Streamline-Based Time-Lapse-Seismic-Data Integration Incorporating Pressure and Saturation Effects

Authors

Shingo Watanabe (Texas A&M University) | Jichao Han (Texas A&M University) | Gill Hetz (Texas A&M University) | Akhil Datta-Gupta (Texas A&M University) | Michael J. King (Texas A&M University) | Donald W. Vasco (Lawrence Berkeley National Laboratory)

DOI

https://doi.org/10.2118/166395-PA

Document ID

SPE-166395-PA

Export citation

Get PDF

Summary

We present an efficient history-matching technique that simultaneously integrates 4D repeat seismic surveys with well-production data. This approach is particularly well-suited for the calibration of the reservoir properties of high-resolution geologic models because the seismic data are areally dense but sparse in time, whereas the production data are finely sampled in time but spatially averaged. The joint history matching is performed by use of streamline-based sensitivities derived from either finite-difference or streamline-based flow simulation. For the most part, earlier approaches have focused on the role of saturation changes, but the effects of pressure have largely been ignored. Here, we present a streamline-based semianalytic approach for computing model-parameter sensitivities, accounting for both pressure and saturation effects. The novelty of the method lies in the semianalytic sensitivity computations, making it computationally efficient for high-resolution geologic models. The approach is implemented by use of a finite-difference simulator incorporating the detailed physics. Its efficacy is demonstrated by use of both synthetic and field applications. For both the synthetic and the field cases, the advantages of incorporating the time-lapse variations are clear, seen through the improved estimation of the permeability distribution, the pressure profile, the evolution of the fluid saturation, and the swept volumes.

File Size 2 MB **Number of Pages** 19

References

Aki, K. and Richards, P. G. 1980. *Quantitative Seismology*. San Francisco: Freeman.

Arenas, E., Kruijsdijk, C. V., and Oldenziel, T. 2001. Semi-Automatic History Matching Using the Pilot Point Method Including Time-Lapse Seismic Data. Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, 30 September–3 October. SPE-71634-MS. https://doi.org/10.2118/71634-MS.

Batzle, M. and Wang, Z. 1992. Seismic Properties of Pore Fluids. *Geophysics* **57** (11): 1396–1408. https://doi.org/10.1190/1.1443207.

Behrens, R., Condon, P., Haworth, W. et al. 2002. 4D Seismic Monitoring of Water Influx at Bay Marchand: The Practical Use of 4D in an Imperfect World. *SPE Res Eval & Eng* **5** (5): 410–420. SPE-79961-PA. https://doi.org/10.2118/79961-PA.

Behrens, R., MacLeod, M., Tran, T. et al. 1998. Incorporating Seismic Attribute Maps in 3D Reservoir Models. *SPE Res Eval & Eng* **1** (2): 122–126. SPE-36499-PA. https://doi.org/10.2118/36499-PA.

Bhark, E. W., Jafarpour, B., and Datta-Gupta, A. 2011. A Generalized Grid Connectivity–Based Parameterization for Subsurface Flow Model Calibration. *Water Resour. Res.* **47** (6): W06517. https://doi.org/10.1029/2010WR009982.

Buckley, S. E. and Leverett, M. C. 1942. Mechanism of Fluid Displacement in Sands. In *Transactions of the Society of Petroleum Engineers*, Vol. 146, Part 1, 107–116. SPE-942107-G. Richardson, Texas: Society of Petroleum Engineers. https://doi.org/10.2118/942107-G.

Cheng, H., Dehghani, K., and Billiter, T. 2008. A Structured Approach for Probabilistic-Assisted History Matching Using Evolutionary Algorithms: Tengiz Field Applications. Presented at the SPE Annual Technical Conference and Exhibition, Denver, 21–24 September. SPE-116212-MS. https://doi.org/10.2118/116212-MS.

Cheng, H., Kharghoria, A., He, Z. et al. 2005. Fast History Matching of Finite-Difference Models Using Streamline-Based Sensitivities. *SPE Res Eval & Eng* **8** (5): 426–436. SPE-89447-PA. https://doi.org/10.2118/89447-PA.

Christensen, N. and Wang, H. 1985. The Influence of Pore Pressure and Confining Pressure on Dynamic Elastic Properties of Berea Sandstone. *Geophysics* **50** (2): 207–213. https://doi.org/10.1190/1.1441910.

Clifford, P., Robert, T., Parr, R. et al. 2003. Integration of 4D Seismic Data into the Management of Oil Reservoirs with Horizontal Wells between Fluid Contacts. Presented at Offshore Europe, Aberdeen, 2–5 September. SPE-83956-MS. https://doi.org/10.2118/83956-MS.

Dadashpour, M., Ciaurri, D. E., Mukerji, T. et al. 2010. A Derivative-Free Approach for the Estimation of Porosity and Permeability Using Time-Lapse Seismic and Production Data. *J. Geophys. Eng.* **7** (4): 351–368. https://doi.org/10.1088/1742-2132/7/4/002.

Dadashpour, M., Echeverri´a-Ciaurri, D., Kleppe, J. et al. 2009. Porosity and Permeability Estimation by Integration of Production and Time-Lapse Near and Far Offset Seismic Data. *J. Geophys. Eng.* **6** (4): 325–344. https://doi.org/10.1088/1742-2132/6/4/001.

Dadashpour, M., Landrø, M., and Kleppe, J. 2008. Nonlinear Inversion for Estimating Reservoir Parameters from Time-Lapse Seismic Data. *J. Geophys. Eng.* **5** (1): 54–66. https://doi.org/10.1088/1742-2132/5/1/006.

Datta-Gupta, A. and King, M. J. 2007. *Streamline Simulation: Theory and Practice*, Vol. 11. Richardson, Texas: Society of Petroleum Engineers.

Deutsch, C. V. and Journel, A. G. 1992. *GSLIB: Geostatistical Software Library and User's Guide*. New York City: Oxford University Press.

Dong, Y. and Oliver, D. 2005. Quantitative Use of 4D Seismic Data for Reservoir Description. *SPE J.* **10** (1): 91–99. SPE-84571-PA. https://doi.org/10.2118/84571-PA.

Doyen, P. M., Psaila, D. E., and Jans, D. 1997. Reconciling Data at Seismic and Well Log Scales in 3-D Earth Modelling. Presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 5–8 October. SPE-38698-MS. https://doi.org/10.2118/38698-MS.

Fahimuddin, A., Aanonsen, S., and Skjervheim, J.-A. 2010. 4D Seismic History Matching of a Real Field Case With EnKF: Use of Local Analysis for Model Updating. Presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy, 19–22 September. SPE-134894-MS. https://doi.org/10.2118/134894-MS.

Falcone, G., Gosselin, O., Maire, F. et al. 2004. Petroelastic Modelling as Key Element of 4D History Matching: A Field Example. Presented at the SPE Annual Technical Conference and Exhibition, Houston, 26–29 September. SPE-90466-MS. https://doi.org/10.2118/90466-MS.

Fanchi, J. R. 2001. Time-Lapse Seismic Monitoring in Reservoir Management. *The Leading Edge* **20** (10): 1140–1147. https://doi.org/10.1190/1.1487246.

Feng, T. and Mannseth, T. 2010. Impact of Time-Lapse Seismic Data for Permeability Estimation. *Computat. Geosci.* **14** (4): 705–719. https://doi.org/10.1007/s10596-010-9182-6.

Foster, D. 2007. The BP 4-D Story: Experience Over the Last 10 Years and Current Trends. Presented at International Petroleum Technology Conference, Dubai, 4–6 December. IPTC-11757-MS. https://doi.org/10.2523/IPTC-11757-MS.

Gassmann, F. 1951. Elastic Waves Through a Packing of Spheres. *Geophysics* **16** (4): 673–685. https://doi.org/10.1190/1.1437718.

Gosselin, O., Aanonsen, S., Aavatsmark, I. et al. 2003. History Matching Using Time-lapse Seismic (HUTS). Presented at the SPE Annual Technical Conference and Exhibition, Denver, 5–8 October. SPE-84464-MS. https://doi.org/10.2118/84464-MS.

Gosselin, O., van den Berg, S., and Cominelli, A. 2001. Integrated History-Matching of Production and 4D Seismic Data. Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, 30 September–3 October. SPE-71599-MS. https://doi.org/10.2118/71599-MS.

He, Z., Yoon, S., and Datta-Gupta, A. 2002. Streamline-Based Production Data Integration With Gravity and Changing Field Conditions. *SPE J.* **7** (4): 423–436. SPE-81208-PA. https://doi.org/10.2118/81208-PA.

Huang, X., Meister, L., and Workman, R. 1997. Reservoir Characterization by Integration of Time-lapse Seismic and Production Data. Presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 5–8 October. SPE-38695-MS. https://doi.org/10.2118/38695-MS.

Kennett, B. 1983. *Seismic Wave Propagation in Stratified Media*. Cambridge, UK: Cambridge University Press.

Kjelstadli, R. M., Lane, H. S., Johnson, D. T. et al. 2005. Quantitative History Match of 4D Seismic Response and Production Data. Presented at Offshore Europe, Aberdeen, 6–9 September. SPE-96317-MS. https://doi.org/10.2118/96317-MS.

Landa, J. and Horne, R. 1997. A Procedure to Integrate Well Test Data, Reservoir Performance History and 4-D Seismic Information into a Reservoir Description. Presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 5–8 October. SPE-38653-MS. https://doi.org/10.2118/38653-MS.

Landrø, M., Digranes, P., and Strønen, L. 2001. Mapping Reservoir Pressure and Saturation Changes Using Seismic Methods: Possibilities and Limitations. *First Break* **19** (12): 671–684. https://doi.org/10.1046/j.1365-2397.2001.00226.x.

Landrø, M., Solheim, O.A., Hilde, E. et al. 1999. The Gullfaks 4D Seismic Study. *Petrol. Geosci.* **5** (3): 213–226. https://doi.org/10.1144/petgeo.5.3.213.

Landrø, M., Veire, H. H., Duffaut, K. et al. 2003. Discrimination Between Pressure and Fluid Saturation Changes from Marine Multicomponent Time-Lapse Seismic Data. *Geophysics* **68** (5): 1592–1599. https://doi.org/10.1190/1.1620633.

Lumley, D. E. 2001. Time-lapse Seismic Reservoir Monitoring. *Geophysics* **66** (1): 50–53. https://doi.org/10.1190/1.1444921.

Lumley, D. and Behrens, R. 1998. Practical Issues of 4D Seismic Reservoir Monitoring: What an Engineer Needs to Know. *SPE Res Eval & Eng* **1** (6): 528–538. SPE-53004-PA. https://doi.org/10.2118/53004-PA.

Lumley, D. E., Behrens, R. A., and Wang, Z. 1997. Assessing the Technical Risk of a 4-D Seismic Project. *The Leading Edge* **16** (9): 1287–1292. https://doi.org/10.1190/1.1437784.

Mavko, G., Mukerji, T., and Dvorkin, J. 1998. *The Rock Physics Handbook: Tools for Seismic Analysis in Porous Media*. Cambridge, UK: Cambridge University Press.

Mindlin, R. D. 1949. Compliance of Elastic Bodies in Contact. *J. Appl. Mech.* **16:** 259–268.

Osdal, B., Husby, O., Aronsen, H. A. et al. 2006. Mapping the Fluid Front and Pressure Buildup Using 4D Data on Norne Field. *The Leading Edge* **25** (9): 1134–1141. https://doi.org/10.1190/1.2349818.

Paige, C. C. and Saunders, M. A. 1982. LSQR: An Algorithm for Sparse Linear Equations and Sparse Least Squares. *ACM Trans. Math. Software* **8** (1): 43–71. https://doi.org/10.1145/355984.355989.

Park, H.-Y., Datta-Gupta, A., and King, M. 2013. Handling Conflicting Multiple Objectives Using Pareto-Based Evolutionary Algorithm for History Matching of Reservoir Performance. Presented at the SPE Reservoir Simulation Symposium, The Woodlands, Texas, 18–20 February. SPE-163623-MS. https://doi.org/10.2118/163623-MS.

Reuss, A. 1929. Berechnung der Fließgrenze von Mischkristallen auf Grund der Plastizitätsbedingung für

Einkristalle. *ZAMM-Journal of Applied Mathematics and Mechanics* **9** (1): 49–58. https://doi.org/10.1002/zamm.19290090104.

Rey, A., Bhark, E., Gao, K. et al. 2012. Streamline-Based Integration of Time-Lapse Seismic and Production Data into Petroleum Reservoir Models. *Geophysics* **77** (6): M73–M87. https://doi.org/10.1190/geo2011-0346.1.

Rwechungura, R., Bhark, E., Miljeteig, O. et al. 2012. Results of the First Norne Field Case on History Matching and Recovery Optimization Using Production and 4D Seismic Data. Presented at the SPE Annual Technical Conference and Exhibition, San Antonio, Texas, 8–10 October. SPE-157112-MS. https://doi.org/10.2118/157112-MS.

Skjervheim, J.-A., Evensen, G., Aanonsen, S. et al. 2007. Incorporating 4D Seismic Data in Reservoir Simulation Models Using Ensemble Kalman Filter. *SPE J.* **12** (3): 282–292. SPE-95789-PA. https://doi.org/10.2118/95789-PA.

Steffensen, I. and Karstadt, P. 1996. Norne Field Development–Fast Track From Discovery to Production. *J Pet Technol* **48** (4): 296–339. SPE-30148-JPT. https://doi.org/10.2118/30148-JPT.

Toinet, S. 2004. 4D Feasibility and Calibration Using 3D Seismic Modeling of Reservoir Models. Presented at Abu Dhabi International Conference and Exhibition, Abu Dhabi, 10–13 October. SPE-88783-MS. https://doi.org/10.2118/88783-MS.

Tura, A. and Lumley, D. 2000. Estimating Pressure and Saturation Changes From Time-Lapse AVO Data. Presented at Offshore Technology Conference, Houston, 1–4 May. OTC-12130-MS. https://doi.org/10.4043/12130-MS.

Vasco, D. W. 2004. Seismic Imaging of Reservoir Flow Properties: Time-Lapse Pressure Changes. *Geophysics***69** (2): 511–521. https://doi.org/10.1190/1.1707071.

Vasco, D. W. and Datta-Gupta, A. 1999. Asymptotic Solutions for Solute Transport: A Formalism for Tracer Tomography. *Water Resour. Res.* **35** (1): 1–16. https://doi.org/10.1029/98WR02742.

Vasco, D. W. and Datta-Gupta, A. 2016. *Subsurface Fluid Flow and Imaging: With Applications for Hydrology, Reservoir Engineering, and Geophysics*. Cambridge, UK: Cambridge University Press.

Vasco, D. W., Bakulin, A., Baek, H. et al. 2015. Reservoir Characterization Based Upon the Onset of Time-Lapse Amplitude Changes. *Geophysics* **80** (1): M1–M14. https://doi.org/10.1190/geo2014-0076.1.

Vasco, D. W., Daley, T. M., and Bakulin, A. 2014. Utilizing the Onset of Time-Lapse Changes: A Robust Basis for Reservoir Monitoring and Characterization. *Geophys. J. Int.* **197** (1): 542–556. https://doi.org/10.1093/gji/ggt526.

Vasco, D. W., Datta-Gupta, A., Behrens, R. et al. 2004. Seismic Imaging of Reservoir Flow Properties: Time-Lapse Amplitude Changes. *Geophysics* **69** (6): 1425–1442. https://doi.org/10.1190/1.1836817.

Vasco, D. W., Yoon, S., and Datta-Gupta, A. 1999. Integrating Dynamic Data Into High-Resolution Reservoir Models Using Streamline-Based Analytic Sensitivity Coefficients. *SPE J.* **4** (4): 389–399. SPE-59253-PA. https://doi.org/10.2118/59253-PA.

Veeken, P. C., Priezzhev, I. I., Shmaryan, L. E. et al. 2009. Nonlinear Multitrace Genetic Inversion Applied on Seismic Data Across the Shtokman Field, Offshore Northern Russia. *Geophysics* **74** (6): WCD49–WCD59. https://doi.org/10.1190/1.3223314.

Williams, M. A., Keating, J. F., and Barghouty, M. F. 1998. The Stratigraphic Method: A Structured Approach to History Matching Complex Simulation Models. *SPE Res Eval & Eng* **1** (2): 169–176. SPE-38014-PA. https://doi.org/10.2118/38014-PA.

Yin, J., Park, H.-Y., Datta-Gupta, A. et al. 2011. A Hierarchical Streamline-Assisted History Matching Approach With Global and Local Parameter Updates. *J. Pet. Sci. Eng.* **80** (1): 116–130. https://doi.org/10.1016/j.petrol.2011.10.014.