Exploration & Production **Technology**

Memo

Title: **Isabella Pore Volume Compressibility Evaluation**

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Objective

- To assess the validity of pore volume compressibility measurements made on rotary sidewall cores recovered from the Isabella well.
- To update the expected compaction during depletion for the reservoir, and to check against the existing well design.

Results

The results of the pore volume compressibility tests (PVC) run on the rotary sidewall cores (RSWCs) are considered to be reliable, and may be used for reservoir performance and reserves recovery estimation. A summary of the results is given below.

Depth (ft. MD)	Porosity @ NCS	Pore volume compressibility ($\times 10^{-6}$ psi^{-1})	Depletion range (psi)
Upper sand			
18168	0.338	18.8	0-3500
		24.9	3500-7000
18209.9	0.303	8.8	0-3500
		6.5	3500-7000
Lower sand			
18926.2	0.277	18.1	0-3500
		11.9	3500-7000
18947	0.253	12.0	0-7000

*Normal consolidation stress is 1850 psi in upper sand, 2100 psi in lower sand

Taking the Omni Laboratories data at face value, by averaging over 6500 psi depletion, a pore volume compressibility of 14.6 μsips (14.6×10^{-6} psi^{-1}) applies to the upper sand samples, and a value of 13.7 μsips applies to the lower sand samples. Testing protocols and sample size effects (specifically length-to-diameter ratio) may result in this value underestimating the actual reservoir compressibility. Work could be undertaken to quantify the magnitude of these effects, but consideration of this is beyond the scope of this memo.

Results of the formation compressibility evaluation indicate that a compaction strain of about 2.7 percent is expected at Isabella for a reservoir depletion of 6500 psi. The reservoir compaction behavior appears to be linear over this pressure range. Reservoir compaction will increase with increasing depletion, therefore, extending over the field operational life. Prior work has shown that well casings may experience about 2 percent plastic strain at this level of compaction strain. This is at a threshold level where some casing integrity issues may begin to emerge late in field life.

Analysis

This evaluation complements the memo authored by Steve Willson dated 5 June 2006[1]. Laboratory tests for pore volume compressibility (PVC) were performed by Omni Laboratories on rotary sidewall cores (RSWC) collected from Isabella. We examine three issues in this analysis: (1) the quality of the test results; (2) PVC values to be used as input to reservoir simulation modeling; and (3) expected plastic strains in the well casing as a consequence of depletion-induced compaction.

Quality of Results

The laboratory test results appear to be of good quality, but some issues remain unresolved and may require additional evaluation: (1) The compaction strains experienced by the samples during application of the initial "seating" loads was not reported. These initial strains are indicators of sample disturbance – if large strains occur during seating, the sample may have been disturbed during sample recovery and the results may be unreliable; (2) The sample compressibilities are consistently greater (zero to 50 percent) for load steps in which a one-hour stabilization period was allowed after decreasing the pore pressure than for load steps in which a thirty-minute stabilization period was allowed. This relationship indicates that time-dependent deformations (creep) may make contribute additional compaction strain to that expected from the results of these "instantaneous" tests if, as expected, the loading rate in the field is slower than in the lab; (3) The Isabella samples were collected as RSWC, presumably parallel to bedding, and tested for compaction within a bedding plane. Compaction in the field is expected to occur perpendicular to bedding (see Figure 1). Typically, reservoir sandstones are stiffer within a bedding plane than in the direction perpendicular to bedding. These test results may therefore underestimate expected compaction in the field.

Recommended PVC Values

Results from the tests indicate that reservoir compaction is nearly linear with reservoir depletion. The mean PVC is about 0.0000146 psi^{-1} or 14.6 μsips for the upper sand and about 13.7 μsips for the lower sand. Accelerated compaction was not initiated in any samples in the pore pressure range tested (depletion of 10000 psi or more) and so is not expected over the life of the field (depletion of 6000 to 7000 psi).

PVCs at each stage of reservoir depletion tested in the lab are shown in Figure 2. The PVCs vary slightly during each test but do not indicate that the reservoir will become more or less compressible as reservoir depletion progresses.

For comparison, the results from Fourier core samples are also shown in Figure 2. The Isabella samples are typically about one-third less compressible than the Fourier samples. The Isabella samples do not appear to become more compressible or to undergo accelerated compaction as reservoir depletion progresses. The Isabella sands may be expected to behave similar to, although slightly less compressible than, the Fourier sands with respect to compaction in the field.

The range of PVCs for the Kepler, Fourier, and Isabella sands are shown as a function of reservoir depth in Figure 3. A trendline best fitted to the PVC for each field is also shown on the figure. It appears that the deeper reservoirs are less compactable at Na Kika.

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[1] Memo from Stephen Willson to John Richey and Nick Lirette, dated 5 June 2006, titled "Isabella: Geomechanics assessment of required casing size / grade based on estimated compaction-related deformations."

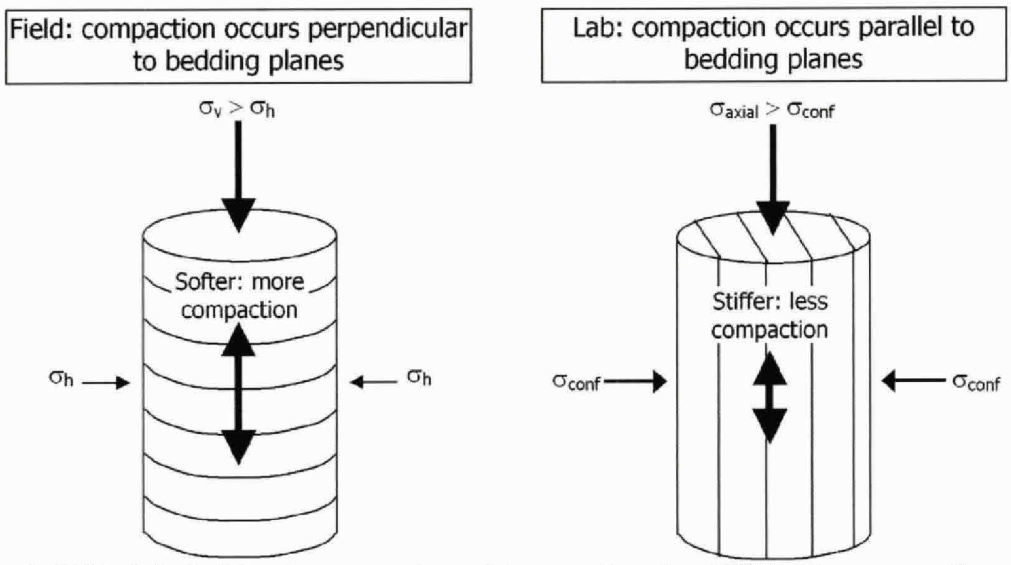

Figure 1. PVC tests in the laboratory may underpredict compaction, since RSWC undergo compaction parallel to bedding planes in which rocks are typically stiffer. In the field, compaction occurs perpendicular to bedding in which rocks are typically softer.

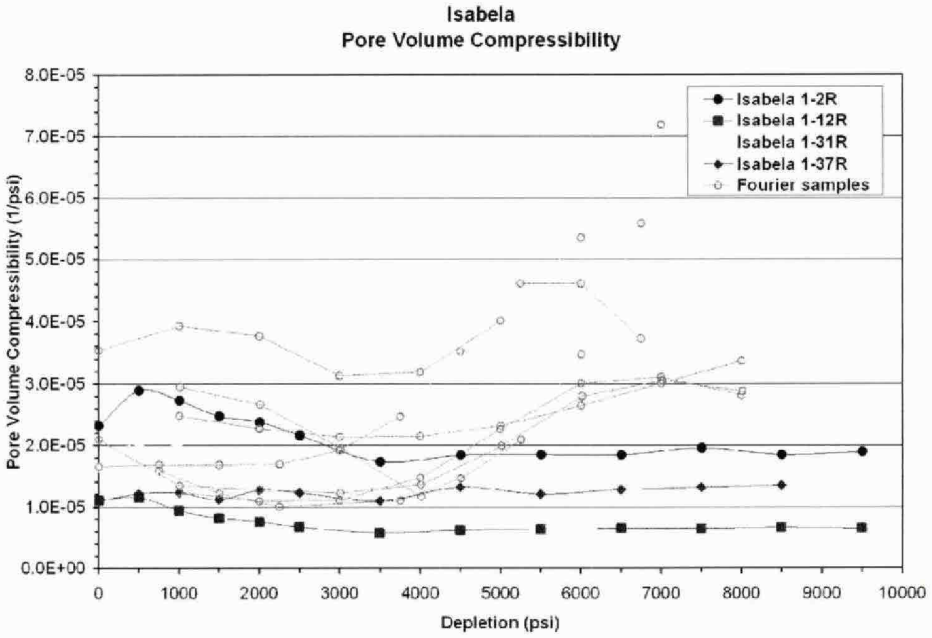

Figure 2. Results of PVC laboratory tests indicate that Isabella sands are somewhat less compressible than Fourier sands. The average PVC is 14.6 μsips in the upper sand, and 13.7 μsips in the lower sand

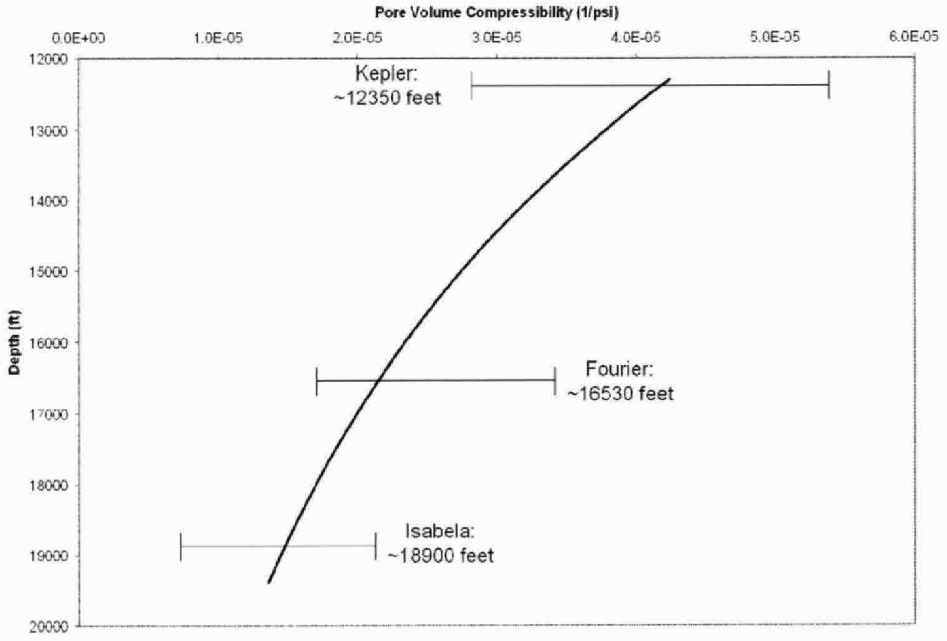

Figure 3. The Isabella sands are less compressible than the shallower Kepler or Fourier sands.

Expected Plastic Strain in Well Casing

On the basis of the test results, the total compaction strain $\Delta\varepsilon_z$ in the reservoir expected at 6500 psi depletion is between 1.5 percent and 4.7 percent, with an average value of 2.7 percent. This value was calculated as the product of the expected reservoir depletion ΔP and uniaxial compaction coefficient C_m. The uniaxial compaction coefficient is calculated from the PVC and initial porosity ϕ_0:

$$C_m = PVC \cdot \phi_0$$
$$\Delta\varepsilon_z = -\Delta P \cdot C_m$$

Prior work[2] has shown that well casings may experience about 2 percent plastic strain at this level of compaction strain. This is at a threshold level where some casing integrity issues may begin to emerge late in field life.

[2] Li, X., Tinker, S.J., Bruno, M., and Willson, S.M. "Compaction considerations for the Gulf of Mexico deepwater King West field completion design," SPE/IADC 92652, presented at the SPE/IADC drilling conference, Amsterdam, The Netherlands, 23-25 February 2005.