United States Nuclear Regulatory Commission Official Hearing Exhibit
In the Matter of: CROW BUTTE RESOURCES, INC.
(License Renewal for the In Situ Leach Facility, Crawford, Nebraska)
ASLBP #: 08-867-02-OLA-BD01
Docket #: 04008943
Exhibit #: NRC-028-00-BD01
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Other:
Identified: 8/18/2015
Withdrawn:
Stricken:

NRC-028
Submitted: 5/8/2015

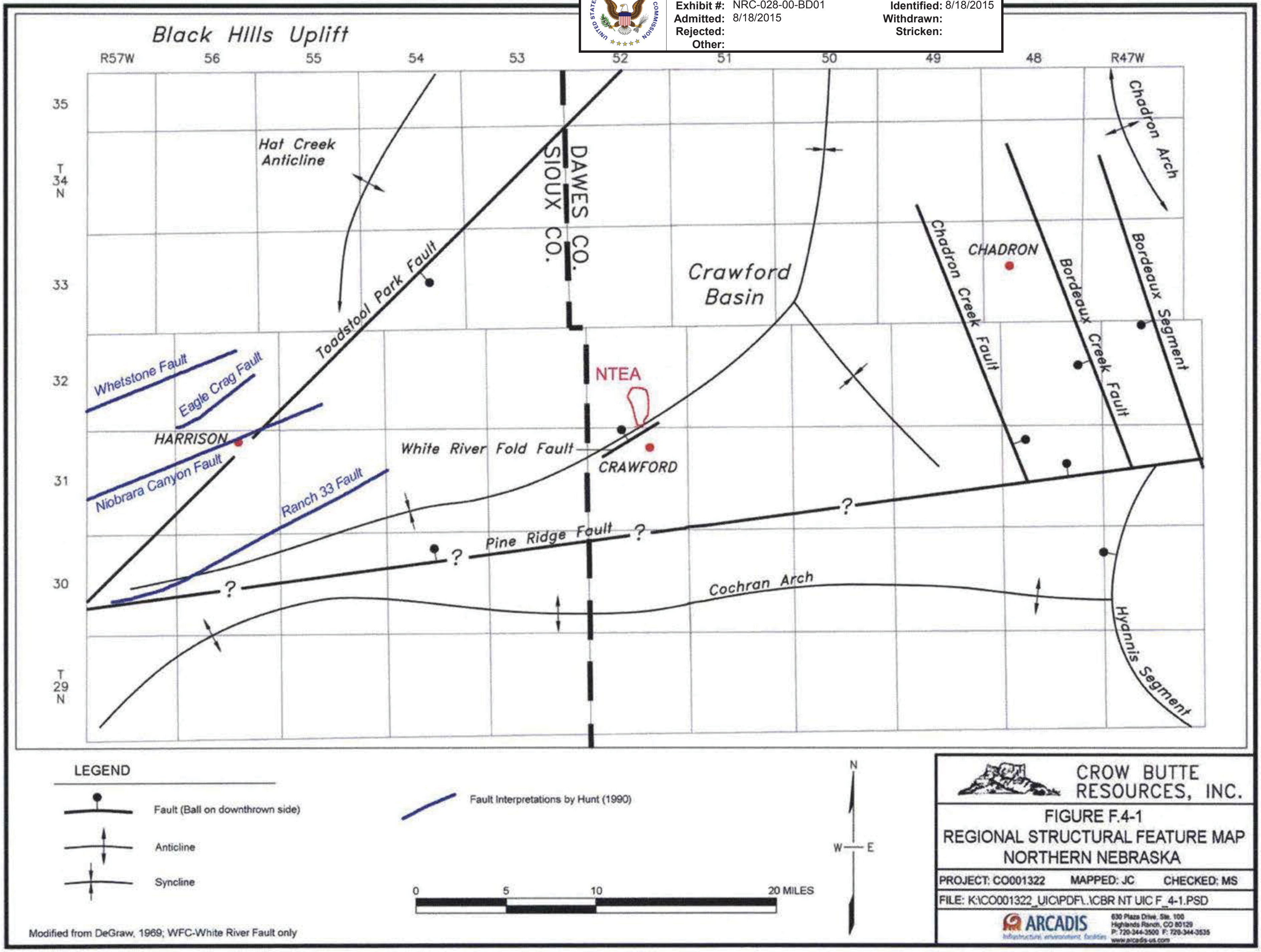
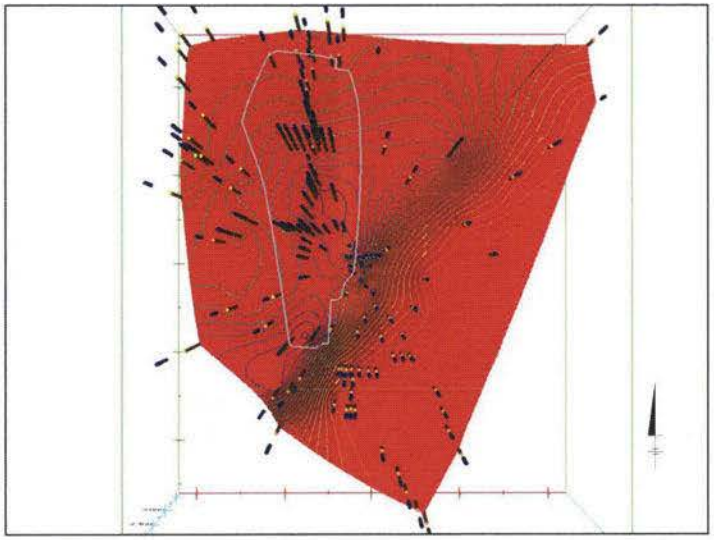
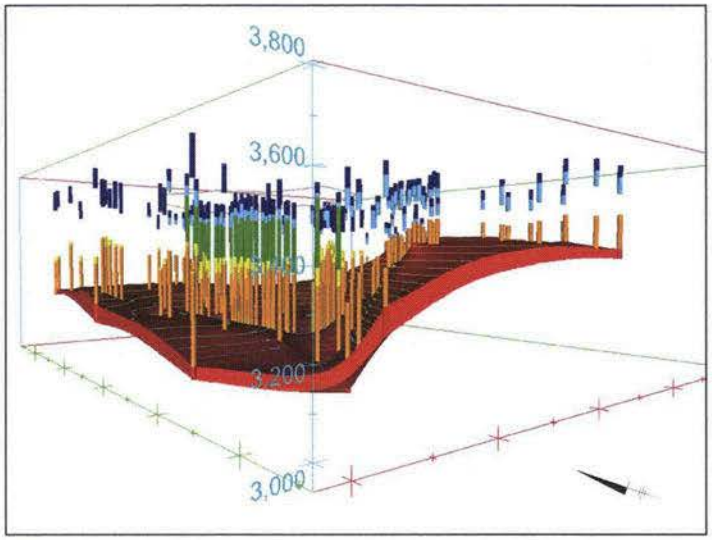


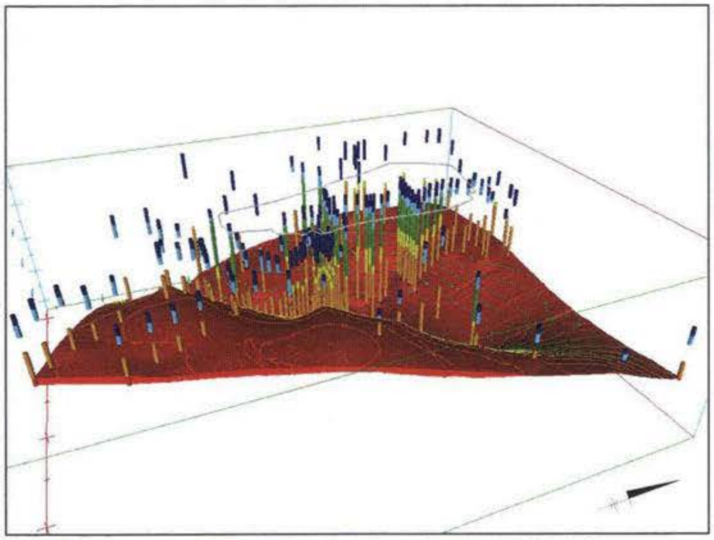
FIGURE F.4-1
REGIONAL STRUCTURAL FEATURE MAP
NORTHERN NEBRASKA



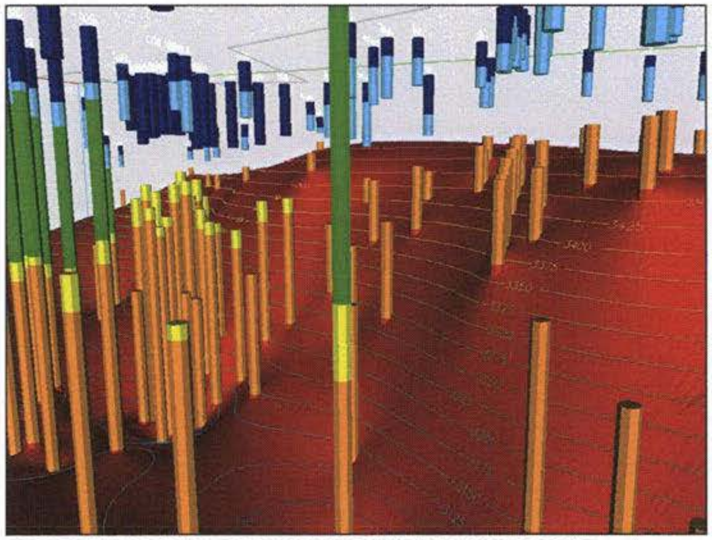
PLAN VIEW (PERMIT BOUNDARY SHOWN)



OBLIQUE VIEW - FACING NORTHEAST (PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW - FACING EAST-NORTHEAST INTO NORTH LIMB OF FOLD

LEGEND:

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

NOTES:

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (axes and contours).

CROW BUTTE RESOURCES, INC.

FIGURE F.3-3a
BASAL CHADRON SANDSTONE
(CHAMBERLAIN PASS FM)

PROJECT: CO001322	MAPPED:	CHECKED: MS
FILE: FIGURE F.3-3a		

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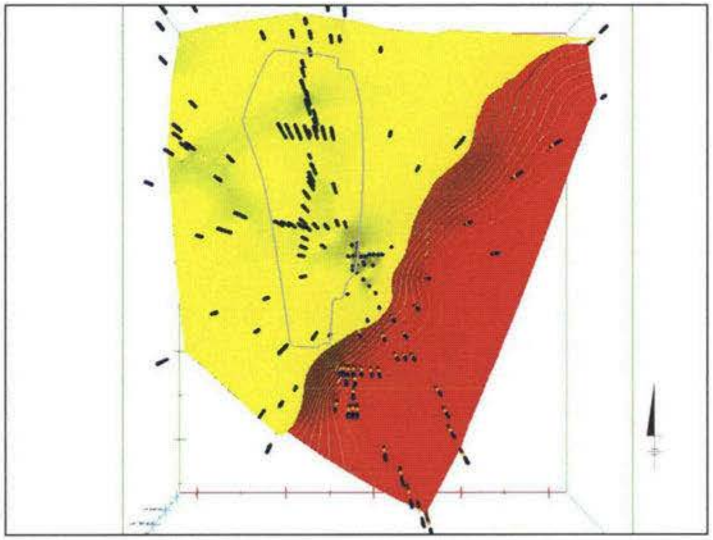
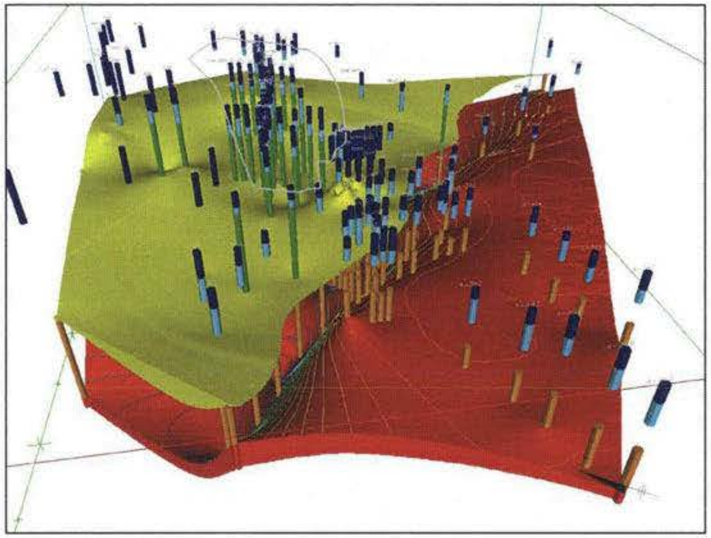
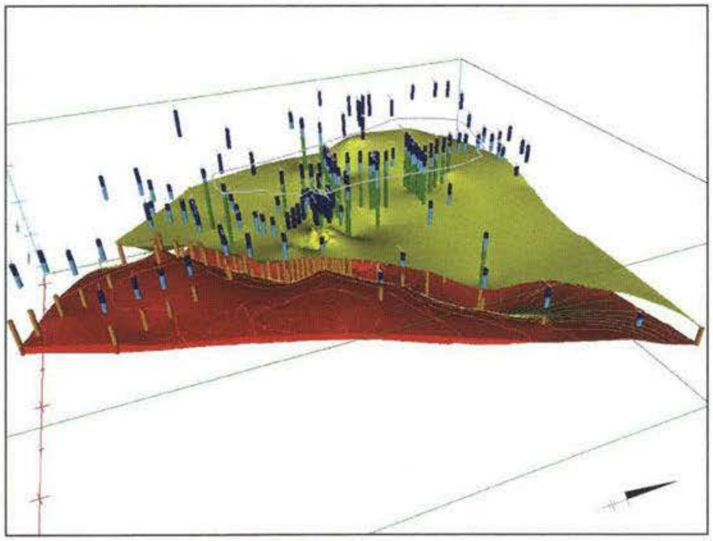


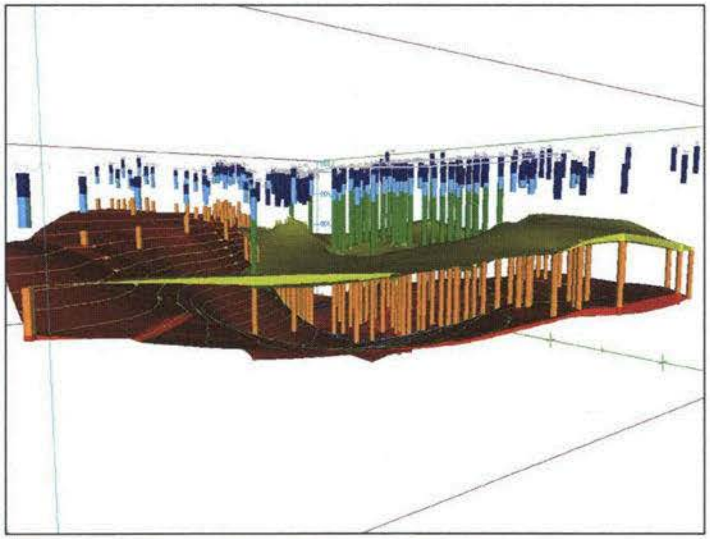
PLAN VIEW (PERMIT BOUNDARY SHOWN)



OBLIQUE VIEW - FACING NORTHEAST (PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW - FACING EAST-NORTHEAST INTO NORTH LIMB OF FOLD

LEGEND:

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

NOTES:

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FIGURE F.3-3b
BASAL CHADRON SANDSTONE (CHAMBERLAIN PASS FM) AND UPPER/MIDDLE CHADRON (BIG COTTONWOOD CREEK MBR)

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: FIGURE F.3-3b

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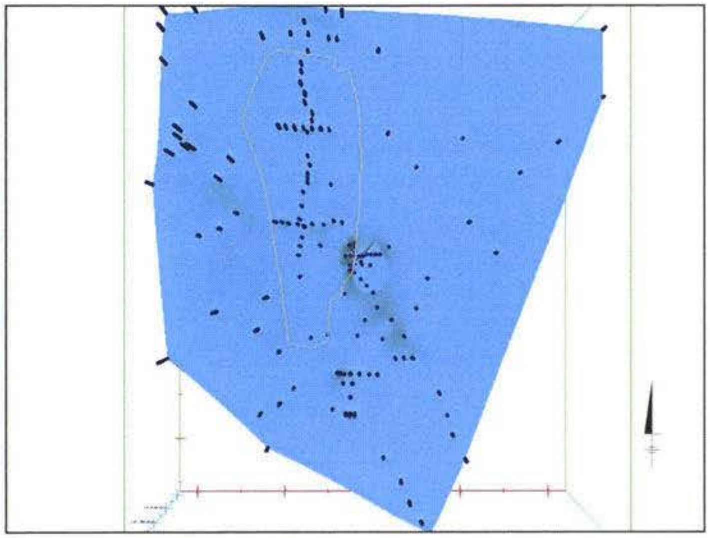
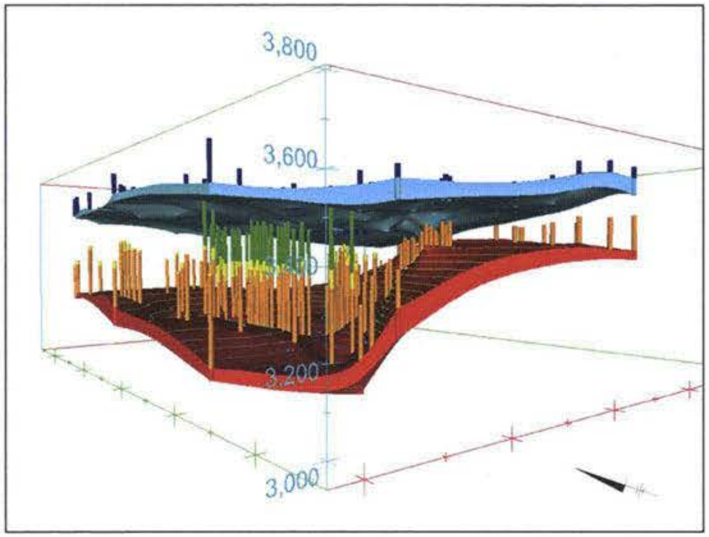
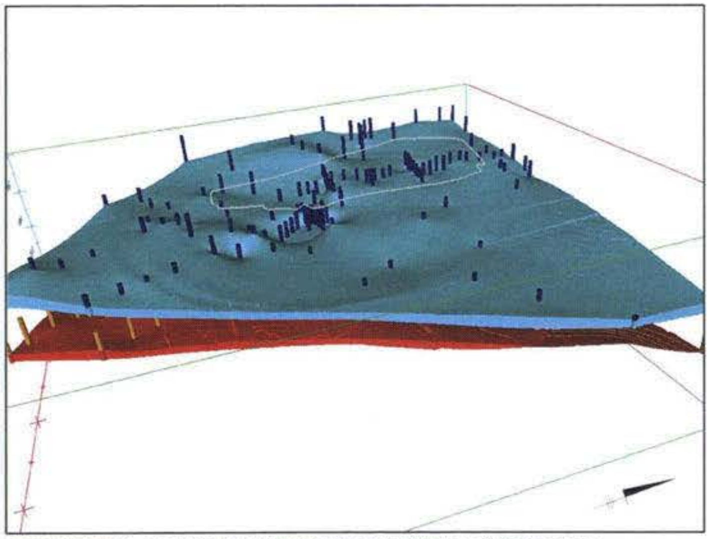


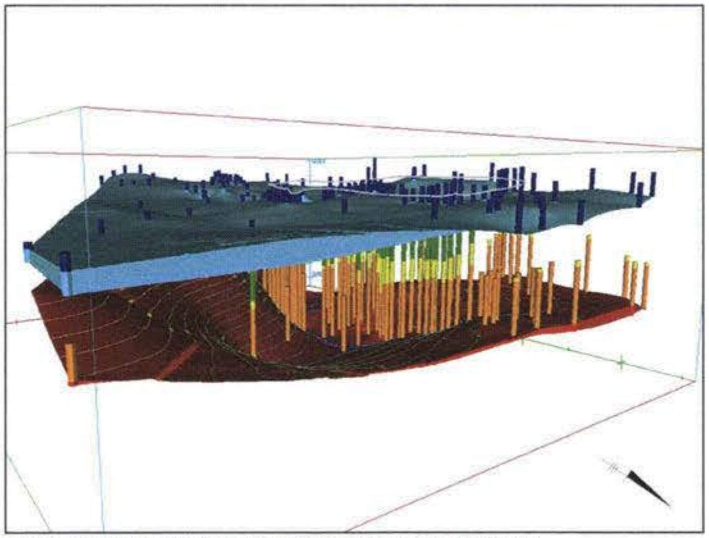
PLAN VIEW (PERMIT BOUNDARY SHOWN)



OBLIQUE VIEW - FACING NORTHEAST (PARALLEL TO FOLD AXIS)



OBLIQUE VIEW - FACING NORTHWEST (PERPENDICULAR TO FOLD AXIS)



OBLIQUE VIEW FACING SOUTHWEST (PARALLEL TO FOLD AXIS)

LEGEND:

STRATIGRAPHY

- Alluvium
- Brule Fm
- Upper Chadron Fm (Big Cottonwood Creek Mbr)
- Upper/Middle Chadron Fm (Big Cottonwood Creek Mbr)
- Middle Chadron Fm (Peanut Peak Mbr)
- Basal Chadron Fm (Chamberlain Pass Fm)

NOTES:

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (axes and contours).

CROW BUTTE RESOURCES, INC.

FIGURE F.3-3c
BASAL CHADRON SANDSTONE (CHAMBERLAIN PASS FM) AND BRULE FM

PROJECT: CO001322 MAPPED: CHECKED: MS

FILE: FIGURE F.3-3c

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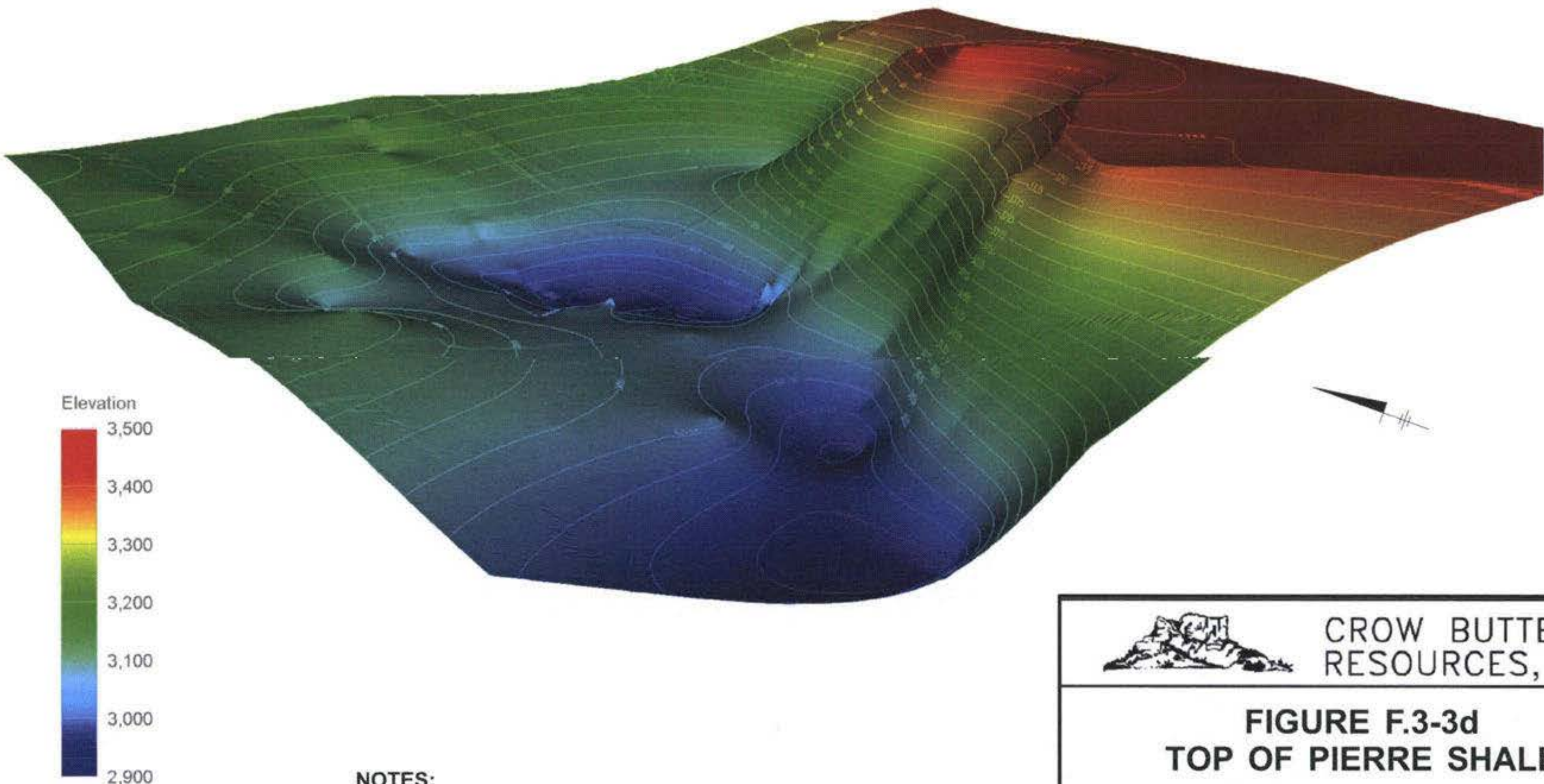

NOTES:

- All of the 3D model output has a 10x vertical exaggeration.
- Elevations are in ft-amsl (color legend and contours).

CROW BUTTE RESOURCES, INC.

FIGURE F.3-3d
TOP OF PIERRE SHALE

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FILE: **FIGURE F.3-3d**

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Additional water-quality samples were collected during three biweekly sampling events from wells in the NTEA in March 2008 to meet the current NRC permit requirements (SUA-1534, Section 10.3). Groundwater sample locations included one Brule Formation well (BOW-1), nine Basal Chadron monitor wells (COW-1, COW-2, COW-3, COW-4, COW-5, COW-6, CPW-2, RC-1, and RC-2), and two Basal Chadron water supply wells (Wells 97 and 123) (**Figure H.2-1** of Chapter H). Attempts were made to collect groundwater samples from a second Brule Formation well (BOW-2); however, this well was dry during each sampling event. All groundwater samples were analyzed for major ions, metals, physical properties, and radionuclides (**Table G.2-6** and **Appendix 7**). Groundwater samples collected in March 2008 from wells in the NTEA were analyzed for each of these daughter products.

Extensive water quality results for the March 2008 sampling event indicate that the Brule Formation and Basal Chadron Sandstone have different geochemical signatures. For the Brule Formation, TDS ranged from 429 to 474 mg/L, uranium concentrations ranged from 0.025 to 0.026 mg/L; polonium-210 concentrations ranged from nondetect to 0.9 pCi/L; and radium-226, thorium-230, and lead-210 concentrations were nondetect for all three sampling events (**Table G.2-6**). For the Basal Chadron Sandstone, TDS ranged from 1,200 to 2,550 mg/L, uranium concentrations ranged from nondetect to 0.0361 mg/L, radium-226 concentrations ranged from nondetect to 44.6 pCi/L, thorium-230 concentrations ranged from nondetect to 0.2 pCi/L, lead-210 concentrations ranged from nondetect to 39.2 pCi/L, and polonium-210 concentrations ranged from nondetect to 7.6 mg/L (**Table G.2-6**). Note that uranium concentrations were nondetect at all sampling locations outside of the NTEA (RC-1, Well 97, and Well 123) (**Figure H.2-1** of Chapter H). Based on the March 2008 results, concentrations of TDS, major ions, uranium, and all daughter products of uranium decay are elevated in the Basal Chadron Sandstone.

Water quality samples collected from the Basal Chadron Sandstone in the CSA and the NTEA indicate that both areas have similar geochemical conditions. Water quality results for the Basal Chadron Sandstone in the CSA are presented in **Table G.2-3** and for the NTEA in **Table G.1-7** and **Table G.2-4** through **Table G.2-6**. Total dissolved solids range from 1,500 to 2,500 umhos in the CSA and from 423 to 2,510 micromhos (umhos) in the NTEA. Calcium ranged from 11 to 41 mg/L in the CSA and from 8 to 77 mg/L in the NTEA. Magnesium ranged from 0.8 to 7.2 mg/L in the CSA and from non-detect to 12 mg/L in the NTEA. Sodium ranged from 340 to 540 mg/L in the CSA and from 41 to 848 mg/L in the NTEA. Potassium ranged from 7 to 19.8 mg/L in the CSA and from 9 to 31 mg/L in the NTEA. Bicarbonate ranged from 308 to 411 mg/L in the CSA and from 244 to 531 mg/L in the NTEA. Sulfate ranged from 254 to 620 mg/L in the CSA and from 51 to 1200 mg/L in the NTEA. Chloride ranged from 134 to 250 mg/L in the CSA and from 27 to 328 mg/L in the NTEA. Uranium concentrations ranged from non-detect to 2.4 mg/L in the CSA and from non-detect to 0.0361 mg/L in the NTEA. Radium-226 concentrations ranged from 0.1 to 619 pCi/L in the CSA and from non-detect to 44.6 pCi/L in the NTEA.

G.3 Aquifer Testing and Hydraulic Parameter Identification Information

During the initial permitting and development activities within the CSA, two pumping tests were conducted in the central portion of the CSA to: (1) assess the hydraulic characteristics of the Chadron Sandstone and (2) demonstrate the confinement provided by the overlying and underlying aquicludes. Those tests, referred to as Test #1 and Test #2, were performed in 1982

and 1987, respectively (Wyoming Fuel Company 1983; Resources Technologies Group 1987). Test #3 was conducted in September 1996 (Harlan & Associates, Inc. 1996). Test #4 was conducted in August 2002 (PetroTek 2002). Results from those tests are summarized in **Table G.3-1**.

Pumping tests on the Basal Chadron Sandstone aquifer were conducted in the NTEA between 2004 and 2006 (**Appendix 5**). Testing activities and findings from pumping test activities in the NTEA are summarized below.

Results from the initial testing activities conducted in 2004 to 2005 (Tests #1 through #5) were not definitive as a result of such problems including improperly abandoned old exploration holes, equipment problems, insufficient stress (drawdown) to provide usable data and infiltration of surface water into observation wells. Prior to testing, CBR installed seven new wells in the Basal Chadron Sandstone (CPW-1, CPW-2, COW-1, COW-2, COW-3, COW-4, and COW-5) (**Figure H.2-8** of Chapter H). CPW-1 was installed specifically for use as a pumping well, but was subsequently abandoned due to casing problems, and CPW-2 was installed as a replacement. The remaining wells were used as observation wells. A pre-existing well that was screened in the Basal Chadron Sandstone (RC-2) was also used as a monitoring location. To assess the hydrogeologic isolation of the Basal Chadron Sandstone aquifer during testing, CBR also installed monitor wells in the overlying Upper/Middle Chadron (MCOW-1 and MCOW-2) and Brule Formation (BOW-1) (**Figure H.2-8** of Chapter H). Because the Basal Chadron Sandstone is underlain by the thick and relatively impermeable Pierre Shale (as discussed in Sections E.3 and G.4), no underlying monitor wells were installed.

A longer pumping test was conducted in June and July 2006 (Test #6) which included installing new monitor wells in the Upper/Middle Chadron (MCOW-3 and MCOW-4) and Brule Formation (BOW-2), and use of automated equipment. The pumping test was conducted in accordance with a Test Plan submitted by CBR to the NDEQ in June 2006. Well information for wells used during the 2006 pumping test is summarized in **Table G.3-2**. Locations of wells used during the 2006 pumping test are illustrated on **Figure H.2-8** of Chapter H.

The 2006 pumping test was designed to assess the following:

- degree of hydrologic communication between the Basal Chadron Sandstone pumping well and the surrounding Basal Chadron Sandstone monitor wells
- presence or absence of hydrologic boundaries within the Basal Chadron Sandstone aquifer over the test area
- hydrologic characteristic of the Basal Chadron Sandstone aquifer within the test area
- degree of hydrologic isolation between the Basal Chadron Sandstone aquifer and the overlying aquifers

The 2006 pumping test was conducted while pumping at COW-5 at 16.4 gpm for 357 hours (14.9 days). The radius of influence (ROI) was approximately 7,500 feet. More than 110 feet of drawdown was achieved during testing, and all wells monitored during the test indicated adequate drawdown (e.g., greater than 1.3 feet), confirming hydrologic communication with the Basal Chadron Sandstone aquifer.

Results of the 2006 pumping test indicate a mean hydraulic conductivity of 2.3 feet/day (8.1 x 10^{-4} centimeters per second [cm/sec]), a mean transmissivity of 60 square feet per day (ft^2/day; ranging from 42 to 75 ft^2/day), and a mean permeability of approximately 1,100 millidarcies (md) based on an assumed water viscosity of 1.35 centipoise (cP) (at 50 degrees Fahrenheit) and a density of 1 (**Table G.3-1**). The mean storativity was 5.3 x 10^{-5} (ranging from 2.3 x 10^{-5} to 8.4 x 10^{-5}) (**Table G.3-1**). Estimated hydraulic parameters for individual well locations for the 2006 pumping test are summarized in **Table G.3-3**. No water level changes of concern were observed in any of the overlying wells during testing. The pumping test results demonstrate the following important conclusions:

- The Test #6 monitor well network is in hydraulic communication with the Basal Chadron Sandstone aquifer throughout the NTEA.
- Hydrogeologic conditions of the Basal Chadron Sandstone aquifer have been adequately characterized within the test area.
- There is adequate confinement between the Basal Chadron Sandstone aquifer and the overlying Upper/Middle Chadron and Brule Formation throughout the majority of the NTEA.
- Transmissivity of the Basal Chadron Sandstone in the NTEA is relatively consistent, but the thickness and hydraulic conductivity vary with direction and location.

These conclusions indicate that, though variance in thickness and hydraulic conductivity may impact mining operations (e.g., well spacing, completion interval, and injection/production rates), it is not anticipated to impact regulatory issues. It should be noted that cross-sections presented in the North Trend Hydrologic Testing Report - Test #6 (Petrotek 2006) differ from cross-sections presented in this application, which are revised interpretations based on a recent extensive review of available site-specific drilling logs and published literature.

The raw data from Test #6 was investigated for apparent boundary conditions as a result of structural folding of the Basal Chadron Sandstone. Extraction pumping at COW-5 produced drawdown in observation wells COW-2 and RC-2, which were used in this analysis due to their proximity to the fold structure. The data was imported into AQTESOLV and analyzed using the Theis solution to radial groundwater flow in a confined aquifer. Estimates of transmissivity and storage were similar and generally agreed with those provided by Petrotek (Petrotek, 2006).

A no-flow groundwater boundary was simulated in AQTESOLV at a distance of 7,000 feet from COW-5. This distance corresponds to the midpoint of the north-dipping fold limb south of the NTEA, which is approximately 1,000 feet south of RC-2. Simulated boundary conditions predict that increased drawdown should have been observed at RC-2. The simulated boundary condition was moved to a distance of 7,500 feet and similar results were observed. Though the 7,500 foot radius of influence (ROI) for Test #6 was adequate to recognize a hydraulic boundary between the top anticlinal axis of the fold structure and the pumping well, increased drawdown was not observed at RC-2 during Test #6. Therefore, a hydraulic boundary likely does not exist within the fold structure.

- Results of the 2006 aquifer pumping test demonstrate no observed drawdown in observation wells screened in overlying water-bearing units throughout the majority of the NTEA (see Section G.3).
- Site-specific x-ray diffraction, particle grain-size distribution analyses, and geophysical logging confirm the presence of two upper confining units, each consisting of thick sequences (up to 250 and 300 feet) of low-permeability mudstone and claystone, and a thick (up to 1,500 feet), regionally extensive lower confining unit composed of very low-permeability black marine shale (see Section G.4.1).
- Large differences in hydraulic head (80 to 90 feet) were observed between the Basal Chadron Sandstone and two overlying water-bearing units (see Section G.4.1).
- Significant historical differences exist in geochemical groundwater characteristics between the Basal Chadron Sandstone and the Brule Formation (Section G.2.2).

G.4.3 Hydrological Affects of Folding

The overall hydraulic gradient direction in the Basal Chadron Sandstone aquifer is generally to the southeast (**Figure H.2-5** of Chapter H). Steep folding of the Basal Chadron Sandstone associated with development of the fold structure immediately south of the NTEA boundary does not appear to effect the overall hydraulic gradient direction. However, there is a noticeable increase in hydraulic gradient south and east of well location COW-2, where the gradient is nearly three times steeper than the hydraulic gradient in the NTEA (**Figure H.2-5** of Chapter H). Several explanations for the increased hydraulic gradient are presented below:

- Based on the occurrence of increased hydraulic gradient coincident with the location of the fold structure and hydraulic head isolines that parallel the strike of the fold axis, it is feasible that development of the fold structure (e.g., jointing, fracturing, compression of the aquifer matrix) as a result of compressional stresses (i.e., reverse faulting) caused a change in pore connectivity, with a bulk decrease in permeability of the Basal Chadron Sandstone. Based on this observed change in gradient, transmissivity appears to be reduced by as much as 50 percent or more in the vicinity of the fold. The occurrence of hydraulic head iso lines that parallel the strike of the fold further support a reduction in transmissivity as a result of compressional folding, as one would expect a reduction in transmissivity to occur along the entire length of the fold.
- Flexural thinning of stratigraphic units located along the length of the fold limb resulted in reduced transmissivity in the Basal Chadron Sandstone aquifer. Though a reduction in hydraulic conductivity may have occurred, only flexural thinning is necessary to reduce transmissivity.
- Potential localized and distributed faulting within the Basal Chadron Sandstone may explain the observed increase in hydraulic gradient. However, hydraulic confinement demonstrated by the 2006 aquifer pump test within the NTEA indicates that even if distributed faulting were present, it currently does not significantly impact hydraulic confinement of the Basal Chadron Sandstone.Heterogeneity may exist within the Basal Chadron Sandstone, which reduces the transmissivity south of the NTEA.

- Any spatial variation in leakage through the upper confining layers could contribute to the observed gradient change. However, the rate of leakage required to produce the observed change in gradient would be minimal.
- Regional influence from pumping (e.g., ISL mining activities at the CSA to the south) may be affecting the observed gradient.
- Any combination of scenarios listed above.

Yecheili et al. (2007) concluded that steep hydraulic gradients associated with pressure-induced permeability reductions were due to compressional stresses on the steep limbs of the Ramallah and Hebron monoclines in a layered structure in the Judea Group Aquifer system in Israel. Their study is analogous to the effects of tectonic folding on the hydrologic conditions within the Basal Chadron Sandstone. However, without a quantitative basis or additional data with which to further evaluate these possible explanations, development of a comprehensive groundwater model with an integrated systems analysis could be used to choose the best quantitative solution, as well as optimize ISL mining scenarios from a cost perspective.

Based solely on the 2006 pumping test results, the existence of a discrete fault surface that cuts upsection into the White River Group (and the Basal Chadron Sandstone aquifer) cannot be ruled out. However, numerous lines of evidence (listed below) support the inference that the White River Fault does not offset the geologic contact between the Pierre Shale and Basal Chadron nor members of the Chadron Formation and, therefore, does not affect the hydraulic confinement of the Basal Chadron Sandstone aquifer:

- There is a lack of obvious linear features on the top surface of the Pierre Shale and Basal Chadron Sandstone that are typically associated with discrete fault displacement, which would indicate a fault rupture (**Figures F.3-3a** through **F.3-3d** of Chapter F).
- Based on geophysical logging, there is adequate spatial resolution of continuous geophysical signatures across the steep fold limb for two important marker beds (Pierre Shale and Basal Chadron Sandstone) that indicate the geologic beds are not offset due to faulting (**Figure F.3-3a** of Chapter F, lower right panel; **Figure F.3-3d** of Chapter F; **Appendix 4**).
- If a permeable fault boundary did exist south of the NTEA, one would expect to observe more dramatically decreased water levels near the fold structure (see **Figures F.2-3a, F.2-3b,** and **F.2-3d** of Chapter F). Significantly decreased water levels have not been observed, thereby indicating that the hydrologic effects of the fold structure are limited to reduced transmissivity within the Basal Chadron Sandstone aquifer).

Deposition of the Brule Formation likely post-dated most, if not all, deformation associated with the White River fold structure (see Section E.4.2). Though the Brule Formation may have experienced a very low magnitude of broad, concentric folding, tensile fracture development requires only very low strains (**Figure F.3-3**). A distinctive and pervasive tensile fracture set associated with even subtle fold development is possible. Such fractures could be due to continued deeper fault movement and shallower bending stresses or due to differential compaction, subsidence and diagenesis across a buried fault-fold structure. However, self-sealing (fracture annealing) due to wall-rock swelling clays should be expected. Additionally, an older