costs impact 45 percent of the total gas-in-place resource. Less than half (45%) of the gas in place in these basins is subject to standard lease terms.

This report provides critical data that will be used internally by Department of Energy planners to support project selection and other programmatic activities. History shows that Federal R&D has significant benefit in developing oil and gas in the U.S., especially those resources that are marginally economic. It is imperative that all stakeholders come together to formulate and implement environmentally sound and economically feasible development of this most important supply of clean burning, domestic energy. Phase 2 of this effort, which focuses on the Anadarko Basin in Oklahoma and the Uinta Basin in Utah, began in October, 2002.

1. Background

In 2001, the National Energy Technology Laboratory (NETL) launched a comprehensive program to assess the long-term sustainability of domestic natural gas supply in the United States. This effort has integrated pre-existing NETL activities of resource characterization and national modeling of natural gas exploration and production technologies to provide a better understanding of three key issues impacting long-term gas supply:

- The size and nature of underutilized gas resources that will be critical to future supply,
- The potential of technology to accelerate the conversion of "unrecoverable" and sub-economic resources into economically-recoverable resources, and
- The volume and nature of resources present on Federal Lands.

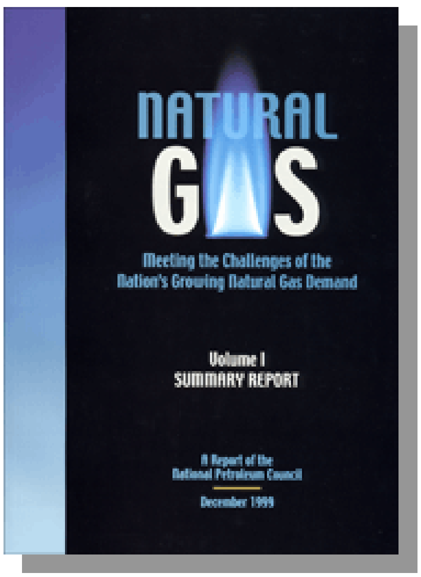

Figure 1: *The NPC's 1999 report is a major inspiration for this study*

This effort is largely in response to recommendations presented by the National Petroleum Council (NPC) in their 1999 report, *"Meeting the Challenges of the Nation's Growing Natural Gas Demand"*. The NPC's recommendations concerning gas supply include the following: 1) *"Establish a balanced, long-term approach to responsibly developing the nation's natural gas resource base"*, and, 2) *"Drive research and technology at a rapid pace"*. These recommendations specifically noted the benefits of 1) improved knowledge of the size and nature of the resource base, 2) an accurate inventory of resources in the Rocky Mountain region and the impact of federal land access restrictions on them, and 3) efforts to define and prioritize R&D opportunities that will expand the resource potential of both producing and unexplored areas. The NPC stated, *"Particular consideration should be given to long-term technology needs for ultra-deep water, low permeability, and non-conventional reservoirs that will contribute more of the nation's gas supply in the future."*

The U.S. Department of Energy shares NPC's view. Over the coming decades, the nation is counting on the expanded use of domestic natural gas to meet critical economic, environmental, and national security goals. Clearly, technology-driven resource expansion will be the key to ensuring adequate supplies of gas. This expansion will occur through both 1) incremental technology advance that steadily increases the recoverability of the known resource base, and 2) technological leaps forward that result in the addition of vast resources that were previously unknown, overlooked, or undervalued. For more information on the background for this effort, please visit our website at http://www.netl.doe.gov/scng/explore/resource/green-river.html.

Natural Gas Technology Modeling

In 1990, NETL commissioned the creation of the Gas Systems Analysis Model (GSAM – see separate GSAM Fact Sheet included on this CD). GSAM serves as a quick-turnaround tool for scoping the national gas production, transmission, and utilization system. Analyses conducted with GSAM provide high-level insight into the relative benefit of a large variety of alternative R&D and policy scenarios. Improvements in GSAM for this purpose are ongoing, including an effort to fully integrate GSAM with the DOE's similar model for oil, *TORIS*.

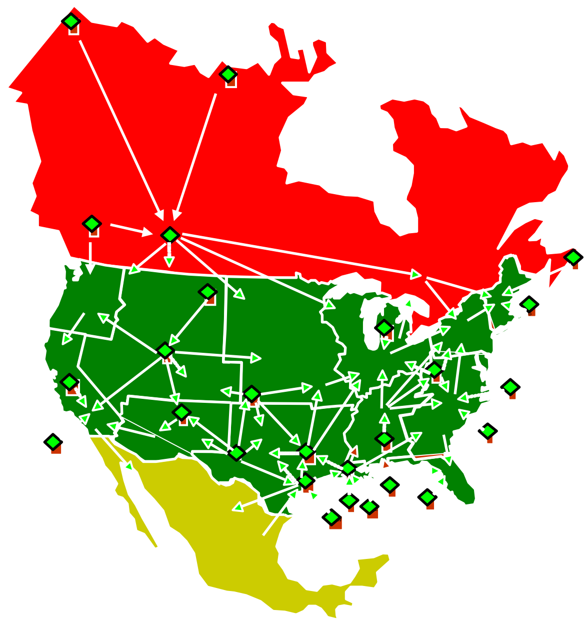

Figure 2: *NETL's Gas Systems Analysis Model (GSAM) models the supply and use of natural gas throughout North America. It is the nation's most sophisticated tool for modeling the impacts of technology.*

In assessing the priorities for its specific program in upstream natural gas exploration and production R&D, NETL is requiring GSAM to provide meaningful results at scales below the national level. Specific analyses of key regions and resource segments are increasingly needed. To meet this goal, the following capabilities are required:

- *Appropriate Modeling Logic and Algorithms*: Detailed analyses with GSAM require enhancements to the code to appropriately account for the circumstances particular to specific regions and resources; for example, the significant differences between conventional and unconventional accumulations or intra-regional variations in drilling costs

- *Appropriate Input Assumptions*. GSAM assesses resource productivity and economics relative to baseline assumptions on a variety of parameters, including drilling, completion, stimulation, and operating/maintenance costs, drilling and other infrastructure capacities, tax and royalty structures, current technical capacity, and others. These data need to capture a true picture of the current state of the industry.

- *Appropriate Resource Characterization*: The model must work with the best possible description of the nation's resources. Specifically, and in relation to the scale of the analysis being attempted, the database must…

    ✓ *Be detailed.* Increased disaggregation of the resource into a larger number of uniquely-defined segments will allow GSAM to more sensitively probe the "response" of the resource to alternative, individual R&D cases. In addition, detailed geographic disaggregation of the resource will provide an improved means to assess the impact of various federal land access stipulations, pipeline availability, and environmental policies on future supplies.

- ✓ *Be comprehensive*. The dataset must include as much of the total resource as possible. It is not appropriate to model the role of technology using datasets that already assume a certain level of technological progress. For example, a dataset for unconventional resources built around estimates of the present technically-recoverable portion will dismiss the vast bulk of the total resource out-of-hand and in particular, the very resources that aggressive R&D programs will target.

- ✓ *Address Reservoir Producibility*. To estimate the recoverability and economics of resources under a variety of future cost/technology scenarios, the model's dataset must contain estimates of permeability.

An Integrated Approach

Based upon review of its modeling needs and current modeling capacity, NETL has determined that significant improvements in both the models and the data feeding the models are warranted and could best be accomplished through the full integration of two long-standing NETL activities: resource-reserve assessment and national modeling of E&P technologies. Integration of these efforts will ensure that data is collected with the needs of the models in mind and that the models are configured to appropriately treat resource elements of particular interest. The remainder of this report describes NETL's efforts to improve its modeling databases through the direct analyses of geologic data in high-priority regions. In addition, a new activity in industry technology tracking has been initiated as a means of providing ground truth to many of the assumptions on technology utilization and impact that are incorporated into modeling base cases.

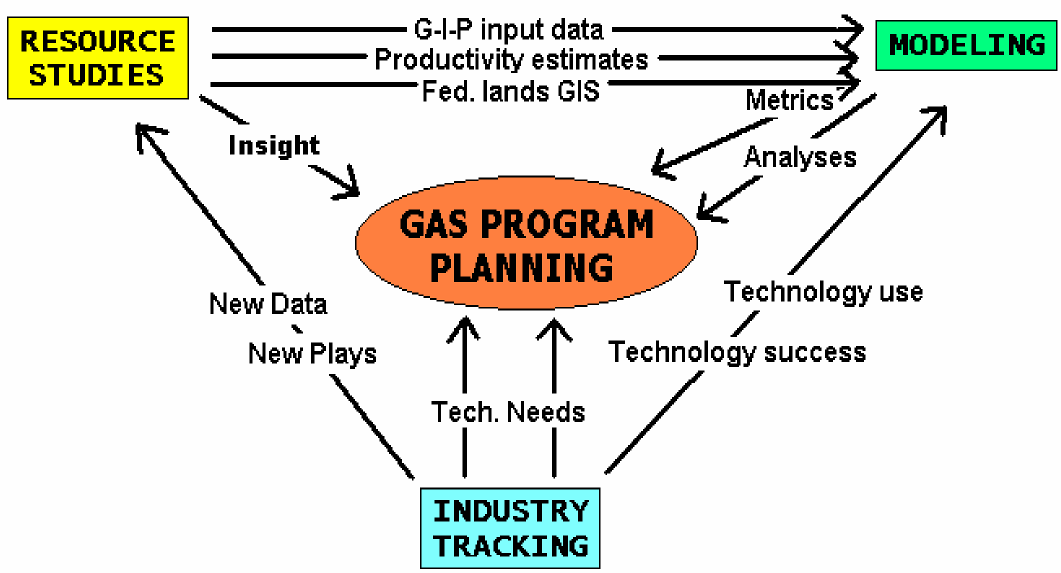

Figure 3: *Schematic of SCNG's integrated approach for planning natural gas R&D to meet the challenge of sustaining long-term domestic gas supply. This new integrated program is designed to assure that NETLs models have appropriate input datasets and logic to allow confident modeling of the role and impact of advanced technologies.*

Selection of Study Areas

The initial studies in this effort focus on deep, unconventional resources in the Rocky Mountain region. This focus is based on the understanding that gas resources in the Rockies are 1) enormous and 2) located almost exclusively on federal lands, and is responsive to the NPC's specific recommendation that the federal government work to assess the long-term natural gas supply potential of the Rocky Mountain region.

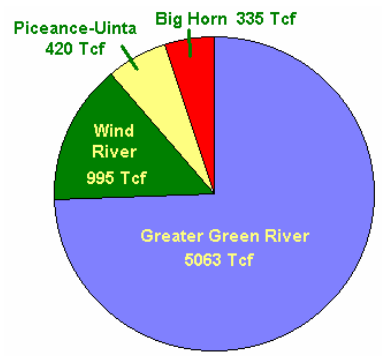

Figure 4: *Overview of the results of USGS gas-in-place assessments in four key Rocky Mountain basins.*

Within the Rockies, the Greater Green River and Wind River basins are selected as the targets for Phase I of this effort. This decision is based on several factors. First, based on a series of gas-in-place assessments conducted by the United States Geological Survey (USGS), these basins are expected to contain the vast majority of the total low-permeability gas resource for the Rocky Mountain region (Figure 4). Second, 15 years have passed since the USGS's landmark 1987 Greater Green River Basin gas-in-place study, providing ample new data. Third, the vast majority of the gas resources in these basins are currently not expected to be technically-recoverable given business-as-usual technology advances (Table 1). For example, as part of their 1995 National Assessment of the nation's technically-recoverable gas resources, the USGS assigned only 119 Tcf of resource to the low-permeability plays of the Greater Green River Basin. Low-permeability gas resources in the Wind River basin were not included in the National Assessment. Comparison of the National Assessment estimates to the separate gas-in-place estimates suggests that 98% of the gas believed to exist within these two basins, roughly 6,000 Tcf of gas, is either unassessed or deemed not "technically recoverable". This enormous untapped potential is one of the key targets of DOE R&D programs. If only 10% of this resource can be accessed, the resulting 600 Tcf of domestic gas supply would provide enormous benefits to the nation's economy, environment, and national security. However, to assess the nature and potential of new technological breakthroughs to expand access to this resource, we need to know as much as possible about the nature and conditions of *all* the resource present.

Table 1: *Overview of the results of USGS gas-in-place assessments in the Greater Green River and Wind River basins illustrating the vast resource currently deemed unrecoverable.*

Greater Green River Basin			Wind River Basin		
Play	*GIP ('89)*	*Tech. Rec. ('95)*	*Play*	*GIP ('96)*	*Tech. Rec. ('95)*
Ft. Union	96	1	Ft. Union	101	Not Assessed
Fox Hills/Lance	707	10	Lance	365	Not Assessed
Lewis	610	19	Meeteetsee	124	Not Assessed
Mesaverde	3,347	52	Mesaverde/Fales Ss.	203	Not Assessed
Frontier-Cloverly	304	37	Cody Sh.	51	Not Assessed
			Frontier	151	Not Assessed
Total	**5,064**	**119**	**Total**	**995**	Not Assessed

2. Project Methodology

The geologic analysis differs fundamentally from previous resource assessment work supported by NETL that were designed to quantify either 1) the gas-in-place with no regard to recoverability, or 2) the recoverable resource present under a single, given set of conditions. In contrast, this work attempts to produce a dataset from which recoverable resources can be reasonably appraised under a wide variety of as-yet-undefined future conditions. Consequently, this effort uses a log-based, gas-in-place approach with an unprecedented level of geographic and stratigraphic detail. Detailed disaggregation of the resource into thousands of uniquely characterized segments that reflect the natural variety in key geologic and engineering parameters is achieved through the analysis of hundreds of well log suites. Further specifics of methodology are provided in Figure 5 and below. A full archive of maps and cross-sections are available elsewhere on this CD.

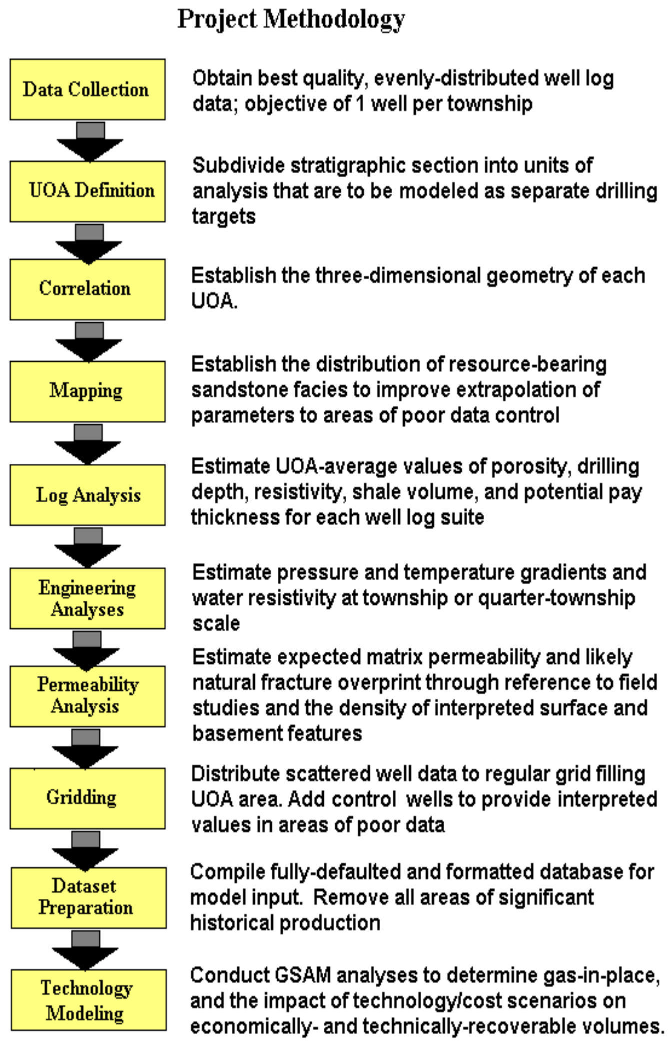

Figure 5: *Overview of project methodology.*

The Units of Analysis

The assessment of two basins, particularly two of the size of the GGRB and WRB, presented a significant challenge. Because these basins are large and contain thick, gas-charged, sedimentary sequences, the initial step was to determine which particular sections to study.

Based on the USGS's previous work, our study began with a review of the Cretaceous and older geologic section in both basins with the goal of identifying plays that 1) encompass the majority of each basin's underutilized resources, 2) are dominated by deep and/or unconventional accumulations that are the targets of DOE R&D programs, and 3) could be accomplished using a log-based methodology. This initial review settled on the following intervals of interest (Figure 6):

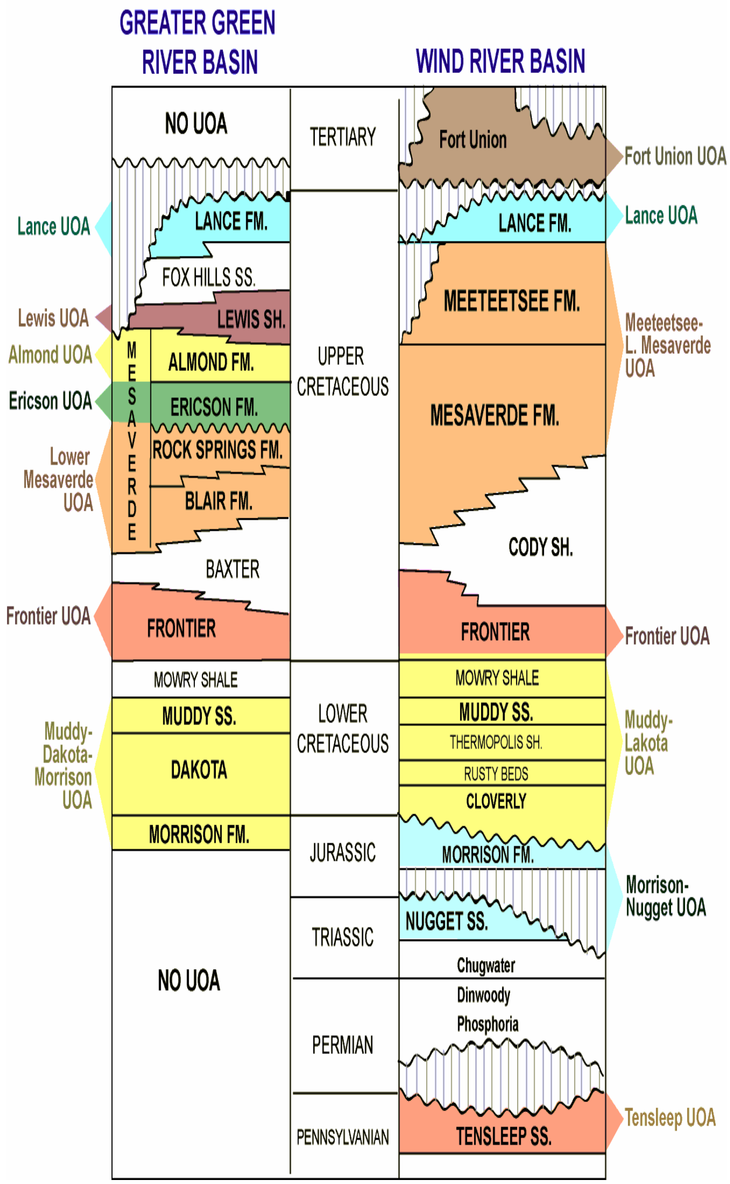

Figure 6: *Stratigraphic chart showing the subject intervals of the GGRB and WRB.*

- *Greater Green River Basin:* The entirety of the section from the top of the Lance formation to the base of sandstones within the Morrison Formation, excluding the Fox Hills sandstone and various stray sandstones within the Cody-Baxter-Hilliard-Steele shale.

- *Wind River Basin:* The entirety of the section from the top of the Lower Ft. Union formation to the Tensleep Sandstone, excluding sandstones within the Cody Shale and the interval from the base of the Nugget Sandstone to the top of the Tensleep.

With target sections established, the next step was to subdivide these intervals into "units of analysis" (UOAs); packets of resource, similar to the concept of a play, that exist in a common geologic condition. More specifically, each UOA is a package of resource that is most appropriate to characterize within the model as the target of individual wells. For example, we could not split apart units that are most likely to be ultimately completed together – doing so would require GSAM to burden each resource with the cost of individual wells. Similarly, we needed to avoid the lumping together of resources that will most likely be produced from separate boreholes. Otherwise, GSAM will calculate overoptimistic economics by assuming that the entire resource can be accessed for the cost of drilling a single well. The final Units of Analyses for the project are outlined in Figures 7 and 8 and described below.

- The *Lance UOA* is comprised of individual and amalgamated fluvial sandstones, and interbedded siltstones, shales and coals of the Lance formation. In the western GGRB where the Fox Hills-Lewis Shale sequences do not occur, the base of the Lance UOA coincides with the horizon equivalent to the point of maximum eastward transgression of the Lewis shale lithology (the top of the Almond UOA). In the central and eastern GGRB, the base of the

Lance UOA is picked at the top of the last coarsening upwards sandstone of the Fox Hills. Top of the Lance UOA was picked at the Cretaceous-Tertiary unconformity between the Lance Formation and Fort Union Formation throughout the GGRB. Given the similar depositional nature of these two continental-fluvial formations, published tops for the Lance formation were used as type sections, and for correlating throughout the GGRB.

- The *Lewis UOA* includes sandstones of two distinct types: 1) clean, coarsening-upwards sandstones interpreted as shallow-water delta-front deposits and 2) thick, vertically-stacked sequences of thinly-bedded and shale-rich sandstones interpreted to represent toe-of-slope turbidites. The shallower-water sandstones occur primarily in the Red Desert basin, but also elsewhere on the periphery of the Lewis Shale lithosome. These units represent extensions of the Fox Hills lithology that have been isolated within the Lewis Shale by significant subsequent transgression. Similar sandstones that are closely overlain by the lenticular sandstone and coal sequences of the Lance Formation are assigned to the Fox Hills Sandstone. Deep water Lewis sandstones are most common in the area between the Wamsutter and Cherokee arches.

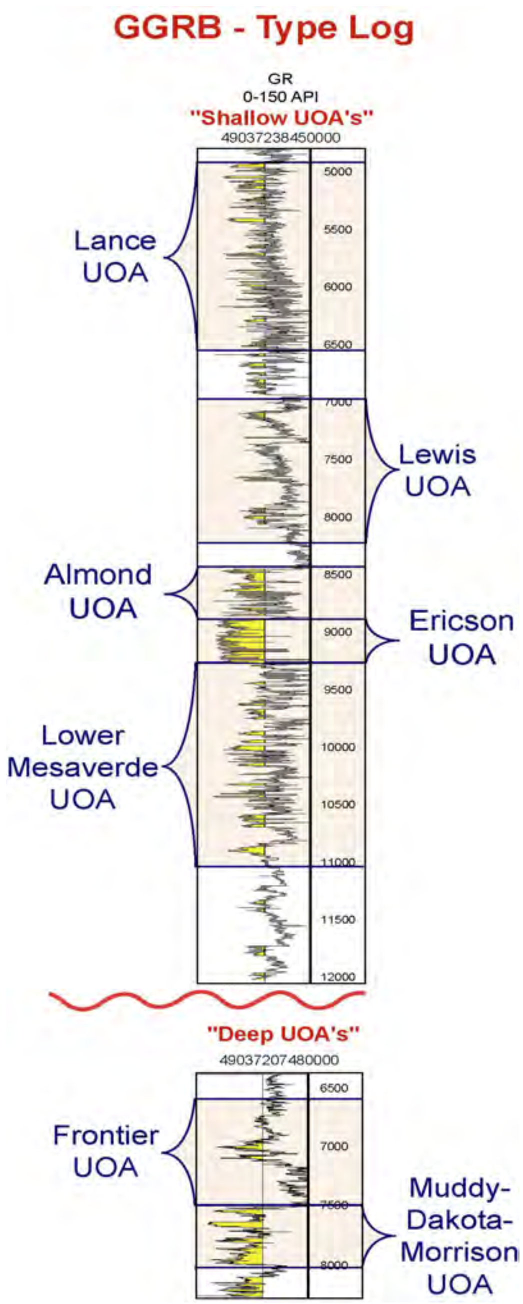

Figure 7: *Type log for the Greater Green River Basin showing UOAs*

In the past, the entirety of the Mesaverde interval has commonly been assessed together. This practice is not suitable because industry has not, and probably will not, target this entire interval with individual wells due to its large stratigraphic thickness. A review of industry practice in the basins east of the Rock Springs uplift indicated that the vast majority of Almond completions are from wells that drill no deeper than the Ericson, with the most of these terminating within the "Main" Almond section. As a result, the Mesaverde interval is divided into three UOAs that we designate as Almond, Ericson, and Lower Mesaverde.

- The *Almond UOA* includes sandstones of two distinct facies. First are the clean, blocky and coarsening-upwards sandstones (commonly referred to as "Upper Almond") marking the transgressive migration of shorelines westward at the top of the Mesaverde Group. Second are the subjacent thinly bedded and highly lenticular lower delta plain sandstones that are interbedded with coals and shales ("Main Almond"). The base of the Almond UOA is marked at the level where sandstones transition into the cleaner and more amalgamated sandstone facies typical of the Ericson UOA. The top of the Almond is clearly marked by the appearance of the Lewis Shale to the east of the Rock Springs Uplift. To the west of the Rock Springs Uplift, the top of the Almond is placed at the interpreted time-equivalent horizon with the maxima of eastward Lewis Shale migration.

- The *Ericson UOA* includes massive, quartz-rich (low radioactivity), and amalgamated fluvial sandstones (Ericson Formation) that commonly occur at the stratigraphic level of the maxima of Mesaverde progradation. The base of the Ericson UOA is clearly marked by the abrupt, commonly disconformable transition to the "dirty" sandstones, coals, and shales of the Lower Mesaverde UOA.

- The *Lower Mesaverde UOA* encompasses two distinct lithofacies. At the base are thick, coarsening-upwards sequences of sandstone (Blair Formation, etc.) associated with the eastward regression of Mesaverde environments into the Cretaceous Interior Seaway. Above is a thick section of highly-lenticular fluvial sandstones and shales of various formations (most notably the Rock Springs) within the sub-Ericson Mesaverde.

Similar to the Mesaverde units, the Frontier through Dakota interval has commonly been assessed previously as one unit. However, based on an analysis of industry drilling and completion practices in the 5 most heavily-drilled GGRB townships, operators have tended to complete either the Frontier or the Dakota individually. Multiple completions are relatively rare (Table 2). Consequently, separate UOAs for the Frontier sands and the deeper Muddy, Dakota, and Morrison sands were analyzed.

Table 2: *Historical drilling completion practices, per well, for the Frontier, Muddy, Dakota, and Morrison formations in the Greater Green River Basin. Townships selected based on number of wells drilled and completed.*

	Single Completions	Recompletions within 6 mos.	Recompletions at least 6 mos. apart	Total number of wells
T27 R113	140 (77%)	28 (16%)	13 (7%)	181
T21 R112	92 (94%)	6 (6%)	0	98
T20 R112	80 (65%)	18 (15%)	24 (20%)	122
T18 R112	65 (48%)	36 (26%)	35 (26%)	136
T23 R103	31 (57%)	17 (32%)	6 (11%)	54
AVERAGE	**68%**	**19%**	**16%**	

- The *Frontier UOA* includes all five benches of the Lower Cretaceous Frontier sandstones as well as any sands that appear within the Mowry shale interval. The top of the Frontier UOA is extended upward to include all sub-Cody Shale sandstones. The majority of the sandstones in the Frontier UOA exhibit very distinctive coarsening-upwards log signatures that are interpreted to reflect progradation of near shore environments such as river/distributary mouth bars. However, the uppermost Frontier sandstone exhibits a fining-upward signature suggestive of fluvial sedimentation.

- The *Dakota UOA* includes the Muddy sandstone, the Dakota sandstone, and sands within the Morrison Formation (Figure 1-type log). These sandstones are interpreted to represent deposition during fluvial-dominated sedimentation. In the Muddy interval, some thick, clean sandstones suggestive of incised valley-fill are noted. The base of the UOA is marked at the lowest significant sandstone in the Morrison sequence.

Wind River basin UOAs

The uppermost intervals in the target section of the Wind River basin contain thick sequences of fluvial and lacustrine clastics of the Fort Union, Lance and Meeteetsee formations. On well logs, particularly on gamma-ray logs, these units are not easily distinguishable. Published interpretations, as well as subtle variations in sandstone-shale ratio, the abundance and clustering of coals, and trends in formation conductivity, are the primary tools for correlation.

- The *Fort Union UOA* and *Lance UOA* are thick, monotonous sequences of interbedded fluvial sandstones, shales, and coals. Although the two units are lithologically very similar, combined they represent too thick a sequence to include within a single UOA. Therefore they are broken into two UOAs based on their interpreted formational contacts. The top of the Fort Union UOA is marked in large areas of the basin by the base of the Waltman Shale. The Fort Union/Lance transition was commonly traced based on previous interpretations (primarily the work of the USGS) conditioned by an attempt to place the contact at the top of a relatively sandstone-poor zone at the top of the Lance.

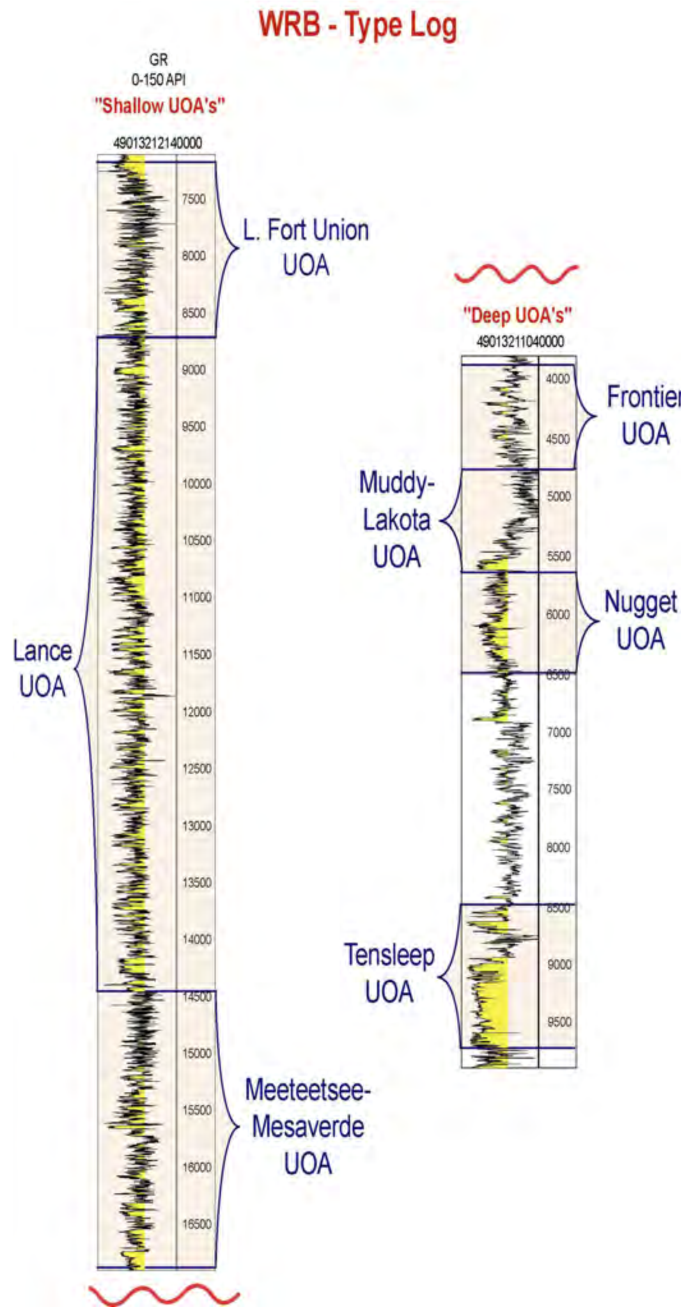

Figure 8*: Wind River basin type log showing UOAs*

- The *Meeteetsee/Mesaverde UOA* includes an array of fluvial-deltaic environments within the Meeteetsee and Mesaverde Formations. The relatively clean and thick Teapot sandstone lies at approximately the middle of the UOA. The upper contact of the unit is placed at the base of the initial sequence of thick fluvial sandstones thought to mark the base of the Lance Formation. The UOA extends down section to the top of the first significant shale within the Cody Shale. Sandstones within the Cody, such as the Shannon and Sussex, are not included.

- The *Frontier UOA* includes the distinctive coarsening-upwards parallic sandstones of the Frontier Formation. The uppermost boundary of the UOA climbs stratigraphically upsection as traced to the east. The lower limit of the UOA is placed at conspicuous and highly radioactive shale marking the top the Mowry shale. This shale most likely represents a sea-level highstand (maximum flooding surface) that proceeded progradation of the Frontier units.

- The *Muddy-Lakota UOA* includes sandstones within the Mowry Shale, as well as the subjacent Muddy, Dakota, and Lakota-Cloverly sandstones. The Mowry is predominantly a marine unit that contains no significant sandstones within the basin. The Muddy is locally very thick and clean, and occurs as highly-lenticular channelized sandstones. The Dakota sandstone is reported as productive in several parts of the basin, however, in this study, the unit identified as Dakota is consistently less than 5 feet in thickness. At the base of the UOA, the Lakota (Cloverly) sandstone is a highly continuous channelized conglomeratic sandstone. The base of the UOA is marked by a low-angle unconformity at the base of the Lakota unit.

- The *Nugget UOA* includes sandstones within the Morrison Formation as well as the Nugget Sandstone. On logs, the Nugget is typified by a highly-serrated and shaley character suggestive of vertical amalgamation of numerous thin sandstone beds. The base of the Nugget UOA is placed at the base of a consistent shaley zone approximately 300 feet above the Alcova limestone marker bed.

- The *Tensleep UOA* includes the thick and massive Tensleep Sandstone only. The unit produces oil almost exclusively in the basin. Only a handful of wells have penetrated the Tensleep Sandstone at depths below 15,000 feet, where gas is expected to dominate.

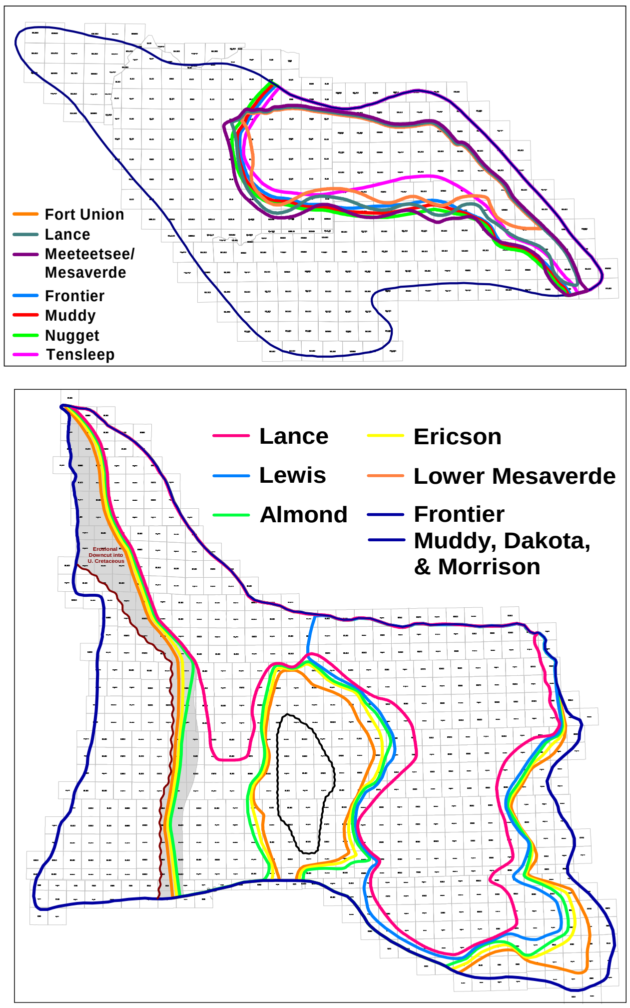

Figure 9: *Areal boundaries for UOAs in the Wind River basin.(top) and Greater Green River basin (bottom)*

Appraised Areas

Each UOA was appraised over the entire area in which it occurred. Ultimate location of the aerial boundaries of each UOA (Figure 9) was later restricted to include only 1) areas with drilling depths of at least 5,000 feet (to exclude shallow high-porosity sandstones that may be considered conventional); and 2) areas deemed to be gas-prone. In the Greater Green River basin, oil production is very uncommon below 5,000. However, in the Frontier and deeper UOAs in the Wind River basin, oil production is common to depths exceeding 10,000'. Consequently, the aerial limits of the Frontier, Muddy-Lakota and Nugget UOAs in the Wind River basin were set at 12,000' drilling depth. The limit for the Tensleep UOA is set at 15,000'. These depth cut-offs are based primarily on a review of data from I.H.S. Energy Data (see Table 3). Finally, note that in many prior assessments, the appraised area has been limited to overpressured areas. However, because this study subdivides each UOA into a large number of geographic cells each with a unique mid-point pressure, no such limitation was necessary.

Table 3: *% of total completions as oil well completions for Deep UOAs (data from I.H.S. Energy Data)*

	GGRB		WRB			
Depth	Frontier	Dakota	Frontier	Mud.-Lak. *	Nugget	Tensleep
6000-7999	1%	19%	86%	35%	100%	100%
8000-9999	3%	6%	8%	89%	100%	100%
10000-11999	3%	20%	33%	52%	0%	100%
12000-13999	0%	5%	0%	100%	0%	100%
14000+	0%	0%	0%	0%		

** includes only completions of the Muddy and Lakota sandstones*

Data Collection

For both basins, well logs were collected with the goal of obtaining quality log suites from one or more of the deepest wells in each township. Well productivity was not considered to ensure the dataset was not biased to higher quality reservoirs. Well data were collected separately for each UOA (although many wells are used for more than one UOA), with the following guidelines:

Table 4: *Well log data density used in the study. Number of wells = total wells used in the study to support correlation and mapping. Full log suites = total wells used in determination of volumetric parameters.*

Unit of Analysis	Number Of wells	Number of full Log Suites in appraised area	Townships in Appraised Area	Full Log Suites per Township
Greater Green River Basin				
Lance	209	88	297	0.30
Lewis	399	297	169	1.76
Almond	369	293	265	1.11
Ericson	301	242	338	0.72
Lower Mesaverde	153	136	353	0.39
Frontier	266	158	489	0.32
Dakota-Morrison	192	131	467	0.28
Wind River Basin				
Fort Union	75	44	49.8	0.92
Lance	63	28	58.8	0.48
Meeteetsee-Mesaverde	60	27	67.1	0.40
Frontier	136	19	56.2	0.34
Muddy-Lakota	123	16	56.6	0.28
Nugget	95	8	55.0	0.15
Tensleep	82	4	24.8	0.06

- Fullest possible penetration of UOA
- Even geographic distribution of data points
- Full and quality log suite, including:
  - Caliper Log (for determination of reliability of porosity data)
  - Gamma-ray well log (for determination of Vsh)
  - Compensated Density Porosity Log (for determination of porosity and potential pay)
  - Induction Log (for determination of shale and formation resistivity)

As expected, the density of quality log data is best for the shallower target intervals. Exceptions include the Lance in the GGRB, which contains many penetrations, but because the targets of these wells were typically deeper formations, full logging suites are relatively rare. In all UOAs, a large number of additional well logs (either lacking full suites or occurring in shallow or oil-prone areas), were used to support correlation and mapping. The poor data density obtained for the Nugget and Tensleep formations in the Wind River basin (particularly at the target depths) precluded further analysis of resources using this methodology. Maps prepared for these intervals using the total well log database are provided.

Correlation

With log data in hand, each UOA was correlated in loop fashion to establish the occurrence and distribution of lithofacies (Figure 10). Correlation was generally lithostratigraphic, and focused on establishing the UOA boundaries. Such correlations establish intervals of consistent lithology, and commonly produce unit boundaries that cross time-lines.

Where appropriate and possible (primarily in marine and marginal-marine intervals), detailed chronostratigraphic correlation was accomplished. These correlations identify rock sequences of equivalent age without reference to lithology and are necessary for

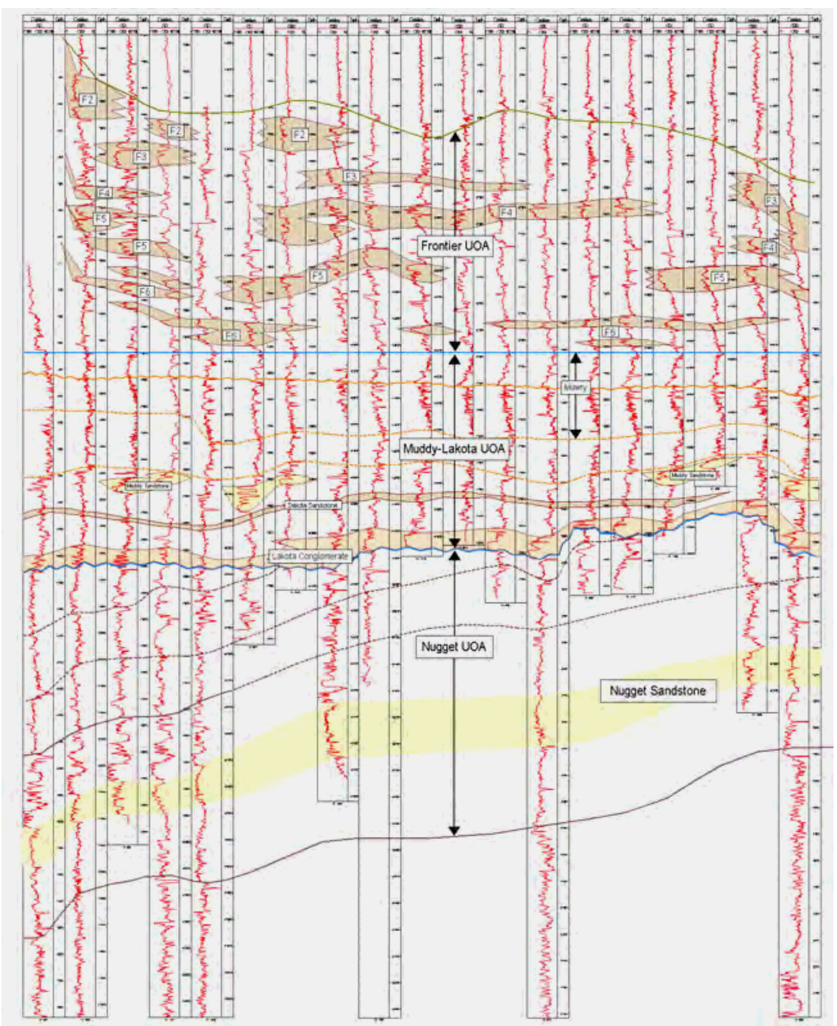

Figure 10: *W-E cross-section showing the correlation of the Frontier, Muddy-Lakota, and Nugget UOAs in the Wind River basin.*

the reconstruction of trends and geometries of depositional environments. A few key marker beds such as the highly radioactive shale ("Asquith marker") present in the lower Lewis Shale, other similar "hot" shales, as well as limestones, and bentonites closely approximate time-lines and are critical in allowing chronostratigraphic correlation. Because such key beds are generally lacking in fluvial and lacustrine facies, no detailed chronostratigraphic correlations were accomplished for the Lance, Fort Union, Lower Mesaverde or Mesaverde-Meeteetsee UOAs. In either lithostratigraphic or chronostratigraphic correlation, the methods used were tailored to the specific needs of each UOA. For example, in the Lewis and Mesaverde UOAs in the GGRB, correlation was achieved almost exclusively through comparison of gamma-ray well log signatures. Other UOAs, such as the Frontier and Dakota in the GGRB and the Fort Union and Lance in the WRB, required that gamma-ray signatures be supplemented with information from resistivity/conductivity curves and other data.

Mapping

The purpose of mapping is to provide a graphical view of the distribution of a geologic parameter. Maps were contoured by hand to allow geologic intuition gained through years of analysis of similar deposits to guide the sound extrapolation of information from areas of good data control to areas where data is lacking.

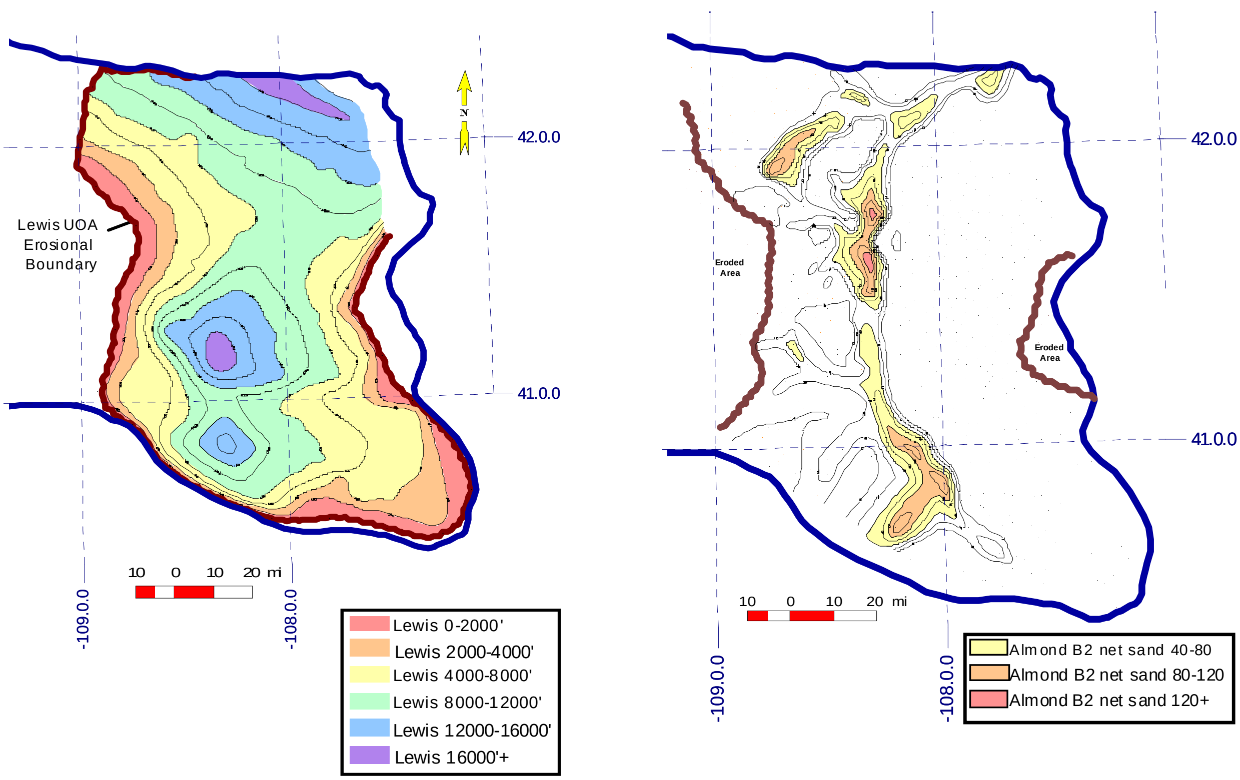

Figure 11: *Example Geologic Maps: Left - Drilling depth to mid-point of the Lewis UOA, GGRB, Sandstone isochore map for marginal-marine Almond "B2" sandstones, GGRB. A complete archive of maps and cross-sections created during this study is presented elsewhere on this CD.*

This effort has produced two basic sets of hand-contoured geologic maps. Drilling depth maps show the distance from surface to the stratigraphic mid-point of the UOA. Sandstone isopach maps (most properly – isochore maps) show the composite vertical thickness of all sandstone present within an interval. The sandstone isopach maps are based on sandstone thickness as determined through the gamma-ray base-lining method with a 50% clean-sand cut-off. The following sandstone isopach maps were created and are available elsewhere on this CD.

Greater Green River Basin

- GGRB: Lance UOA – Total sandstone thickness
- GGRB: Lewis UOA – Total sandstone thickness plus 6 interval isopachs (Lewis 8 (youngest); Lewis 7, Lewis 6, Lewis 5, Lewis 4, and Lewis 3 (oldest))
- GGRB: Almond UOA – Total sandstone thickness plus 6 interval isopachs (representing various horizons of the "Upper Almond" sandstone - Almond A (youngest and westernmost), Almond B1, Almond B2, Almond B3, Almond B4, and Almond C (oldest and easternmost)
- GGRB: Ericson UOA – Total sandstone thickness
- GGRB: Lower Mesaverde UOA – Total sandstone thickness
- GGRB: Frontier UOA – Total sandstone thickness plus 6 sandstone isopachs (Frontier 0 (youngest), Frontier 1, Frontier 2a, Frontier 2b, Frontier 3-4, Frontier 5 (oldest)).
- GGRB: Dakota UOA – Total sandstone thickness plus 3 sandstone isopachs (Muddy (youngest), Dakota, and Morrison (oldest)).

Wind River Basin

- WRB: Fort Union UOA – Total sandstone thickness
- WRB: Lance UOA – Total sandstone thickness
- WRB: Meeteetsee-Mesaverde UOA – Total sandstone thickness
- WRB: Frontier UOA – Total sandstone thickness plus 4 sandstone isopachs (Frontier 1-2 (youngest), Frontier 3, Frontier 4 and Frontier 5 (oldest))
- WRB: Muddy-Lakota UOA – Total sandstone thickness plus 2 interval isopachs (Muddy and Lakota)
- WRB: Nugget UOA – Total sandstone thickness plus 1 interval isopach (Nugget)
- WRB: Tensleep UOA – Total sandstone thickness

Log Analysis

Given a logs with UOA boundaries marked, the procedure for log analysis was as follows:

- Record drilling depth at mid point.
- Determine thickness of sandstone lithology for the purpose of mapping through baseline analysis of the gamma-ray log.
- Mark the potential pay zones through collective reference to the gamma-ray, density-neutron, resistivity, and caliper logs.

- Determine the composite average shale-volume across all the potential pay zones through analysis of the gamma-ray well log.

- Determine the average porosity in the potential pay zone through analysis of the compensated density porosity log.

- Determine the average resistivity in the potential pay zones through analysis of the resistivity log.

- Determine the shale resistivity throughout the UOA from the resistivity log.

The following, supplemented by Figure 12, describes these steps in further detail:

Drilling depth mid-point was calculated for every UOA in each well analyzed. This depth is used in the model to estimate drilling, completion, stimulation, and operating/maintenance costs.

Sandstone Thickness: To determine net sandstone thickness, sand and shale baselines were drawn for every gamma ray (GR) log analyzed. The "100% sand" baseline is a vertical line on the log indicating the reading expected for totally-shale free sandstone. Such sandstones are rare, and in many instances, the 100% sand line is drawn based on the reading exhibited by limestones where present or by assuming that the very cleanest sandstones in the section contained only a

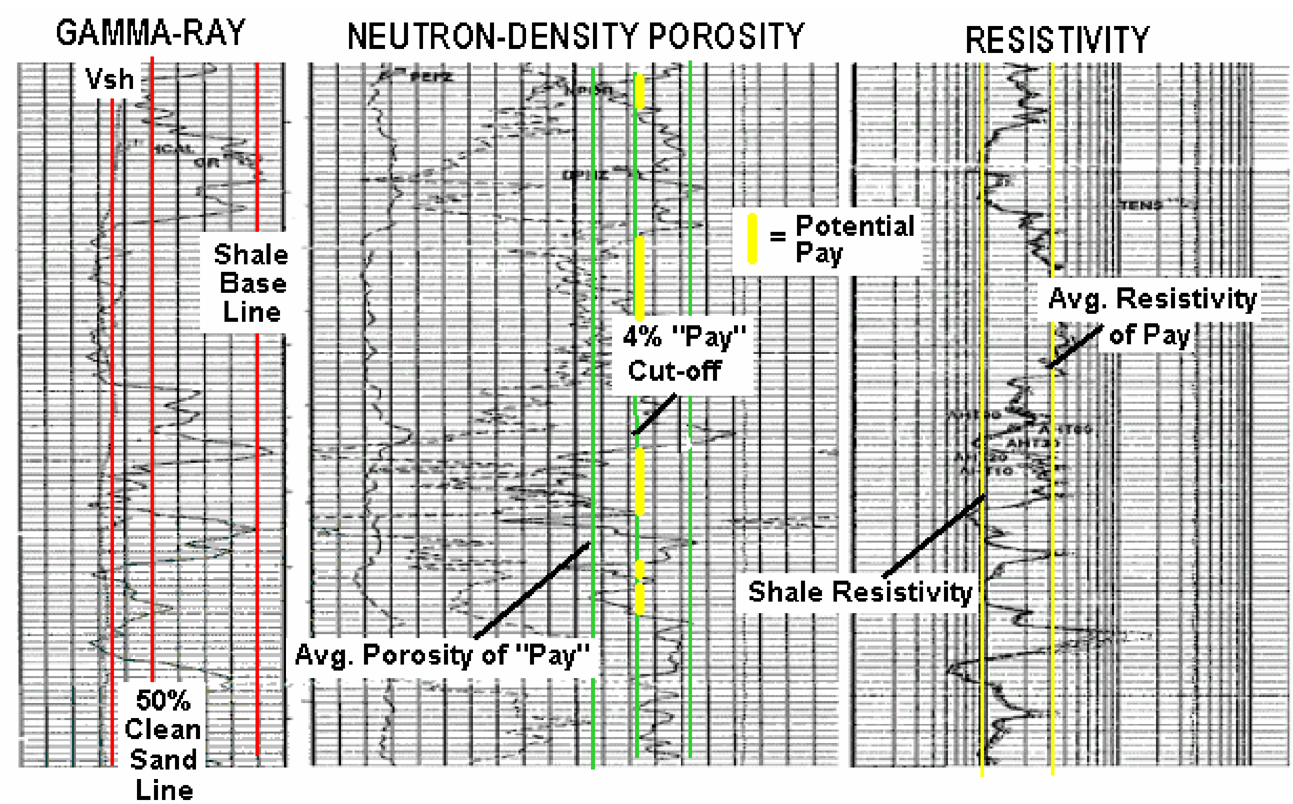

Figure 12: *Sample well log showing the key elements of the well log analysis procedure. "Potential Pay" is the thickness of interval characterized for each UOA. The average values for Vsh,, Porosity, and Resistivity are all relative to the potential pay intervals only*

minimal amount of shale (5 – 10%). The “100% shale” baseline indicates the expected GR reading for shale. The location of the shale baseline is allowed to change with depth to reflect changing hole conditions and shale lithology. (The goal is to construct baselines that reflect the contribution to total unit radioactivity of the shale likely to be incorporated into each sandstone). These two lines are bisected by the 50%-sand line. To determine total sandstone thickness, all readings to the left of the 50%-line are interpreted as sandstone. All readings to the right are siltstone or shale. GR-log baselining, like many aspects of regional resource appraisal, is not an exact science. Once a geologist has looked at several hundred logs in a region, trends can be identified that allow the baselines to be used to standardize all of the GR logs and correct the interpretations of logs that may not have been recorded optimally.

Potential Pay Thickness: A pivotal determination in the log-analysis procedure is the determination of “potential pay thickness”. In general, the term “pay” is usually equated with an interval that is expected to produce under current circumstances. Geologists are accustomed to establishing practical reservoir or field-specific porosity (for example 6 or 8%) and gas saturation (commonly 60%) cut-offs in determining pay. However, the goal of this effort is to create resource descriptions that will allow a computer model to determine what segment of the total resource *might be pay* as much as 20 years into the future under cost/technology scenarios that may be very different from what currently exists. Therefore, aggressive cut-offs have been used in defining “potential pay” with the understanding that under most technology/cost conditions, the models may not consider much of this low-quality “potential pay” to be viable. Once zones are identified as “potential pay”, estimates for all remaining parameters (shale volume, porosity, resistivity) were determined for these zones only.

The criteria for potential pay is as follows (note; all these conditions must be met before the unit is included as potential pay):

- Less than 75% shale volume – that is; units not counted as sandstones in the lithofacies mapping (Vsh between 50% and 75%) can still be counted as potential pay given appropriate porosity.

- Greater than 4% porosity – in practice, this criteria amounts to including all noticeable deflections from the expected porosity reading for shale.

- Greater than a set minimum thickness – isolated thin beds are not included, however, the composite thickness of a series of thin beds that form a larger unit (such as a turbidite deposit) was included.

- Less than 70% water saturation (Sw), based on our current best understanding of water resistivities.

- Adequate caliper indicating no large washouts or severe rugosity in the wellbore that would make porosity log readings unreliable.

Average Shale Volume of Potential Pay: The average shale volume (Vsh) is determined though visual inspection of the gamma-ray reading of potential pay zones relative to the gamma-ray base line. In UOAs with highly variable Vsh, weight averaging through the UOA was used.

Average Porosity of Potential Pay: An average porosity for the potential pay in each UOA was determined almost exclusively from recent vintage, full-scale (the "5-inch log"), compensated density-porosity logs. In many instances, the average porosity was taken through visual inspection of the log. Where density-neutron "cross-over" occurred, porosity is taken by the average of the two readings. Where there was no "cross-over" the density porosity log reading was used. Also, similar to gamma-ray baselining, the determination of porosity provides the geologist with the opportunity to normalize porosity data gathered from a variety of decades, tools and operators. A basic assumption is that the density porosity log should read consistently low (0 – 4%) in shale. Where log data were more erratic, a baseline was drawn through the average density porosity value in shales, and the average porosity reading was then determined by counting the deflection to the left of the baseline. Furthermore, in UOAs known to consist primarily of thin-bedded units (for example, the Lewis Shale turbidites), the porosity recorded was at the common maximum reading, and not at the visual average. This approach (which is also applied to determination of resistivity) helps to counteract the misleading log readings obtained for intervals containing numerous individual units that are thinner than the logging-tool resolution.

Average Resistivity of Potential Pay is approximated using the detailed 5" resistivity log. When large differences in resistivity occurred within one interval (e.g. 20 ohms readings for 100 feet of potential pay mixed with 200-ohm reading for another 50 feet of potential pay), resistivity was weight-averaged over the interval. However, in most instances, the value is determined by visual averaging.

Average Shale Resistivity (Rsh) across the UOA is approximated from the detailed ("5-inch") resistivity log. Shale resistivity is allowed to vary from one UOA to another in a given well. Such variation is common due to changes in formation pressure and shale lithology (for example, marine shales versus non-marine shales).

Note on Estimation of Water Saturation: Water saturation can be estimated using shaley-sand formulations (we have used the Simondoux equation) that correct total measured resistivity for water resistivity (Rw), shale volume (Vsh), and shale resistivity (Rsh). Unfortunately, the water resistivity parameter is very difficult to determine. It can only be estimated from well logs given the presence of 100% water-wet sandstones. However, due to the ubiquity of gas in basin-centered accumulations, such wet sandstones, particularly ones in close proximity to the units being analyzed, are not common. As a result, to calculate Sw, Rw must be determined from other data. For the Lewis UOA, sufficient water chemistry data was available to allow estimation of Rw. For the other UOAs, Rw's were based on experience and trial and error. We intend to revisit these calculations once ongoing NETL studies to sample and analyze Rocky Mountain region formation waters and other industry data provide better information.

Note on Parameter Averaging: The GSAM model requires that each resource package to be analyzed (each grid cell in each UOA) be given a single value for each parameter. Therefore,

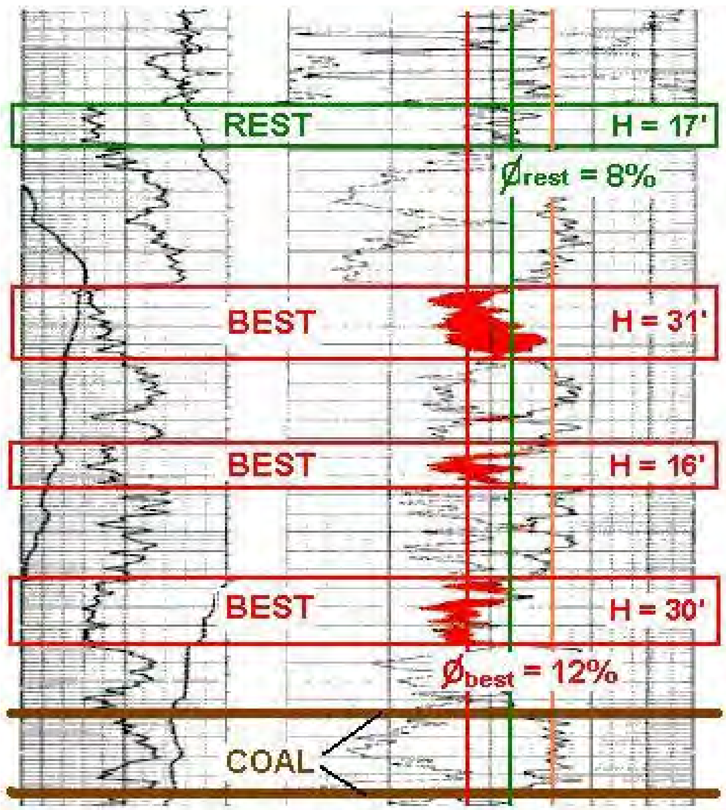

Figure 13: *Example of the use of separate 'best' and 'rest' categories in the Almond UOA.*

despite our efforts to create detailed and disaggregated datasets, it remained necessary to average parameters across large vertical sections. For many units of analysis, this averaging did not create any major difficulties, as parameters such as porosity and saturation were often fairly consistent within a unit. In many instances, the "averaging" was done visually; in others (where the parameter displayed greater variability), detailed counts were conducted and averages obtained through weight-averaging. However, for the upper Mesaverde "Almond" UOA in the GGRB, averaging of values across the high-quality marginal-marine "Upper Almond" sandstones and the numerous lower-quality "Main Almond" units was not ideal. Such averaging produces a characterization that may not appropriately describe any part of the interval. Therefore, the solution was to prepare separate characterizations of the "best" and "rest" potential pay zones within that unit (Figure 13). Included within the "best" category are zones that would be most likely to be completed (commonly those marked by density-neutron cross-over). All lower-quality potential pay is assigned to "rest".

The intention of differentiating best and rest zones in the GGRB Mesaverde (including Almond, Ericson, and Lower Mesaverde UOAs) is to provide for more precise modeling of current industry behavior, and allow the analyses of technological advances that might allow more of the potential pay to be completed. GSAM does not currently have the capacity to utilize the "best vs. rest" distinction; however modifications to the model to better handle thick sequences of stacked reservoirs of varying quality are currently in planning.

4. Engineering Analysis Methodology

The engineering analysis was designed to provide data that could not be obtained directly from well log analysis. Data obtained or estimated for each UOA at either the township or quarter-township level include 1) pressure gradient; 2) temperature gradient; 3) water resistivity; 4) matrix permeability; and 5) fracture permeability overprint.

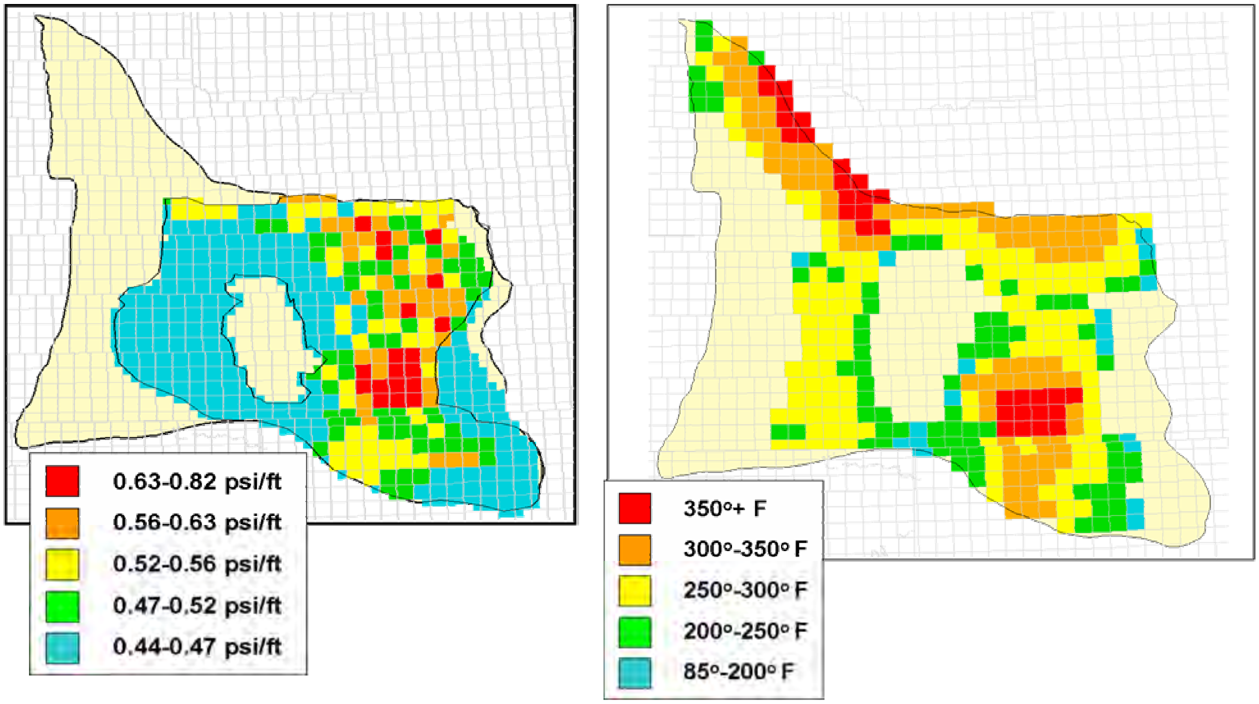

Figure 14: *Example maps of engineering parameters: Left – Reservoir pressure gradients per township for the Lower Mesaverde UOA, GGRB. Right - Reservoir temperature for the Frontier UOA, GGRB.*

Reservoir Pressure

Average reservoir pressure gradient for each UOA is based on information from previous work by Advanced Resources International in the GGRB as supplemented by new work. The data on reservoir pressure was assembled from a combination of individual pressure build-up tests on key wells supplemented by drilling mud-weight data. The mud-weight data was calibrated to actual well test data where possible. Where calibration was lacking, the conversion from mud-weight to pressure gradient was accomplished by the following: $P_{gradient}$ = Mud Weight X 0.0552. The resultant pressure gradient was then gridded throughout the study area to provide gradients at either a quarter- township or township scale. Pressure for each cell is then determined by multiplying gradient by mid-point drilling depth. This methodology provides accurate pressure estimations assuming that drilling is commonly in balance; overestimation of formation pressure may occur where drilling is typically accomplished overbalanced.

Reservoir Temperature

Temperature gradients for each UOA are based on an existing ARI databases supplemented by bottom-hole temperatures recorded on well logs. Temperature gradients were then gridded throughout each play area to provide estimates at the quarter-township or township scale. Reservoir temperature was determined for each grid cell by assuming a near surface temperature of 60 ^{o}F as follows: $T_{reservoir} = 60 + (T_{gradient} * \text{Depth})$.

Formation Water Resistivity

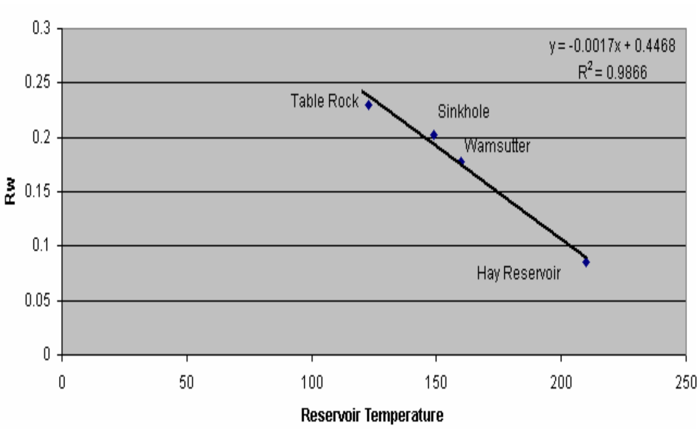

Figure 15: *A plot of four Rw values for published Lewis water analyses versus reservoir temperature*

Formation water resistivity (Rw) data are needed to determine water saturation (Sw) from well log data. Unfortunately, Rw data for both the Greater Green River and Wind River basins are highly variable and not widely available. However, for the Lewis UOA, measured Rw's from four Lewis fields were available, and were converted to subsurface conditions using Arp's equation:

$$Rw_{reservoir\ conditions} = Rw_{surface}\ X$$
$$(T_{surface}+6.77)/T_{reservoir}+6.77)$$

These data were plotted (Figure 15) and the resultant relationship *(Rw = -0.0017T + 0.4468)* was used to estimate Rw for all cells in the Lewis UOA. Unfortunately, reliable water chemistry data was not available for the remainder of the UOAs to allow similar determination of Rw. Therefore, the data used are primarily assumptions based on limited information (Table 5). We have generally assumed higher Rw's for those UOAs that are dominantly non-marine and lower values for marine and near-shore UOAs. We have also generally assumed decreasing Rw with depth. For example, in the Frontier and Dakota UOAs in the GGRB, Rw was set to range from 0.04 for cells with the greatest drilling depths to 0.09 for those with the shallowest drilling depths.

Figure 16 illustrates the dependence of calculated Sw on Rw. This observation underscores the potential error inherent in calculating Sw from log data without reliable Rw data. However, it unlikely that this practice produces greater error than the direct assumption of Sw. Therefore, we have elected to assume Rw, note the difficulties, and calculate Sw.

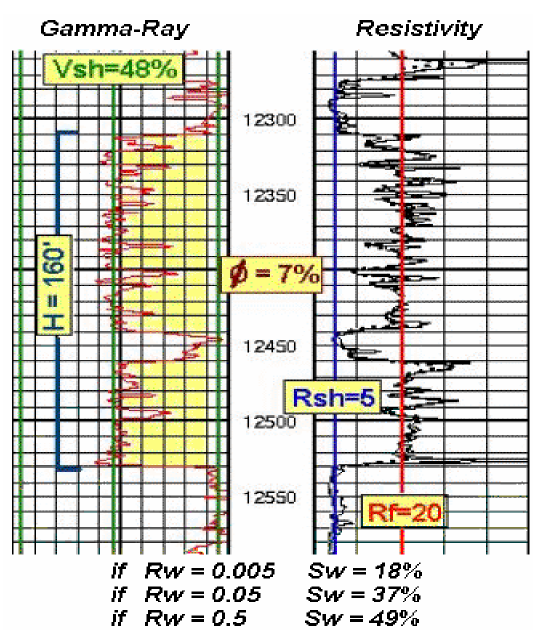

Figure 16: *A typical log from the Lewis UOA showing the impact of various Rw assumptions on calculated Sw.*

This allows us to use the observed variations in shale volume, shale resistivity, and formation resistivity to produce datasets with reasonable estimates of the regional variation in Sw. As noted above, final Sw estimates will be revised as new Rw data becomes available.

Table 5: *Water Resistivity Assumptions (Ohm-m)*

Greater Green River Basin		Wind River Basin	
Lance	0.10	Fort Union	0.40
Lewis	Variable	Lance	0.35
Almond	0.23	Meeteetsee-Mesaverde	0.25
Ericson	0.70	Frontier	0.05
Lower Mesaverde	0.23	Muddy-Lakota	0.05
Frontier	0.04-0.09	Nugget	0.05
Dakota	0.04-0.09	Tensleep	0.05

Effective Permeability

The pivotal element in providing datasets to model the future economics and productivity of these resources is an estimation of effective permeability. Although it is well known that matrix permeability in tight sandstones is commonly less than 0.01 millidarcies (md), to assume this value as the pervasive permeability for these formations would ignore the contribution of natural fracturing. Unfortunately, fracture permeability (or the overall effective permeability) is typically not reported or measured in the field. Therefore, finding a reasonable methodology to approximate the magnitude and aerial variability in effective permeability in areas that are largely unexplored is a significant challenge. Our solution for Phase I of this effort is to estimate structural complexity from remote sensing data, correlate that information to permeability in areas where data is present, and then estimate permeability in each grid cell of each UOA through the extrapolation of these data.

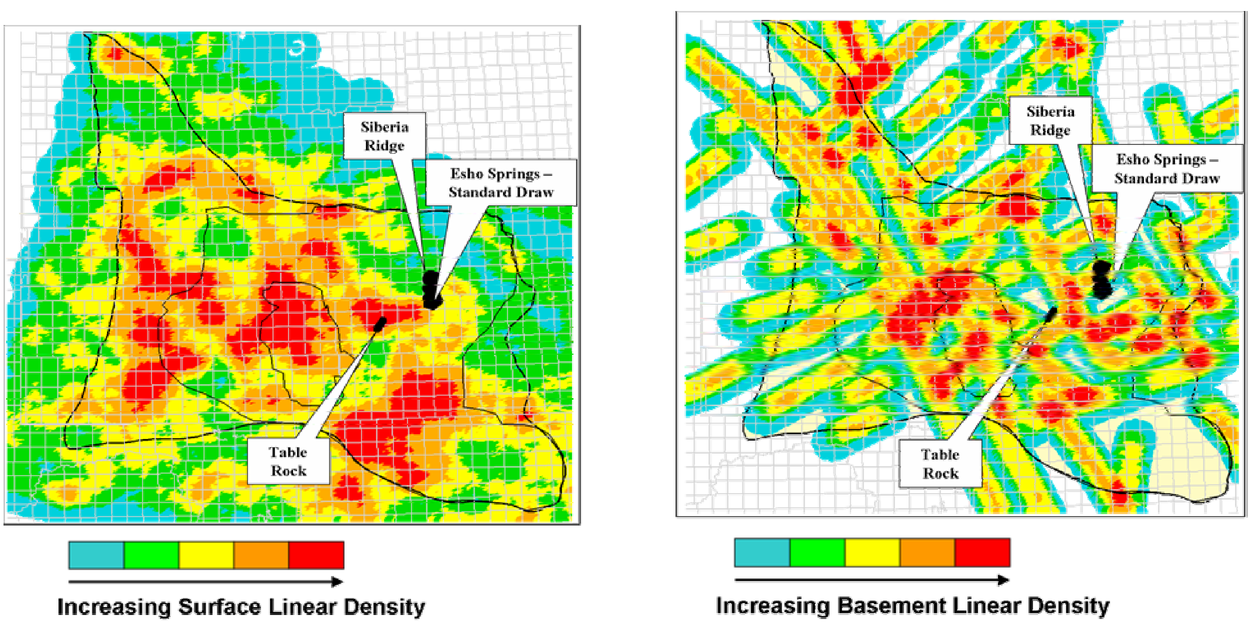

Figure 17: *Two components in the calculation of structural complexity. Right: Basement component as determined from remote sensing data (magnetic and gravity): Left: Surface component based on density of mapped surface lineaments.*

Structural Complexity: The structural complexity for each township was based on a combination of two sets of information. Mapped surface lineaments are used to determine density of surface features. Gravity and aeromagnetic data are used to interpret the location of basement features. The combination of these two, with unique corrections for the average relative location of each UOA with regard to surface and basement, is then used to derive a structural complexity score for each cell in each UOA. For example, the basement component is given more weight for the Frontier UOA than for the Lewis. The composite structural complexity score is assumed to correlate directly to the density of natural fractures. Figure 17 provides examples of these data for the Greater Green River basin.

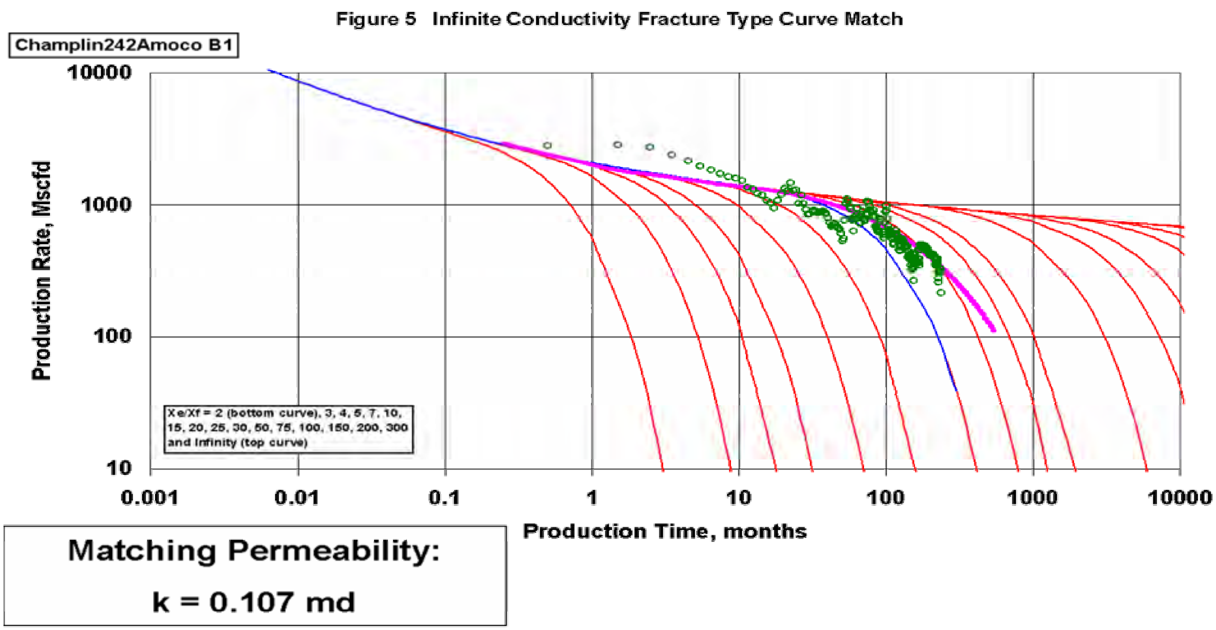

Figure 18: *Type curve match for the control well for Mesaverde UOAs in the Echo Springs field, eastern GGRB. Permeability assigned to this well (0.107 md) is assumed to be typical of the grid cell.*

Permeability Estimation in Control Data Sets: The general basis for estimation of permeability is the detailed analysis of productivity and log character for a typical well extracted from as many as 10 sample fields per UOA. For each type well, logs were analyzed to establish net completed pay, porosity, gas saturation, pressure and temperature. Production profiles were then matched to type curves to establish an estimate of effective permeability (Figure 18) that represents the sum of both matrix and fracture contributions

Permeability Estimation beyond Control Data Sets: As no production profiles exist in much of the appraised area, our approach to extending the prediction of effective permeability beyond the vicinity of the control wells was to separately estimate both the matrix and natural fracture components in each grid cell of each UOA. Determination of matrix permeability was determined by simply applying the best available correlation with estimated porosity. This correlation is one established for the Almond sands in the eastern GGRB by Cluff (2000).

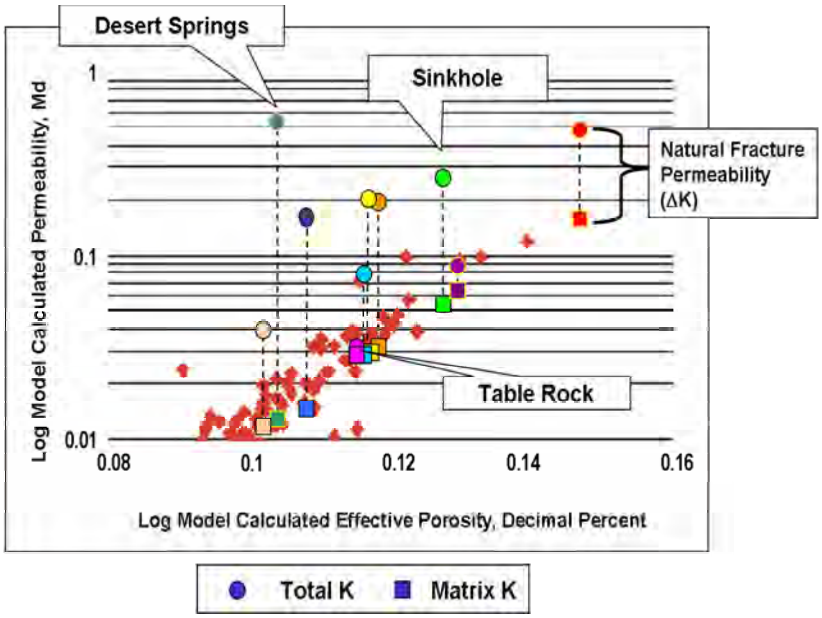

Figure 19: *Method for partitioning effective permeability into matrix and natural fracture overprint components. Example from the analysis of the Lewis UOA, GGRB.*

Establishing the natural fracture contribution to permeability for each cell was accomplished through correlation with observed structural complexity as follows. For each control well, expected matrix permeability (based on control well porosity and water saturation) was subtracted from the effective permeability estimate derived from type curve matching to determine the natural fracture contribution. In the example provided as Figure 19, type curve matching returned an estimated effective permeability of approximately 0.27 md for the Lewis UOA at Sinkhole Field. Based on analysis of logs from Sinkhole, 0.053 md of this total is interpreted to reflect matrix permeability. The remaining 0.217 md is therefore attributed to natural fracture overprint

Correlation of Fracture Permeability to Structural Complexity: Our methodology only has value if the estimates of structural complexity for the cells with control wells show a reasonable correlation to interpreted natural fracture permeability overprint. This test was conducted for the Lewis UOA (GGRB) and the Fort Union UOA (WRB). As shown in Figure 20, the correlation is respectable, and indicates the general utility of the methodology for the purposes of this study. That is, our method provides a reasonable approach to providing NETL's analytical models with realistic and areally-varying estimates of total effective permeability that recognize the contribution of natural fracturing. Clearly, however, this method does not have the resolution or accuracy to support the estimation of permeability at any given location, and is therefore not compatible with well siting.

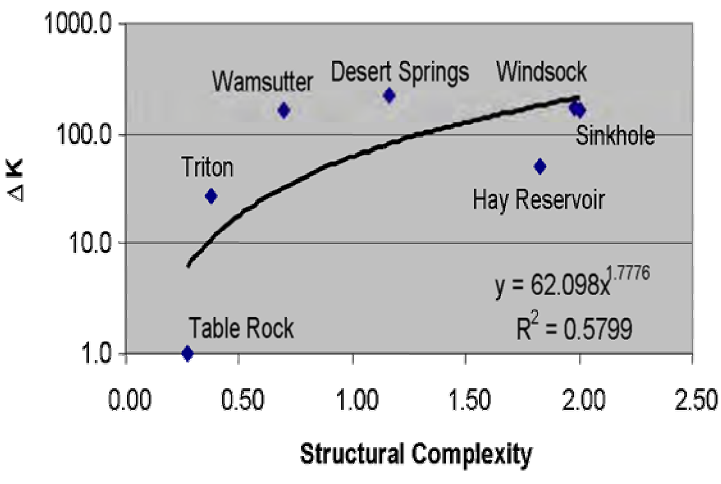

Figure 20: *Correlation of structural complexity and estimated natural fracture contribution to permeability (K) for 7 control fields in the analysis of the Lewis UOA. A similar comparison for the Fort Union UOA, WRB, found a similar correlation.*

Dataset Preparation

The purpose of this effort is to produce a dataset for input into NETL's Gas Systems Analysis Model that reflects, as much as practical, the natural variety present in key reservoir parameters. To do this, it is necessary to divide the resource into a large number of separate packets, with each packet having unique information on pay thickness, porosity, drilling depth, permeability, and other key factors. Therefore, a critical step in the creation of the model input datasets is the merger of the geologic data (collected relative to specific well locations) and the engineering data (collected relative to full or quarter townships) into a regular, cell-based, database.

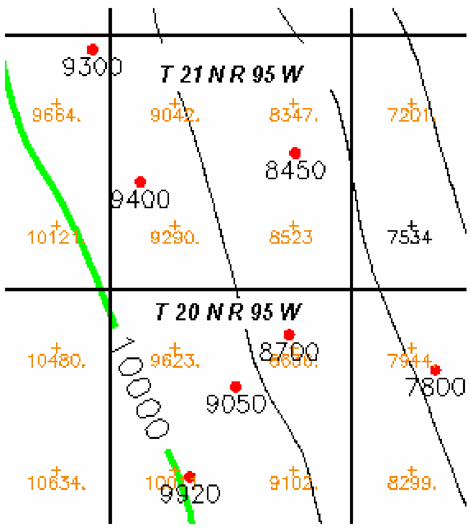

Figure 21: *An example of a gridded dataset – in this case drilling depths. Red dots are well locations. Orange values mark the centers of grid cells - in this example, cells are 9 mi^2 in size. Each cell is assigned a unique depth based on computer extrapolation of scattered well data.*

Figure 21 illustrates this process. The dataset of well-log-based values (red dots) is entered into computer software (EarthVision) and gridded (a typical first step in computer contouring programs in which values are interpolated at regular intervals from scattered data). To ensure that the program grids appropriately in areas of poor well control (and fills the entire play outline with data), roughly 20-40 "control" wells are created and added to the database for each UOA. These imaginary wells are placed along play boundaries, at the centers of interpreted structures, and in areas of poor well control in an effort to persuade the computer contours to match the geologic model.

The size of the grid cells used was 5,760 acres (equivalent to a quarter-township) for UOAs above the Cody Shale and 23,040 acres (full township size) for sub-Cody UOAs. Each volumetric parameter is gridded in this manner, producing a dataset that divides the entire resource into a large number of separate, and square, segments of equal size.

Finally, grid-cell level data were then converted into the specific format required for model input. Model input files were edited to remove grid cells that fall outside the play area and to ensure that the entire play area was gridded. In addition, all cells within the play area that have been drained by previous production were removed. In accounting for past production, our convention was to remove all cells from which existing wells had produced from the subject UOA in more than 25% of the available well locations. We believe this approach should provide a conservative estimate of remaining resources.

Distribution of Permeability within Grid Cells

The methodology described above was used to create a database characterizing roughly 8,000 unique resource packets, each with a unique combination of estimates for volumetric parameters, drilling depth, and matrix and effective permeability. Within each packet, therefore, a single characterization applies to all available drilling locations (equal to 36 160-acre locations per gird cell for UOAs above the Cody shale and 144 160-acre locations for those above – note that the.

current spacing assumption (160-acres) can easily be modified as later analyses require). Given the large number of cells, using a single average to represent these small numbers of locations clearly provides more than enough detail for our modeling purposes. However, with regard to permeability, further data manipulation was warranted for two reasons.

First, the permeability methodology is likely to have provided numbers that are not truly typical of the grid cell. They are typical of the control fields they represent, however, it is likely that those fields represent slightly better productivity than the remainder of the cell in which they reside. Also, the data quality necessary for type curve matching was found to be more common in better-producing wells. Second, and more importantly, permeability is not likely to be uniform across a grid cell. Although this is likewise true of the volumetric parameters, permeability is expected to deviate over a much larger range, and these deviations (small numbers of very good wells and large numbers of poorer wells) will have a much greater impact on modeled productivity and recoverability. Therefore, for the estimation of permeability, each cell was further divided into four unequal segments, with a modified effective permeability assigned to varying number of available well locations. For example, assume a cell in the Frontier UOA (a 36-mi^2 cell holding 144 possible 160-acre well locations) is assigned a permeability of 0.1 from the structural complexity analysis. For modeling purposes, this cell is broken into four cells of unequal size. Permeability is then assigned as illustrated in Figure 22, with the largest of sub-cell (holding 54 of the 160 available well locations) assigned a permeability equal to 30% of the original cell estimate and the smallest cell (holding 10 of the 144 well locations) assigned a permeability 3 times the original estimate.

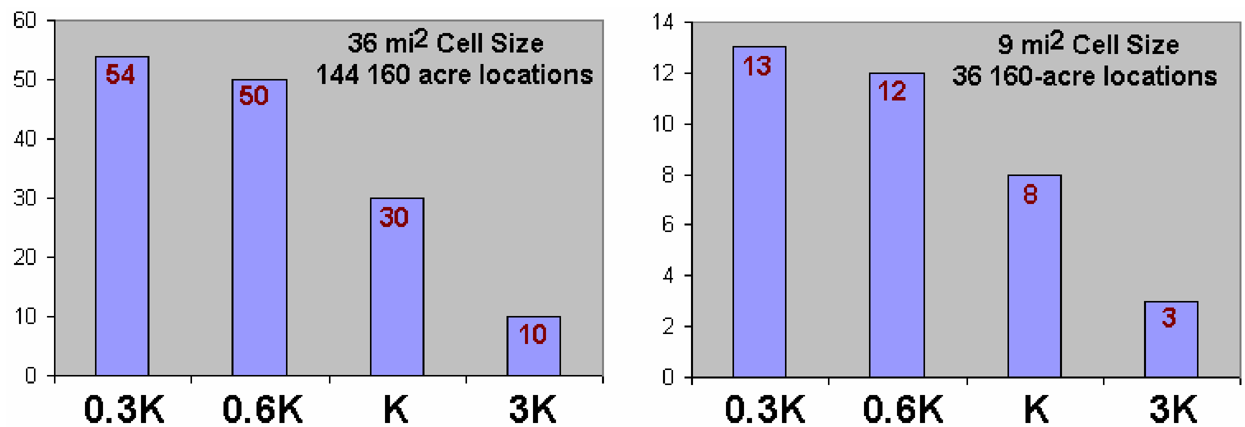

Figure 22: *Procedure for distributing a range of permeability within grid cells based on estimated average cell permeability.*

5. Results

The primary result of this work is the construction of detailed and disaggregated resource characterizations for major gas accumulations in the GGRB and WRB. These datasets, and the methodology that produced them, are specifically tailored to allow meaningful analyses of the relative impact of alternative future technology, cost, and policy scenarios using NETL's Gas Systems Analysis Model (GSAM). By compartmentalizing the resource both geographically and vertically into thousands of discreet packets, these datasets capture the natural variation in drilling depth, porosity, water saturation, pressure, temperature, and permeability that are necessary for meaningful modeling of specific technologies.

Figures 23 and 24 illustrate the improved detail of the new resource characterizations relative to those previously existing in NETLs models. Figure 23 shows the extent of improved aerial detail for the Lewis UOA, eastern GGRB. Whereas pre-existing datasets described the entire area of the Lewis gas resource relative to a single estimate for many parameters (such as drilling depth, pressure, temperature, and others), the new datasets divide the area into hundreds of uniquely-described segments. Figure 24 further illustrates this point of increased resolution with regard to the distribution of resource within each UOA. For example, whereas previous datasets for the GGRB placed all 159 Tcf assigned to the "Mesaverde Play" at a common depth of 15,000 feet,

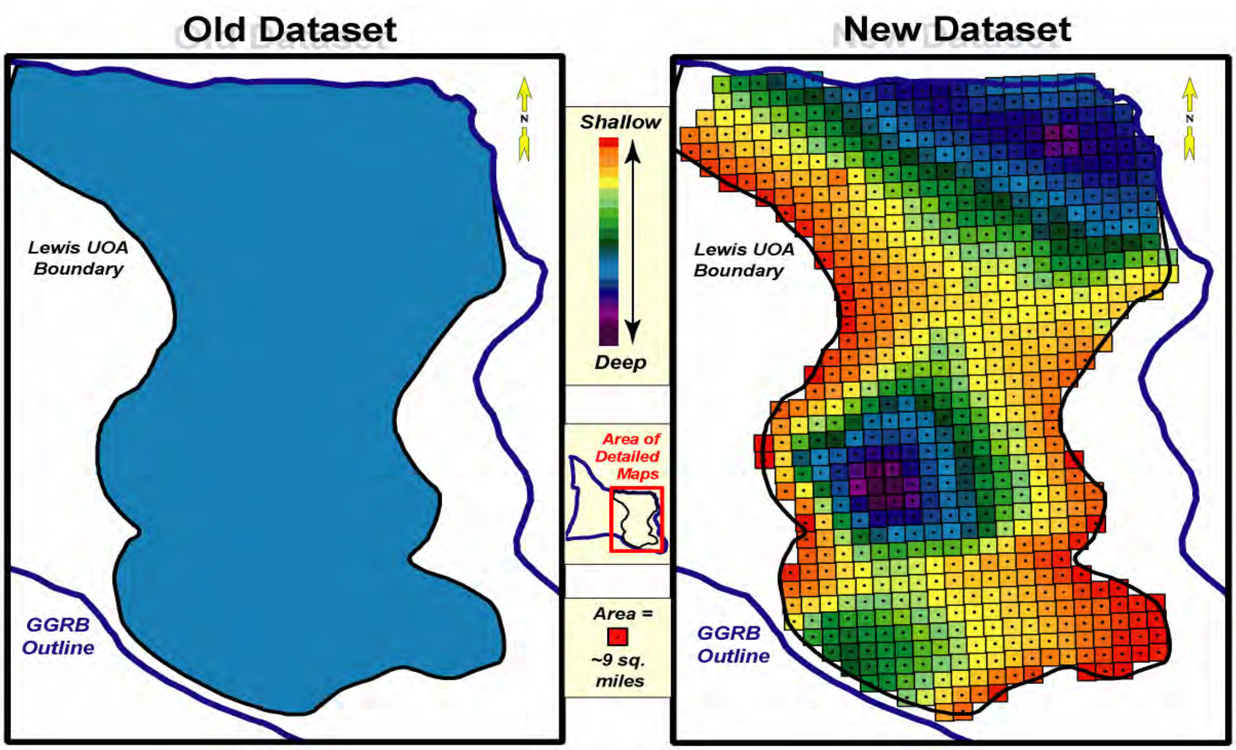

Figure 23: *Comparison of previously-existing NETL model characterization (left) with dataset prepared in this study (right) with regard to description of drilling depth. Example is from the Lewis UOA, GGRB.*

our new datasets divide more than 1,800 Tcf of in-place “Mesaverde” resource into three UOAs (Almond, Ericson, Lower Mesaverde), each with resources distributed in accordance with the true structure of the basin.

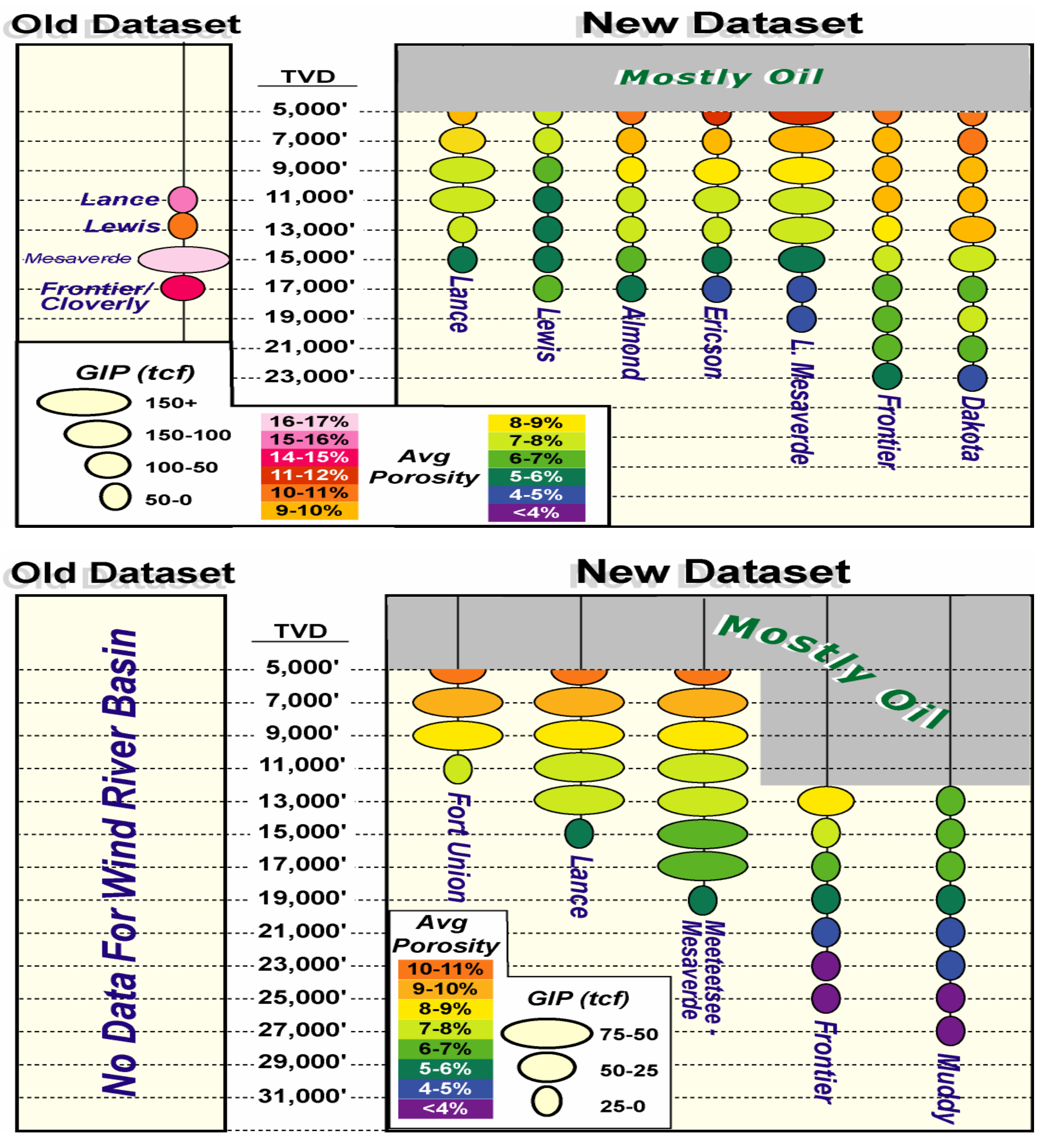

Figure 24: *Schematic comparisons of previous and new datasets relative to the distribution of resource with depth in 12 UOAs; Top – GGRB, Bottom – WRB. Previous datasets had less stratigraphic detail and placed all resources in each unit at a single depth. New datasets distribute depth among more units and across the full natural range of depth. Similar improvement is found relative to other parameters, including pressure, porosity, permeability, and water saturation. Note that previous datasets contained no Wind River basin resource.*

Volumetrics

The results of the volumetric analysis are summarized in Table 6 and Figure 25.

Table 6: *Gas-in-place and average volumetric parameters for GGRB and WRB UOAs. Average values refer only to the potential pay in each grid cell. For example, 7% porosity means that the average porosity of the zones identified as potential pay over all grid cells is 7%. Total values are the aggregate values for all grid cells.*

	Greater Green River Basin UOAs						
	Lance	**Lewis**	**Almond**	**Ericson**	**L. Msvd**	**Frontier**	**Dakota**
Area (thousands of acres)	5,247	4,332	8,363	8,484	9,066	11,128	11,796
Avg. Thickness (ft.)	341	82	27	119	305	46	55
Avg. Porosity (%)	8	7	9	9	8	8	8
Avg. Water Saturation (%)	58	61	62	53	58	39	35
Avg. Drilling Depth (Ft.)	8,628	10,104	9,882	9,729	10,778	14,511	14,629
Avg. Pressure (psi)	4,322	5,232	5,430	5,322	5,739	8,498	9,592
Avg. Temperature (^oF)	164	181	179	177	189	249	250
Avg. Z-Factor	0.99	1.05	1.03	1.06	1.06	1.39	1.40
In-place Resource (Tcf)	714	149	120	519	1,257	351	528
Resource below 15,000’ (Tcf)	0.7	8	5	24	201	145	212
	Wind River Basin UOAs						
	F Union	**Lance**	**M-Mvd**	**Frontier**	**M-Lak**	**Nugget**	**Tensleep**
Area (thousands of acres)	1,094	1,267	1,480	1,613	1,866	1,682	1,247
Avg. Thickness (ft.)	408	560	524	135	53	76	285
Avg. Porosity (%)	10	9	8	6	6	5	6
Avg. Water Saturation (%)	56	50	42	41	35	*	*
Avg. Drilling Depth (Ft.)	8,240	10,003	12,021	18,931	20,058	19,485	20,458
Avg. Pressure (psi)	3,663	4,736	7,410	12,219	13,585	13,444	14,184
Avg. Temperature (^oF)	175	200	228	325	340	372	387
Avg. Z-Factor	0.94	1.03	1.16	1.52	1.52	1.57	1.61
In-place Resource (Tcf)	190	329	456	129	65	*	*
Resource below 15,000’ (Tcf)	0	12	159	89	54		

**not estimated due to insufficient data*

The volume of gas present within each UOA was calculated on a per grid-cell basis. Average Z-factors were determined for each cell assuming 0.65 gravity pure methane gas using a modified form of Drunchak’s equation coded into a Microsoft Excel function. In general, this study confirms past accounts of vast volumes of natural gas existing in these two basins (see Figure 25 for comparison to previous estimates). Specifically, we estimate approximately 4,800 Tcf of gas exists in-place within the appraised formations and areas of the Greater Green River (3,635 Tcf) and Wind River (1,169 Tcf) basins. The majority of this resource lies within the thick, dominantly fluvial sections of the Lance, Ericson, and Mesaverde UOAs of the GGRB and the Fort Union, Lance, Mesaverde-Meeteetsee UOAs of the WRB. Of this total, approximately 900 Tcf lies at depths below 15,000 feet. Figure 25 also compares the total gas-in-place estimates for

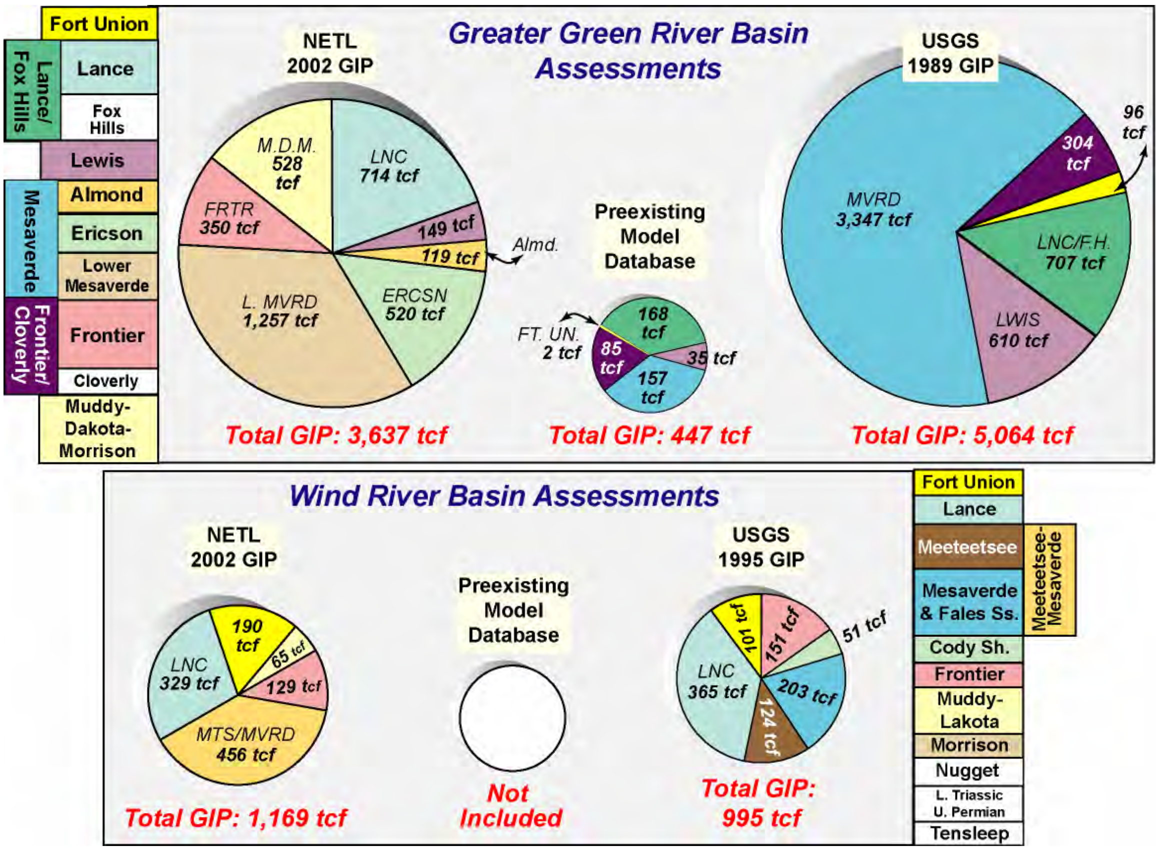

Figure 25: *Summary of the gas-in-place results of this study ("NETL 2002 GIP") with in-place resource characterizations previously available to NETL's analytical models databases and the findings of previous USGS gas-in-place studies (GGRB, 1989; WRB, 1995). Top: Results for the Greater Green River basin; Bottom: Results for the Wind River basin. Color keys to pies are provided. Pie size is proportional to total in-place resource.*

each UOA with the estimates previously utilized by NETL's analytical models for technology modeling. These previous estimates were based primarily on United States Geological Survey (USGS) estimates of technically-recoverable volumes from the 1995 National Assessment.

The volumetric results presented above present the sum total resource present in more than 8,000 separately-characterized resource segments, allowing the construction of histograms of the distribution of key volumetric parameters for representative UOA. Figure 26 provides some examples of these data - additional data are provided in charts and figures found separately on this CD. These distributions reveal the natural range and variety that exists for each of the critical parameters. For example, the left chart on Figure 26 shows the number of grid cells in the Lewis UOA, GGRB, that are assigned porosities in 1%-increments ranging from 4% to 20%. The plot shows a feature typical of many UOAs; values are not normally distributed around the average, but are instead slightly skewed to the lower values. The chart to the right, showing the distribution in potential pay thickness for the Fort Union UOA, Wind River basin, shows a similar skewing, as well as the common distribution of pay thickness across a large range (here nearly an order of magnitude).

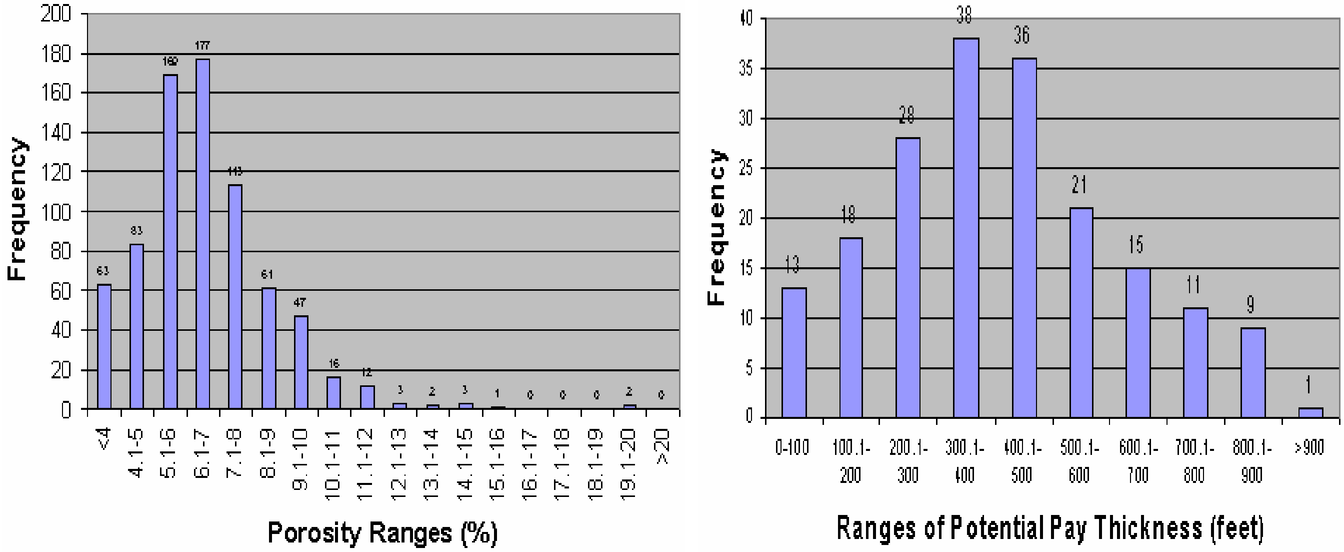

Figure 26: *Example histograms of volumetric parameters. Left – Histogram of potential pay thickness, Fort Union UOA, WRB. Right -Histogram of Porosity distribution in the Lewis UOA, GGRB.*

Resource Recoverability

Key to determining resource recoverability are our estimates of effective permeability. The distribution of estimated permeability shown in Figure 27 for the Lewis and Meeteetsee-Mesaverde UOAs are typical of those for all analyzed UOAs. Matrix permeability is commonly very low, less than 0.01 md, and often less than 0.001 md. However, total effective permeability spans a wide range. Values ranging upwards to 1 md (relatively rare) are present, with many cells assigned values in the range of 0.05 md.

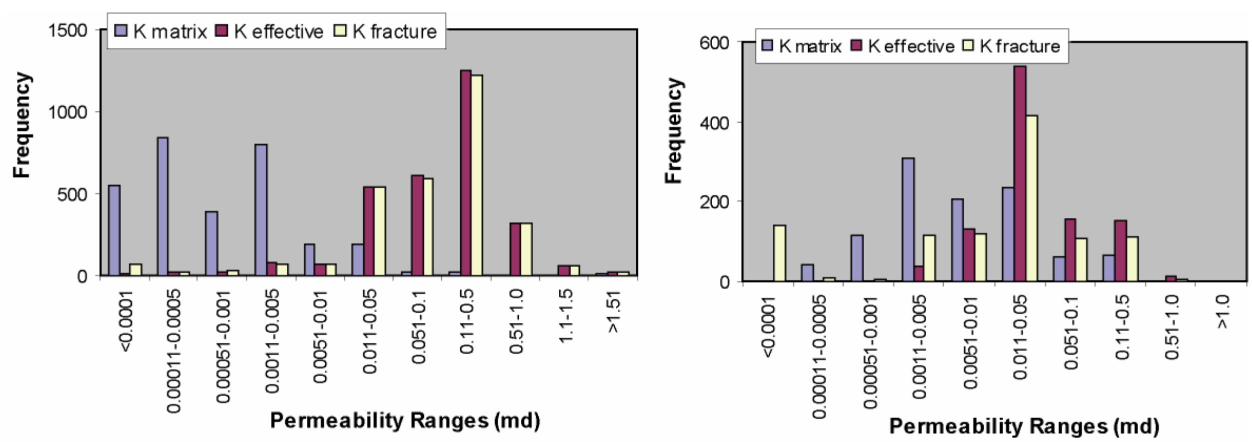

Figure 27: *Distribution of matrix, natural fracture, and total effective permeability in two representative UOAs. Frequency refers to the number of ¼-township grid cells. Left – data from the Lewis UOA, GGRB; Right – data for the Meeteetsee-Mesaverde UOA, WRB.*

Given the improved resource description and various input assumptions describing E&P technologies and costs, NETL's Gas Systems Analysis Model is used to estimate resource recoverability. GSAM's "technically-recoverable" resource is that portion of the in-place resource that can be extracted given current technologies and drilling practices without regard to price. GSAM also allows estimation of "economically-recoverable" resources through its assignment of a unique Minimum Acceptable Supply Price (MASP) to each resource segment (each grid cell in each UOA). The MASP is that price at which net present value for production of that resource equals zero (when long range production income balances costs at the assumed hurdle rate). Therefore, the economically-recoverable resource can be calculated for any given price, and will equal the sum of the technically-recoverable resources in all cells with MASP at or below that price. It should be noted, however, that the primary goal of GSAM is to estimate the *relative* merits of various alternative R&D approaches. Consequently, the absolute values for outputs such as recoverable resource for any particular case are not necessarily as meaningful as the magnitude and direction of change in these numbers between cases.

Table 7*: Selected base case components for GSAM analyses of the new GGRB and WRB datasets*

Parameter	*Marginal Marine UOAs*	*Basinal UOAs*	*Fluvial UOAs*	*Thick Fluvial UOAs*
Drilling Cost	*Set at JAS 2000 regional cost per foot relative to UOA drilling depth*			
Stimulation Efficiency	*60%: As this number increases, the cost of obtaining induced fractures of a given length decrease.*			
Operating/Maintenance Costs	*$8,963/well + $1.04/foot*			
Discount Rate	*25%: Represents the hurdle rate imposed on all projects by the operator.*			
Dry Hole Rate	*0%: As every cell presented to the model contains some gas, there are no truly dry holes, however - a vast majority of the cells in any reasonable case will be "dry" as they produce insufficient volumes to support drilling, completion, or operating costs.*			
Productivity (% of AOF)*	*25%*	*20%*	*20%*	*15%*
Skin Factor	*2*			
Induced Fracture Half-length	*300 feet*			
Induced Fracture Conductivity	*100 md-feet*			
Minimum System Pressure	*150 psi*			
Well Spacing	*160 acres*			
Recovery Factor	*50%*	*50%*	*20%*	*20%*

Explanation: Marginal-marine UOAs = Almond, Frontier-GGRB, Frontier- WRB; Basinal UOA = Lewis; Fluvial UOAs = Dakota-GGRB, Ericson-GGRB, Muddy-WRB; Thick Fluvial UOAs = Lance-GGRB, Lower Mesaverde, Fort Union, Lance-WRB, Meeteetsee-Mesaverde.

The results from GSAM, as from any model, are tied fully to the modeling assumptions incorporated into the "base case". In this study, the base case used reflects our attempt to represent current technology and costs. For the initial analyses of the GGRB and WRB datasets, we have produced a base case (Table 7) designed to capture the distinction between the expected drainage and productivity of 1) exceptionally thick fluvial UOAs (Lance, Lower Mesaverde, Fort Union, and Meeteetsee-Mesaverde), 2) thinner fluvial sections (Ericson, Dakota, Muddy), 3) marginal marine UOAs (Almond, Frontier) and 4) basinal UOAs (Lewis). Two model levers were used in creating this distinction. The first lever is a "productivity" parameter in GSAM that controls the percentage of calculated absolute open flow that will be produced. This lever is intended to account for various factors, including well flow restriction and less than full completion of the total available pay. The lever is set at lower values for thicker units to recognize the fact that lesser portions of the total available pay are likely to be completed. The second lever accounts for variations in recovery efficiency (the % of the spacing area to be drained) and recognizes the inherently higher lenticularity of fluvial units.

Table 8 provides GSAMs estimates of base case technically-recoverable resources for each UOA as calculated by GSAM. Note that the Nugget and Tensleep UOAs in the Wind River basin were not analyzed due to lack of sufficient data. The estimates for base case economically-recoverable resources at $2.00/mcf and $3.50/mcf gas prices are also presented.

Table 8: *GSAM estimates of technically and economically-recoverable resources in each UOA. Values in Tcf.*

Greater Green River Basin				***Wind River Basin***			
UOA	*Technically-Recoverable*	*Economic @ $3.50*	*Economic @ $2.00*	*UOA*	*Technically-Recoverable*	*Economic @ $3.50*	*Economic @ $2.00*
Lance	68	46	18	*Fort Union*	18	10	4
Lewis	33	18	12	*Lance*	29	11	5
Almond	27	8	3	*Meet.-Mvrd.*	37	9	2
Ericson	44	11	4	*Frontier*	32	3	<1
L.Mesaverde	95	21	6	*Muddy*	6	<1	<1
Frontier	59	<1	<1				
Dakota	37	1	<1				
TOTAL	**363**	**105**	**43**	***TOTAL***	**122**	**33**	**12**

GSAM's estimates of 363 Tcf technically-recoverable and 105 Tcf economically-recoverable (at $3.50/mcf price) for the Greater Green River basin significantly exceed the estimates of the USGS in association with the 1995 National Assessment (119 technically-recoverable and 3.3 Tcf economically-recoverable at $3.34/mcf gas price). A 2002 update by the USGS has further reduced the GGRB estimate to 82 Tcf of technically recoverable resource. The differences stem from employing alternative methodologies, different geologic models, and different assumptions. The fact that USGS produces a more conservative answer than our methodology is to be expected when the methodologies are compared. USGS estimates for continuous-type plays are based on the extrapolation of past production history to that play's remaining untested regions and therefore, is influenced by the past economic decisions of operators. These decisions include what technologies to use, whether to complete the well and in what zones, and when to shut-in. In contrast, GSAM's estimate of technically recoverable resource is based on the fundamental reservoir geology modeled under current technology conditions and assuming full resource development. Nonetheless, the GSAM estimate does recognize the practical limits of technical recoverability by including factors that limit recovery factor and productivity (see Table 7.)

Technology Sensitivities

These new characterizations of marginal and sub-economic gas resources were completed primarily to help assess the relative potential of alternative R&D approaches to improve the resource's technical and economic recoverability. Consequently, the most significant outcome of these GSAM analyses is the indication that the resource recoverability is not fixed, but is instead very highly sensitive to changes in both technology and economic conditions. Figure 28

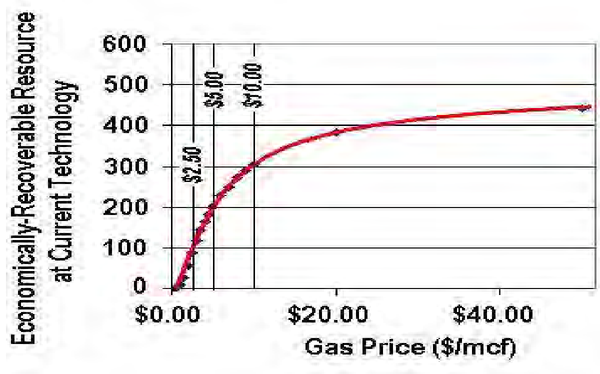

Figure 28: *Economically-recoverable resource versus gas price for the GGRB and WRB datasets*

shows how economically-recoverable resource varies with gas-price. For example, at a wellhead gas price of $2.50/mcf, 89 Tcf of the assessed resource in the GGRB and WRB is economic; however, this volume more than doubles to nearly 200 Tcf at a price of $5.00/mcf. This sensitivity to price clearly translates directly into sensitivity to technology advance. Figure 29 details the sensitivity of the economically-recoverable resource to potential changes in six representative GSAM technology/cost parameters. For example, GSAM predicts the addition of roughly 15 Tcf to the economically-recoverable resource (at $3.50/mcf price) for every 10% reduction in drilling costs. Similarly, each 10% improvement in stimulation cost efficiency adds approximately 8 Tcf to economically-recoverable volumes. These findings indicate that realistic technology advance can have a profound impact on the future recoverability of these resources.

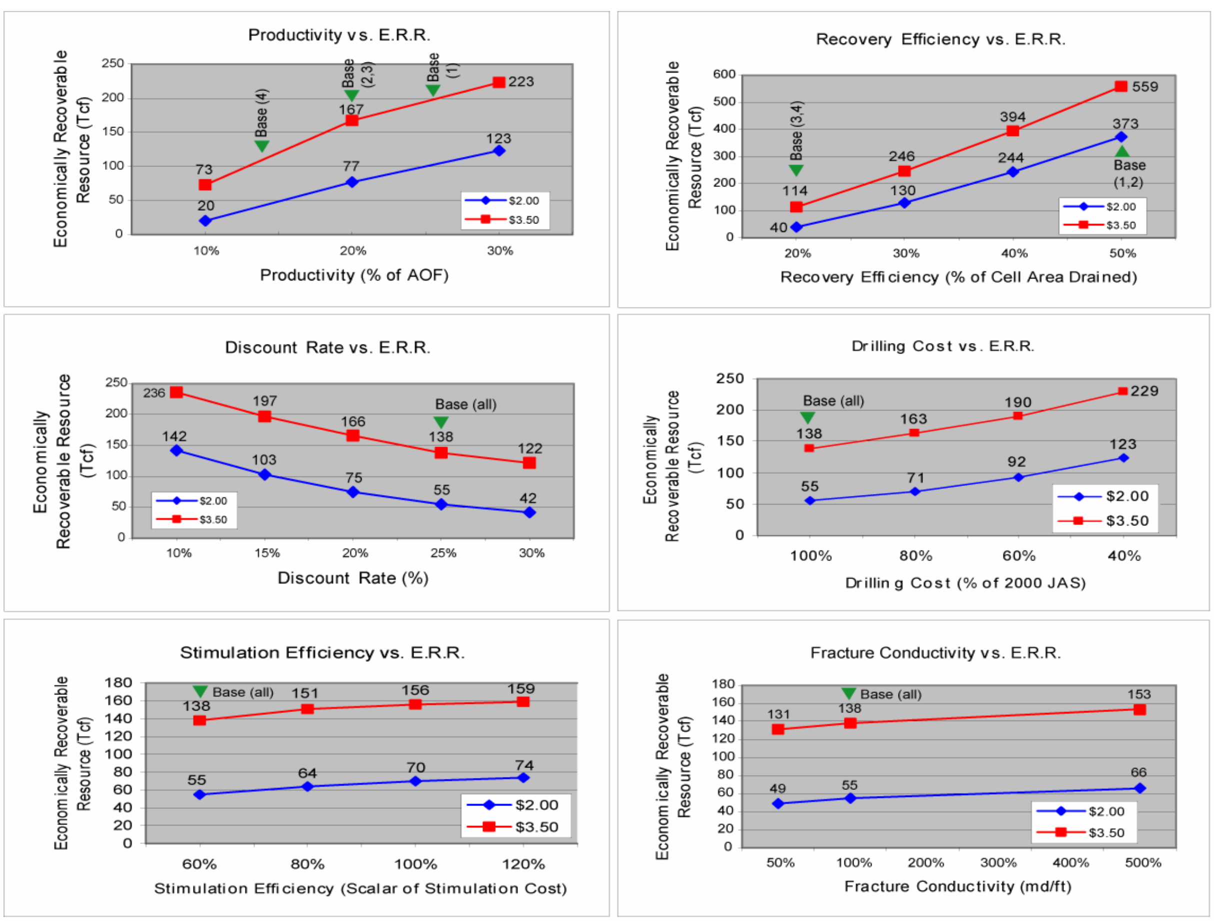

Figure 29: *Sensitivity of GSAM estimates of economically-recoverable resources to incremental changes in key model parameters that are used to represent technology advance. The green triangles indicate the settings for these values for unique portions of the base case ("1" = marginal marine UOAs, "2" = basinal UOAs, "3" = fluvial UOAs, and "4" = thick fluvial UOAs.*

Distribution of Gas-in-Place Resource Relative to Federal Land Access Stipulations in the GGRB.

This study provides a detailed geographic depiction of natural gas resources in the Greater Green River and Wind River basins. In addition to supporting the modeling of technologies, this detail provides an opportunity to assess fully the distribution of resources relative to various classes of Federal land access.

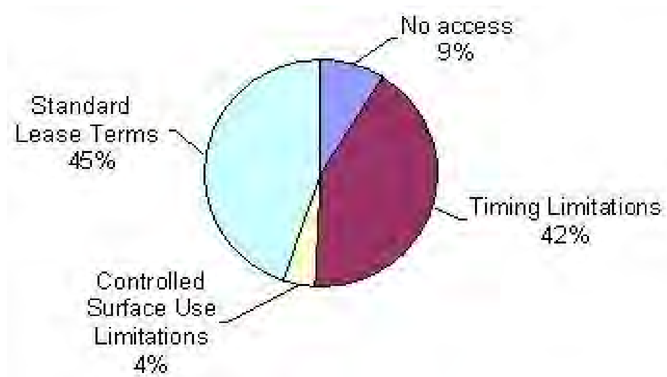

Figure 30: *Distribution of gas-in-place in 6 GGRB UOAs relative to four categories of federal land access restriction.*

To accomplish this, NETL's work on resources has taken advantage of the results of an ongoing inventory of Greater Green River basin federal land access stipulations being conducted pursuant to the Energy Policy and Conservation Act (EPCA) Amendments of 2000. The study is being performed by Advanced Resources International (ARI) for the EPCA Interagency Team that which includes the Department of Interior (Bureau of Land Management, U.S. Geological Survey), Department of Agriculture (Forest Service), and Department of Energy (Energy Information Agency and Office of Fossil Energy). For each grid cell in each UOA of the GGRB, we have determined the percentage of gas-in-place resource that falls within four Federal leasing and land use categories, as follows (Figure 30):

- ***No Access to Resources*** includes four EPCA access categories: (1) no leasing due to statutory or executive order restrictions; (2) no leasing, due to land pending use planning actions; (3) no leasing, due to local (administrative) restrictions; and (4) leasing allowed, but surface occupancy restrictions make access impractical

  Under current legislation or land use plans, these Federal Land areas are "off limits" to oil and gas development. Changes to portions of these land use categories may occur over time, but no reliable means exists on how to forecast this on a township/play level basis.

  Future updates of EPCA would provide new information that would be incorporated to update the NETL database on Federal land use and access. Sensitivity runs with GSAM could be used to examine policies or technology that would relax the no leasing or access constraint.

- ***Leasing, with Drilling/Development Timing Limitations*** also contains four EPCA access categories:

  – Drilling limitations of 9 months, an extremely small category.
  – Drilling limitations of 6 to 9 months, a moderate size category.
  – Drilling limitations of 3 to 6 months, the largest and dominant category.

– Drilling limitations of less than 3 months, a very small category.

Assessing the impact of this category of restrictions is complicated by the fact that, about 40% of the time, drilling limitations can be waived to expand the drilling time window. However, on average, lands falling within these categories are available for drilling only 8 months of the year. This restriction has significant implications for reducing the pace of development and adds costs for extra rig-move or stand-by time.

- ***Leasing, with Controlled Surface Use Restrictions*** is an EPCA Federal land use category that represents stipulations that add significant costs in addition to those existing under standard leasing terms.

- ***Leasing, Standard Lease Terms.*** These Federal lands contain standard lease terms which impose significant costs for environmental compliance.

The gas resources in each Federal land use category were summed to determine the total gas-in-place resource present by stipulation category. The results (Figure 26) show about half (45%) of the total gas-in-place in the GGRB is available under standard lease stipulations. Of the 55% of resource carrying restrictions, 42% are timing restrictions, 4% are controlled surface usage stipulations, and 9% are resources that are restricted from leasing.

Table 9*: Gas resources relative to four categories of land access for six GGRB UOAs.*

UOA	No Access	Timing Limitations	Controlled Surface Use Limitations	Standard Lease Terms
Lewis	7% (10 Tcf)	36% (54 Tcf)	5% (7 Tcf)	52% (77 Tcf)
Almond	11% (12 Tcf)	38% (42 Tcf)	7% (8 Tcf)	44% (49 Tcf)
Ericson	9% (45 Tcf)	45% (233 Tcf)	3% (16 Tcf)	43% (221 Tcf)
Lower Mesaverde	11% (134 Tcf)	40% (494 Tcf)	4% (45 Tcf)	46% (570 Tcf)
Frontier	7% (22 Tcf)	49% (164 Tcf)	3% (9 Tcf)	41% (138 Tcf)
Dakota	8% (37 Tcf)	45% (217 Tcf)	4% (19 Tcf)	43% (209 Tcf)

Table 9 provides this information at the UOA scale, showing the variation in percentages that reflect the differences in the distribution of resource among various geologic units. For example, resources in the Lewis UOA, located exclusively in the eastern half of the basin, show significantly less restriction that those of other plays with wider geographic distribution.

Next Steps

Our analyses indicate that approximately 4,800 Tcf of natural gas exists in-place in the subject intervals of the Greater Green River and Wind River basins. Going forward, this resource characterization will be subjected to numerous analyses using NETL's analytical models to determine how recoverability of this resource relates to various scenarios of future technological progress. In addition, NETL will continue to support efforts that analyze the impact of federal land access stipulations, recognizing the potential of future technology/cost/policy scenarios to significantly expand the technical and economic recoverability of this resource.

In October, 2002, NETL kicked off Phase II of this effort, consisting of similar resource characterization studies of the marginal and sub-economic resources of the Anadarko (Oklahoma-Texas) and Uinta (Utah) basins.