KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 2003-77

FOLLOW-UP STUDIES RELATED TO VENT WELLS AROUND YAGGY STORAGE FACILITY, HUTCHINSON, KANSAS

by

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Introduction

As per KGS OFR (2002-71) the Kansas Geological Survey (KGS) recommended selective plugging of the vent wells that had been drilled by ONEOK to bleed subsurface gas after the natural gas explosions at Hutchinson, Kansas, in 2001. Acting on the recommendations of the KGS, the Kansas Department of Health and Environment (KDHE) directed ONEOK to plug all vent wells in Group-1 except 7 wells. The 5 observation (OB) wells were kept open for continued monitoring. KDHE also directed ONEOK to plug all but 4 wells in Group-2. Acting on the directive from KDHE, ONEOK conducted shut-in surveys at the vent wells that were left open in intervals of 6 months. KGS received a copy of the data collected during two such surveys. The first survey was carried out during January-February 2003 while the second was recorded in July-August 2003.

Data recording

In each survey, surface shut-in pressures were recorded at each Group 1 well after 70+ hrs along with the standing fluid column in the well. At the observation wells, the shut-in surface pressures were recorded after 96+ hrs of shut-in along with the standing fluid column in the well. OB wells #3, #4, and #5 have packers in them such that the tubing connects to the salt below the 3-Fingers (3F) gas zone. In these wells, the 3F-zone connects to the annulus between the casing and the tubing. For these wells, the standing fluid columns were recorded in the casing-tubing annulus. Subsurface pressure at 3F-zone was estimated by adding the surface shut-in pressure to the pressure exerted by the corresponding hydrostatic column above the gas zone using a hydrostatic pressure gradient of 0.5 psi/ft.

Analysis of shut-in data from vent wells – January/February 2003 survey

All DDV wells have a standing fluid column above the 3F-zone and show shut-in pressure at the surface. This means that in each of these wells, subsurface gas is able to overcome the hydrostatic column above 3F-zone and record a shut-in pressure at the surface. Table 1 summarizes the data recorded in this survey along with the estimated pressures at the 3F-zone. For the DDV wells, the estimated subsurface pressures vary between 59 psi to 116 psi. The highest subsurface pressure, 173 psi, was recorded at OB#2 well. At OB #1, #4, and #5, the surface shut-in pressures remained at zero psi even after shut-in periods of 96+ hrs. With these data, it is not possible to determine if the 3F-zone is pressurized at these wells. The pressures noted against the 3F-zone at these wells correspond to the standing hydrostatic head. With zero surface shut-in pressures, it is difficult to determine if the 3F-zone at these wells has negligible pressure or a pressure equal or less than the estimated hydrostatic column. Water columns in the casing annulus of OB #1, #4, and #5 do not extend to the surface, thus maximum pressures in the 3F-zone, if any are subhydrostatic. Therefore, the 3F-zones remain sub-hydrostatically pressurized (Figure 1) in the vicinity of the unplugged Group 1 wells.

Shut-in period of all Group-1 wells was extended to 408 hrs after which, at each well, the surface shut-in pressure was again recorded. However, the standing fluid column in each well after 408 hrs of shut-in was not recorded. Table 2 summarizes the data from this extended shut-in. Lacking fluid column data corresponding to a 408 hr shut-in, the fluid column depth recorded after 72+ hours of shut-in was used to estimate the gas pressure at the 3F-zone after 408 hours of shut-in. It appears that the subsurface gas pressure increased, between 7.3 to 39.7 psi, when the shut-in time was extended from 72+ hrs to 408 hrs. The subsurface pressure appears to have declined between 72+ hrs and 408 hrs of shut-in only for well DDV#68 perhaps due to some leak in the system. For the observation wells, no records of shut-in pressures corresponding to the tubing-casing annulus were made available after the extended shut-in period of 408 hrs.

Table 3 compares the estimated subsurface pressure at 3F-zone between the July 2002 and January 2003 surveys. The pressures compared correspond to a shut-in time between 72 to 96 hrs. It appears that for most of the vent wells, the subsurface pressures have declined, between 3 to 46 psi over this time giving credence to the fact that these open vent wells are still able to bleed out some of the subsurface pressure over time. However at DDV #42, the pressure in the 3F-zone has increased by 26 psi. At OB #1, #4, and #5, the surface shut-in pressures have been zero in the July 2002 and January 2003 surveys. Thus it is not possible to evaluate if the change in the estimated subsurface pressures is due to increased gas pressure in 3F-zone and/or increase in standing fluid column in the respective wells.

Additional comments on January-February 2003 survey

The plugging criteria that was used by KGS to determine if a vent well was to be left unplugged was that the well should have registered a tubing-head-shut-in-pressure (THSP) greater than zero psi and that the estimated pressure in 3F-zone should have been in excess of 100 psi. The well

DDV #9 had been recommended for plugging because it had reached a target depth (TD) of only 63 feet while the top of the 3F-zone was at 286 feet. The well had been kept shut for months and the THSP as of July 2002 was 39 psi. Because this well had failed to reach the 3F-zone, it had been recommended for plugging. However for reasons unknown, this well was left unplugged at the time of the January 2003 survey. During this survey, most of the shut-in pressure bled off during the lowering of the pressure recorder in the well. However within the time frame of this survey, the surface pressure at the well again build up to 33.2 psi. It is therefore appropriate to look into the source of the gas flowing into this well particularly given the fact that the well TD does not reach the 3F-zone.

The TD of well DDV #12 has been reported as 204 feet while the top of the 3F-zone is around 262 feet. Thus the TD of this well also fails to reach the 3F-zone. However, a THSP of 3 psi was recorded at this well after 73 hours of shut-in period, which rose to 6.9 psi upon extending the shut-in period to 408 hrs. Like DDV#9, it is recommended that the source of this gas be investigated at DDV #12 particularly when the well TD falls short of the 3F-zone.

The well DDV #17 had been recommended for plugging. However for reasons unknown, this well remained unplugged at the time of the January 2003 survey, during which the THSP remained zero after 72.7 hours of shut-in. This well meets the plugging criteria and is therefore recommended for plugging.

Analysis of shut-in data from vent wells – July/August 2003 survey

Table 4 summarizes the data collected from the July-August shut-in survey on the Group-1 vent wells. As in the previous survey, standing fluid columns above the 3F-zone were recorded at each well along with a non-zero THSP. Thus, the estimated subsurface pressures at the 3F-zone are due to resident gas. The estimated subsurface pressures vary between 55 psi to 100 psi in the DDV wells. As before, the highest subsurface pressure (152 psi) in the 3F-zone was recorded at OB#2 well. At OB #1, #4 and #5, the surface shut-in pressures remained at zero psi even after shut-in periods of 96+ hrs leaving it impossible to determine if the 3F-zone around these wells remain pressurized or not. The pressures noted against the 3F-zone at these wells correspond to the standing hydrostatic head and therefore serve as the maximum pressure that can be expected in the 3F-zone if it were to be charged with gas. Water columns in the casing annulus of OB #1, #4, and #5 do not extend to the surface, thus maximum pressures in the 3F-zone, if any, are subhydrostatic. Thus, 3F-zones remain sub-hydrostatically pressurized around the unplugged Group-1 wells (Figure 2).

Surface shut-in pressures were recorded again at all Group-1 wells after 408 hours. As before, no measurement of standing fluid columns in each well was carried out at the end of this extended shut-in period. Table 5 summarizes the data from this extended shut-in. Lacking fluid column data corresponding to a 408 hr shut-in, the fluid column depth recorded after 72+ hours of shut-in was used to estimate the gas pressure at the 3F-zone after 408 hours of shut-in. It appears that there was an increase in subsurface gas pressure, ranging between 0.4 to 26.5 psi, when the shut-in time was extended from 72+ hrs to 408 hrs. The maximum increase, of 41.6 psi, occurred at the observation well OB#2. The final pressure recorded at this well was 193.6 psi, which is very close to the pressure (182.2 psi) recorded at this well after a similar shut-in in January 2003. The subsurface pressure appears to have declined between 72+ hrs and 408 hrs of shut-in only for well DDV#67 perhaps due to some leak in the system. For the observation wells OB#3, #4, and#5, no records of shut-in pressures corresponding to the tubing-casing annulus were made available after the extended shut-in period of 408 hrs. Thus as in January 2003 survey, subsurface gas pressures increase at most wells when the shut-in periods are extended.

Table 6 compares the estimated subsurface pressure at 3F-zone after a shut-in period ranging between 72 to 96 hours at 3 points in time, i.e., July 2002, January 2003, and July 2003. Between July 2002 and July 2003, the estimated subsurface pressures have declined, between 7 to 60 psi, for all DDV wells except DDV #42. At DDV #42, the pressure in the 3F-zone has increased by 25 psi during this period of time. At OB#1, #4 and #5, the surface shut-in pressures have been zero in both the July 2002 and July 2003 surveys. Thus it is not possible to evaluate if the change in the estimated subsurface pressures is due to increase in gas pressure in 3F-zone and/or increase in standing fluid column in the respective wells. In general it appears that most of the remaining open vent wells are still venting gas resulting in lowering of subsurface pressure in the 3F-zone.

Group 2 wells

Group-2 vent wells at Hutchinson never produced measurable quantities of gas since they there drilled and completed. All but 4 Group-2 wells had been recommended for plugging and have been plugged.

At the time of the January 2003 survey, the four unplugged Group-2 wells had been shut-in for many months (1500+ hrs). During this survey, the THSP and the standing fluid columns had been recorded. However as these wells had been shut-in for many months prior to the survey, it was difficult to make use of the gathered data. Obviously due to their long shut-in periods, these wells had reached a state of equilibrium by locking in the built-up pressure that corresponded to the early period (days) of the shut-in period. This made it difficult to evaluate if the 3F-zone in the vicinity of the wells still remained charged. It was therefore recommended that ONEOK open these wells before the July 2003 survey to bleed off the built-up pressure and then proceed on to record the THSP and standing fluid columns after 72+ hrs of shut-in.

The results of the July 2003 survey data of Group-2 wells are listed in Table 7. It is apparent that the THSP at 3 of the 4 wells remained at zero after a shut-in period varying between 72 and 96 hrs. Data could not be recorded at DDV #45 because the recording tool got lost in the hole. Though standing fluid columns were recorded at the wells, this data in conjunction with the THSP was insufficient to determine if the calculated pressure at the top of 3F-zone represented gas pressure or the hydrostatic head of the water column in the well. However, each of the Group 2 wells had been opened under unloaded conditions after their completions and none produced any measurable volumes of gas. Thus, it is not unreasonable to assume that the 3F-zone around these wells is (perhaps) incapable of delivering significant volumes of gas into the vent wells even if the vent wells were unloaded.

Review of ONEOK's procedure for determining the maximum annual storage pressure for reporting to KDHE

(Based on a request from KDHE. Report reviewed was dated April 3, 2003, and was prepared by Baker & O'Brien Inc. for ONEOK.)

Objective

Evaluate the approach used by ONEOK to identify the maximum daily average POD1 pressure in Yaggy for reporting to KDHE.

Reporting procedure followed by ONEOK

Step 1: For the entire Yaggy field, identify the highest end of month storage volume for the calendar year.

Step 2: For selected month of highest (field) inventory, identify the highest daily storage volume for the entire Yaggy field. ONEOK calls this day as the "Gas Day".

Step 3: Confirm the no injection or production took place on "Gas Day" – i.e., static conditions prevailed.

Step 4: For the highest inventory month, calculate daily average pod pressures for each pod.

Step 5: Review calculated daily average pod pressures and select the highest daily average pod pressure for the maximum inventory month.

Additional points related to ONEOK's reporting process

1) ONEOK eliminated any of the daily average pod cavern pressures that may have been impacted by any unusual circumstances or on days when gas was flowing in or out of the Yaggy field.

2) ONEOK did not report instantaneous maximum pressure values.

Review comments

1) The emphasis of this work revolves around maximum daily pressures in POD1. Without reviewing the entire annual data for the field and each POD, it is not possible to state that the maximum volume of gas stored in POD1 will always occur on a day of the highest inventory month for the entire field. The maximum volume of gas stored in POD1 could well have occurred on any day of any month of the year. Thus based on the information available in the consultant's report, solely focusing on the maximum inventory month of the whole field to identify the maximum storage pressure in POD1 is inadequate.

2) ONEOK is not reporting the instantaneous pressure peaks. Pressure failures occur when instantaneous pressure build-ups in a system exceed the rupture strength of the confining materials. Thus, it is pertinent to include both the value and frequency of valid instantaneous pressure peaks that get recorded by the SCADA system.

3) It is understandable that recordings during transducer calibration are disregarded. However, pressure peaks recorded during injection or production of gas from a pod should not be excluded.

4) SCADA (supervisory control and date acquisition) systems enable transmission of pressure-time date from remote locations to a centralized office via telemetry. The transmitted data is normally available for display (as pressure-time plots) at the central station. It is worthwhile to inquire how this data is electronically stored, and if all the pressure recordings from POD1 over a year can be displayed in one single plot. If so, this plot can be used to identify all the pressure peaks in POD1. Discrepancies can be analyzed against periods when transducer calibrations were conducted. Such a display will help to spot patterns, trends, and cycles related to pressure peaks.

5) Pressure data included in the Tables 1 to 3 attached to the consultant's report indicate minimum pressures to be greater than 600 psi in the vast majority of cases. The top of the POD1 cavern is approximately 800 ft. Thus on the days reported in Tables 1 to 3, the minimum pressure gradient in POD1 was close to 0.86 psi/ft.

6) A review of standard procedures followed by gas storage companies for reporting pod pressures to regulatory bodies (in the US) will be helpful in putting ONEOK's reporting process within the perspective of current accepted practices prevalent in the gas storage industry.

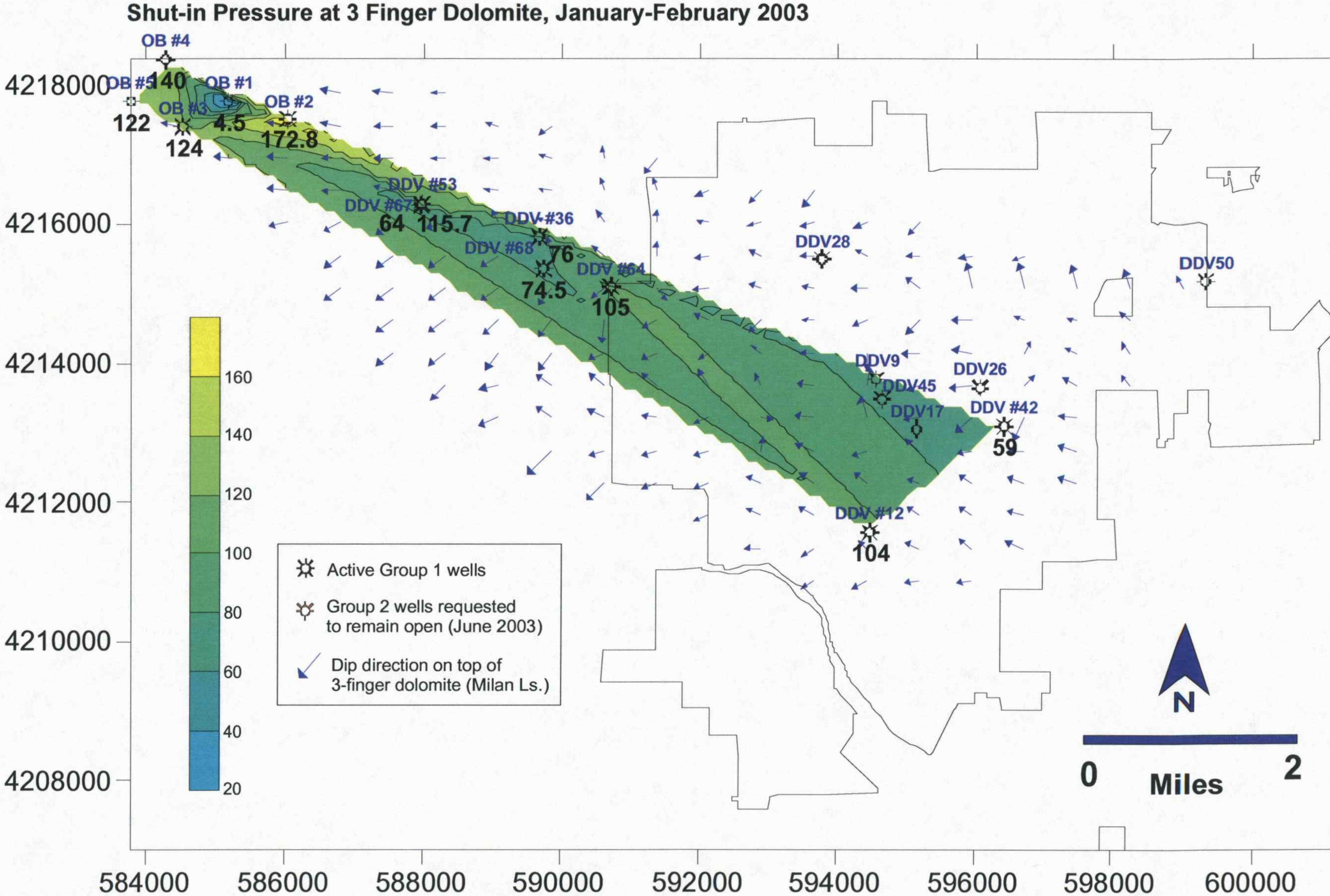
Updating structure map on top of 3F-dolomite

The structure map on the top of the 3F-dolomite was redone (Figure 3) to reflect a small adjustment in log zero datum for DDV #57 resulting in a reduction in slope of the southwest flank of the anticline that extends between the Yaggy gas storage area and the City of Hutchinson.

Table 1

Well	Elevation	Csg depth, ft	TD reached ft	SI time hrs	THSP/CHSP Surface Pr shutin, psig	Water level, ft	BHSP Static Pr at TD, psig	Data quality check BHSP-(THSP+wtr col)	Top of 3F ft	Wtr column above Gas, ft	Pr @ 3F zone, psi	Comments
DDV #12	1523	201	204	72.70	3	60	70	-5	262	202	104	3F >>TD
DDV #36	1547	201	571	73.30	19	208	206	6	322	114	76	
DDV #42	1525	202	550	72.00	31	192	220	10	248	56	59	
DDV #53	1559	202	585	73.70	68	245	238	0	341	96	116	
DDV #64	1541	201	582	73.20	15	120	258	12	300	180	105	
DDV #67	1556	201	569	73.80	24	258	187	8	338	80	64	
DDV #68	1545	201	524	73.70	29	220	189	8	311	91	75	
OB #1	1569	250	454	96.40	0	385	46	12	394	9	5	
OB #2	1564	536	460	96.00	173		174		387		173	No water in the well
OB #3	1579	537	599	96.50	6	171			407	236	124	Annulus water level
OB #4	1574	539	550	96.8	0	147			427	280	140	Annulus water level
OB #5	1570	538	614	97.2	0	186			430	244	122	Annulus water level

Figure 1



Shut-in Pressure at 3 Finger Dolomite, January-February 2003
OB #4
140
OB #5
122
OB #3
124
OB #1
4.5
OB #2
172.8
DDV #53
DDV #67
64
115.7
DDV #36
DDV #68
76
74.5
DDV #64
105
DDV28
DDV50
DDV9
DDV45
DDV17
DDV26
DDV #42
59
DDV #12
104
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000
160
140
120
100
80
60
40
20
Active Group 1 wells
Group 2 wells requested to remain open (June 2003)
Dip direction on top of 3-finger dolomite (Milan Ls.)
N
0
Miles
2

Table 2

Well	SI time hrs	THSP/CHSP Surface Pr shutin, psig		SI time hrs	THSP/CHSP Surface Pr shutin, psig	Pr increase psi	Comments
DDV #12	72.70	**3**		408	6.9	3.9	
DDV #36	73.30	**19**		408	58.7	39.7	
DDV #42	72.00	**31**		408	50.4	19.4	
DDV #53	73.70	**68**		408	86.3	18.6	
DDV #64	73.20	**15**		408	22.3	7.3	
DDV #67	73.80	**24**		408	61.7	37.7	
DDV #68	73.70	**29**		408	18.2	-10.8	Possible leak
OB #1	96.40	**0**		408	0.0	0.0	
OB #2	96.00	**173**		408	182.2	9.4	
OB #3	96.50	**6**		408			**CHSP NA @ 408 hrs**
OB #4	96.8	**0**		408			**CHSP NA @ 408 hrs**
OB #5	97.2	**0**		408			**CHSP NA @ 408 hrs**

Table 3

	Jan-03	Jul-02		Change between Jan03 and Jul 02
Well	Pr @ 3F	Pr @ 3F		Pr @ 3F zone, psi
	zone, psi	zone, psi		
DDV #12	104	107		-3
DDV #36	76	98		-22
DDV #42	59	33		26
DDV #53	116	121		-5
DDV #64	105	118		-13
DDV #67	64	110		-46
DDV #68	75	90		-15
OB #1	5	5		0
OB #2	173	179		-6
OB #3	124	103		21
OB #4	140	124		16
OB #5	122	93		29

Table 4

					THSP/CHSP		BHSP	Data quality check			
Well	Elevation	Csg	TD	SI time	Surface Pr	Water	Static Pr	BHSP-	Top of	Wtr column	Pr @ 3F
	ft	depth, ft	ft	hrs	shutin, psig	level, ft	at TD, psig	(THSP+wtr col)	3F ft	above Gas, ft	zone, psi
DDV #12	1523	201	204	74.17	**0.5**	63	66	-5	262	199	**100**
DDV #36	1547	201	571	75.08	**16.0**	207	205	7	**322**	115	74
DDV #42	1525	202	550	73.50	**19.0**	171	221	13	**248**	77	58
DDV #53	1559	202	585	96.58	**61.0**	na	238		**341**	0	61
DDV #64	1541	201	582	74.50	**13.0**	130	257	18	**300**	170	98
DDV #67	1556	201	569	75.08	**13.0**	255	180	10	**338**	83	55
DDV #68	1545	201	524	74.75	**18.0**	199	186	6	**311**	112	74
OB #1	1569	250	454	96.33	**0.0**	346	48	-6	**394**	48	24
OB #2	1564	536	460	96.33	**152.0**		151		**387**		152
OB #3	1579	537	599	98.10	**1.2**	**139.5**			**407**	267.5	135
OB #4	1574	539	550	96.5	**0.0**	**131.75**			**427**	295.25	148
OB #5	1570	538	614	97.2	**0.0**	**147.25**			**430**	282.75	141

Figure 2

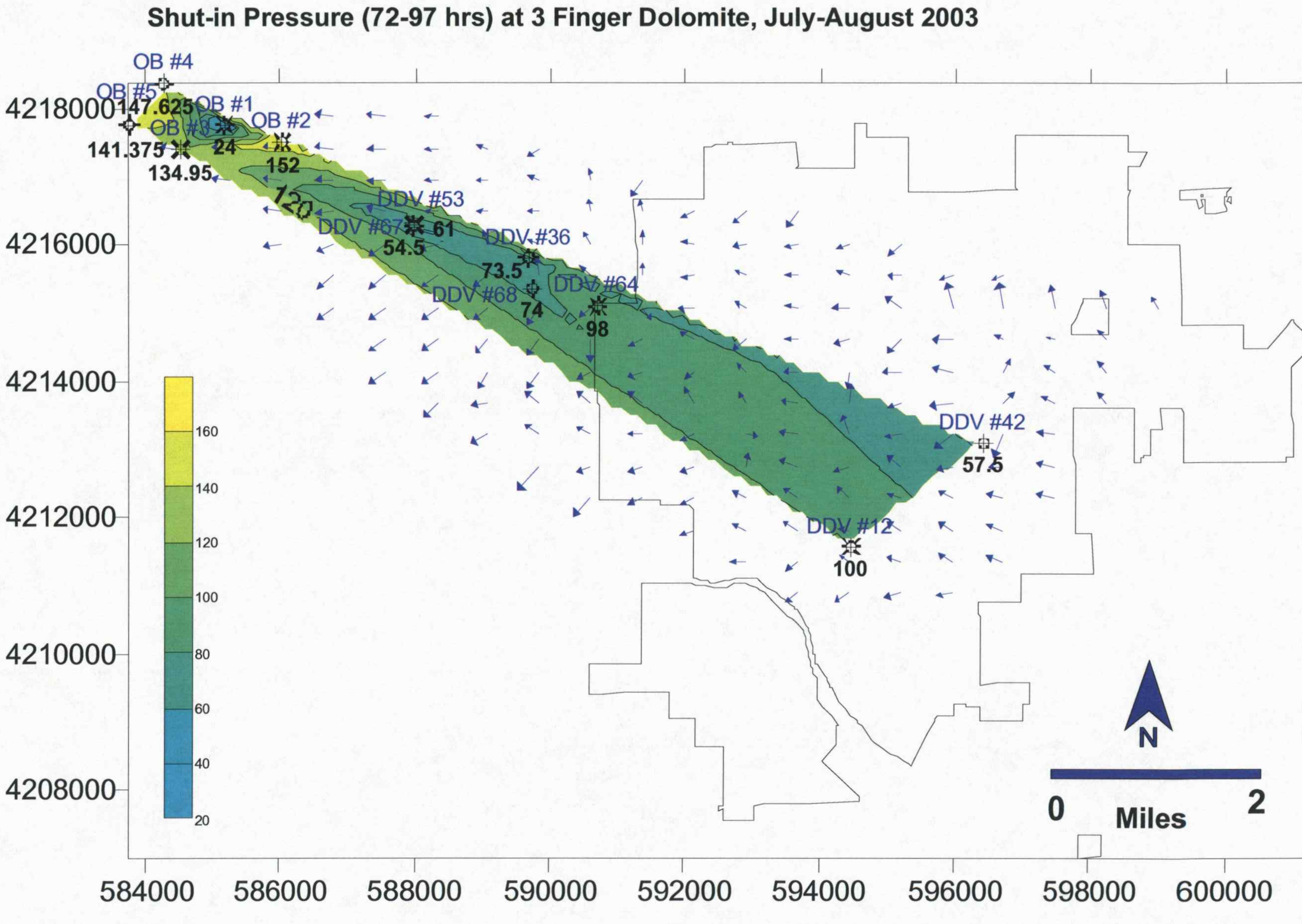

Shut-in Pressure (72-97 hrs) at 3 Finger Dolomite, July-August 2003
OB #4
OB #5
OB #1
OB #3
OB #2
147.625
141.375
134.95
24
152
120
DDV #53
DDV #67
61
54.5
DDV #36
73.5
DDV #68
74
DDV #64
98
DDV #42
57.5
DDV #12
100
160
140
120
100
80
60
40
20
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000
N
0
Miles
2

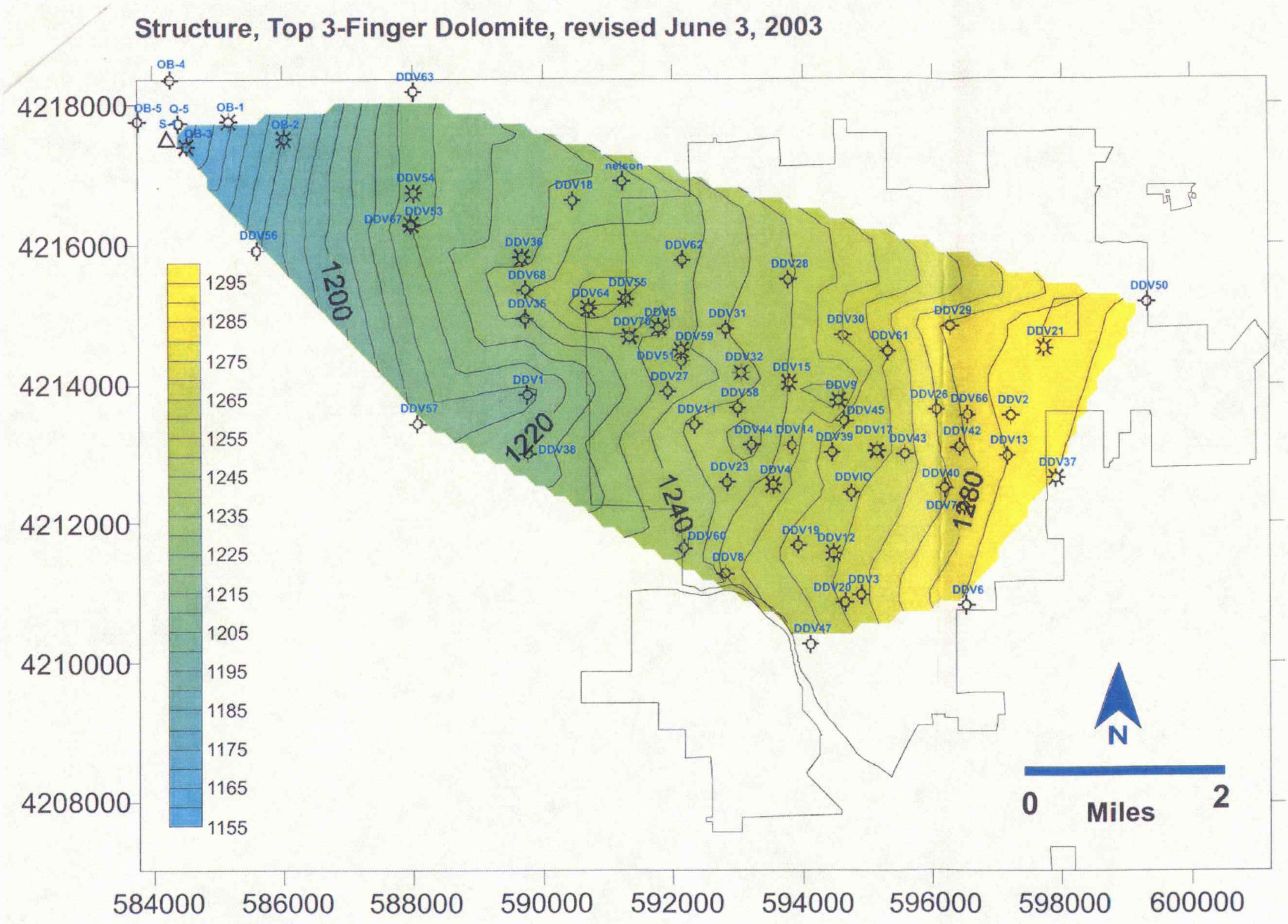
Table 5

		THSP/CHSP			THSP/CHSP		
Well	**SI time**	**Surface Pr**		**SI time**	**Surface Pr**	**Pr increase**	
	hrs	**shutin, psig**		**hrs**	**shutin, psig**	**psi**	Comments
DDV #12	74.17	**0.5**		408	0.9	0.4	
DDV #36	75.08	**16.0**		408	42.5	26.5	
DDV #42	73.50	**19.0**		408	34.6	15.6	
DDV #53	96.58	**61.0**		408	78.1	17.1	
DDV #64	74.50	**13.0**		408	20.2	7.2	
DDV #67	75.08	**13.0**		408	19.7	6.7	Possible leak
DDV #68	74.75	**18.0**		408	38.2	20.2	
OB #1	96.33	**0.0**		408	0.0	0.0	
OB #2	96.33	**152.0**		408	193.6	41.6	
OB #3	98.10	**1.2**		408			**CHSP NA @ 408 hrs**
OB #4	96.50	**0.0**		408			**CHSP NA @ 408 hrs**
OB #5	97.20	**0.0**		408			**CHSP NA @ 408 hrs**

Table 6

	Aug-03	Jan-03	Jul-02		Change between Jan03 and Jul 02
Well	Pr @ 3F zone, psi	Pr @ 3F zone, psi	Pr @ 3F zone, psi		Pr @ 3F zone, psi
DDV #12	100	104	107		-7
DDV #36	74	76	98		-25
DDV #42	58	59	33		25
DDV #53	61	115	121		-60
DDV #64	98	105	118		-20
DDV #67	55	64	110		-56
DDV #68	74	75	90		-16
OB #1	24	5	5		20
OB #2	152	173	179		-27
OB #3	135	124	103		32
OB #4	148	140	124		24
OB #5	141	122	93		48

Figure 3



Structure, Top 3-Finger Dolomite, revised June 3, 2003
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000
1295
1285
1275
1265
1255
1245
1235
1225
1215
1205
1195
1185
1175
1165
1155
1200
1220
1240
1280
N
0
Miles
2

Table 7

Data from January 2003 survey

Well	TD, feet	B/3F, feet	Water level, ft	SI hrs	THSP, psi	Comments
DDV #2B	494	245	190	9174	0	
DDV #26	136	N/A	15	9097	4	3F>> TD
DDV #45	547	278	150	9098	8	
DDV #50	424	245	200	9174	11	

Data from July-August 2003 survey

Well	TD, feet	B/3F, feet	Water level, ft	SI hrs	THSP, psi	Comments
DDV #2B	494	0	125	96	0	
DDV #26	136	N/A	23	72.8	0	3F>> TD
DDV #45	547	0				Lost tool in hole
DDV #50	424	0	215	72	0	