GEOGULF2021
AUSTIN
October 27–29, 2021

Repurposing Legacy Seismic Reflection Data in Support of Aquifer Characterization in Texas

Thomas E. Ewing[1], Cody H. Draper[2], and Daniel M. Lupton[2]

[1]Frontera Exploration Consultants, San Antonio, Texas

[2]INTERA Inc., Austin, Texas

ABSTRACT

New supplies of groundwater, both fresh and brackish, will be critical for meeting the future water needs of Texas. Conventional seismic reflection data (2D and 3D surveys with low-frequency sources and larger group and source intervals, as are typically acquired for oil and gas exploration and development) may provide important refinements to hydrogeologic understanding of deep fresh and brackish aquifers, including structural and stratigraphic interpretation, estimating aquifer extents, and imaging water-bearing geobodies. Seismic data cannot determine salinities, and conventional seismic quality is typically limited by acquisition geometry and source frequency parameters that were designed for deeper targets; however, reprocessing can help to mitigate these limitations.

To better define the ways that conventionally acquired seismic reflection data can help our understanding of the stratigraphic and structural features of brackish aquifers within Texas in the depth range of 1000–5000 ft, we undertook five tasks:

(1) review of existing literature relevant to groundwater exploration using conventional data, along with a brief description of seismic techniques and a look at high-resolution data;

(2) evaluation of seismic data availability, leading to statewide maps showing coverage from major vendors;

(3) evaluation of seismic data quality and limitations, including research on sand-shale reflectivity versus depth in the Gulf Coast region;

(4) development of an integrated workflow for using seismic data in brackish aquifer studies (including summary analysis of suitability of conventional seismic for various aquifers); and

Ewing, T. E., C. H. Draper, and D. M. Lupton, 2021, Repurposing legacy seismic reflection data in support of aquifer characterization in Texas: GeoGulf Transactions, v. 71, p. 83–99.

(5) testing of this workflow by reprocessing and interpretation of the Stratton 3D dataset in Nueces County, within the brackish part of the Gulf Coast aquifer system.

A dozen or so aquifers across Texas show great potential for use of conventional seismic data, and several more show limited potential. Of these aquifers, the Cenozoic aquifer systems of the Gulf Coast region are most prospective, due to abundant 2D and 3D data, slow seismic velocities that allow enhanced resolution, relatively deep brackish zones, and complex internal geometry. As seismic acquisition in these areas has focused on deeper targets, reprocessing is expected to improve imaging and understanding of the shallow water-bearing section. Reprocessing of the Stratton 3D dataset confirms this expectation, and shows that use of conventional seismic will improve our understanding of aquifer resources.

INTRODUCTION

Abundant and dependable water supplies are essential to meeting the growing water needs of Texas. Surface water supplies in the state are very limited and are susceptible to drought. Potable groundwater resources found at shallow depths are also much used and are insufficient in many areas. Future water supplies will rely significantly on deep fresh groundwater in a few aquifers, and on abundant brackish water resources located in many parts of the State (some of these are shown on Figure 1).

Brackish water is defined by the Texas Water Development Board (TWDB) as water with a total dissolved solids content between 1000 and 10,000 parts per million (ppm). Water below 1000 ppm is fresh, water above 10,000 ppm but below seawater concentration (35,000 ppm) is categorized as 'slightly saline' or 'moderately saline'. Brackish water is not drinkable and cannot be used for most irrigation. However, it can be used as-is in some applications, such as oil and gas fracturing fluids, given current technology. Desalination is a proven technology for converting brackish or saline water to potable water; such desalination is substantially cheaper if one can use less saline water as input. Desalination is currently used by 49 municipal water facilities, 35 of which are processing brackish groundwater. Desalination also has application for industrial activities.

In 2019, the TWDB estimated that Texas has more than 2.7 billion acre-ft of brackish groundwater in 27 aquifers. This compared with the annual statewide use (based on 2015 data) of 6.5 million acre-ft of fresh water, of which some 2.0 million acre-ft was used for municipal and commercial supply. The Brackish Resource Aquifer Characterization System (BRACS) project was begun in 2009 to evaluate the brackish aquifers of Texas and designate producible brackish groundwater zones.

As brackish aquifers commonly occur at greater depth than existing groundwater wells, a wide array of data must be used for aquifer evaluation and for development of projects. This data largely derives from oil and gas exploration and development efforts, usually based on geophysical logs (run since the 1930s), and occasional production tests. To date, seismic reflection data acquired from oil and gas efforts has not been used in groundwater studies in Texas; but there is a large library of such data that should be relevant to deep brackish water (and deep fresh water) resources and project development.

For this reason, the BRACS project commissioned a study of the potential for the use of 'conventional' seismic reflection data (generated for hydrocarbon exploration and development) in groundwater studies. This paper is a summary of the final report of that work (Draper et al., 2021), showing that this repurposed data can be highly relevant in such studies, especially in subregional and detailed work. Reprocessing may be required to fully realize its potential, however. Work on the Gulf Coastal aquifers will be highlighted, including an initial report on 'test-case' reprocessing of the Stratton 3D dataset in Nueces County.

This report considers only 'conventional' seismic data—that is surveys, either 2D lines or 3D volumes, that were acquired for oil and gas exploration and development. Conventional data

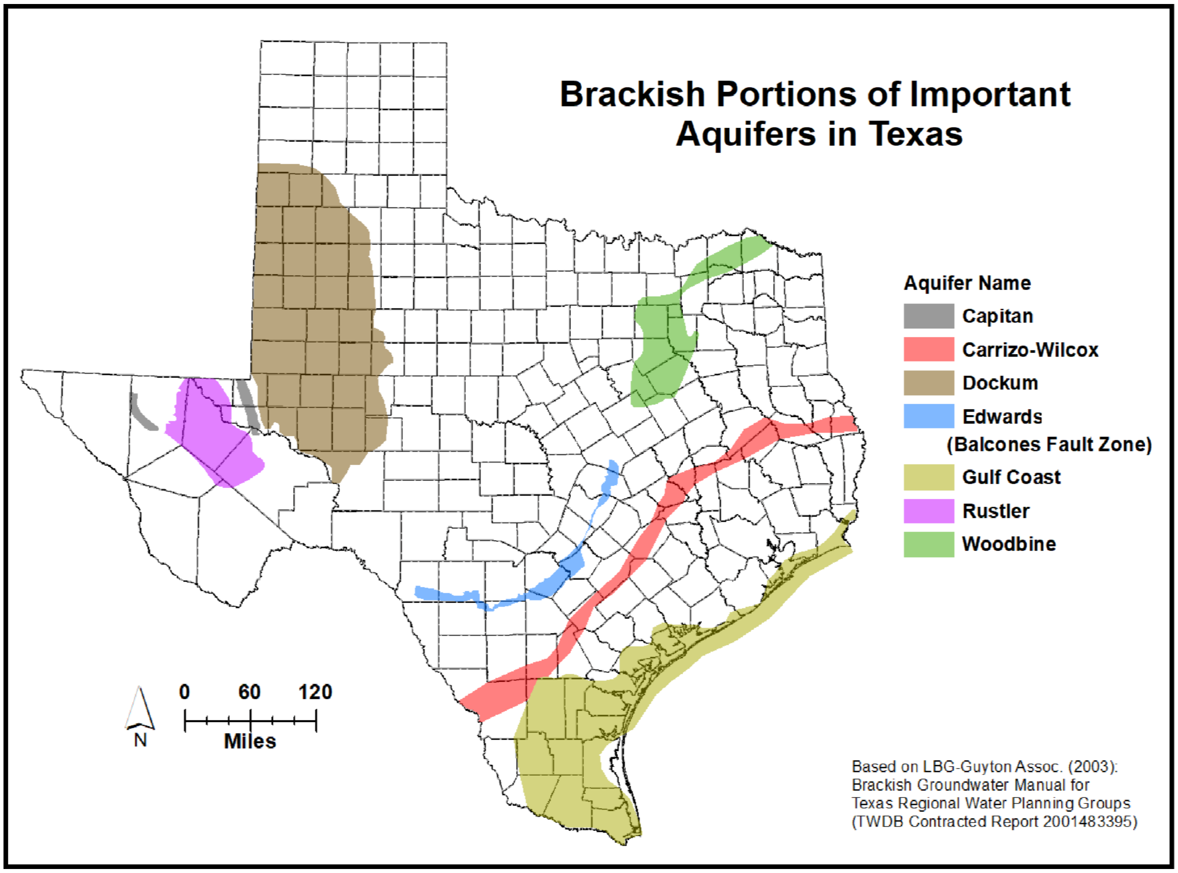


Figure 1. Brackish aquifers of interest in Texas. Only minimal extents are shown.

are typically acquired using seismic frequencies less than 100 Hz and with large group and shot intervals (and line intervals), allowing for deep signal penetration and resolution of hydrocarbon targets, as well as economical field effort to cover substantial areas (10–200 mi^2). In addition, considerable amounts of 'high-resolution' data have been acquired for engineering and hydrogeologic projects (including hazard surveys); such datasets are generally optimized for near-surface questions (often shallower than 250 ft) by use of high frequency (200–2000 Hz) sources and receivers, use very close source and receiver spacing, and cover small areas (less than 5 mi^2). These data are acquired for specific purposes at relatively low cost per project, and are not retained in data libraries. Because the acquisition costs of conventional data per project are higher, such surveys are retained either by the acquiring firm or in large data libraries. Such datasets are available to be licensed, interpreted, and reprocessed in support of groundwater surveys or projects.

PREVIOUS WORK

Several published studies report using conventional seismic reflection data for aquifer studies. In Abu Dhabi, Woodward and al-Jeelani (1993) used 2D seismic profiles to collect shallow data; they reprocessed the data to get shallow reflections that were muted in the original processing. Hanot et al. (2011) reprocessed 2D seismic data in the Paris Basin in support of a carbon sequestration study. Flores Capetillo et al. (2014) reprocessed existing 2D lines and added new lines in the Mexico City area to identify future water supplies. Cunningham et al. (2018) have acquired new seismic data (considered high-resolution, but similar to high-quality 'conventional' data elsewhere) to study carbonate aquifers in South Florida; they resolve karst-related subsidence features at 600 msec (2500 ft) depth. Offshore New Jersey, Thomas et al. (2019) used seismic and controlled-source electromagnetic data to identify fresh and brackish water reservoirs to a depth of 6500 ft. Similar studies have been successful elsewhere (see Bertoni et al., 2020).

Nearly all of the published work has used 2D profiles. Small 3D surveys have been acquired as part of high-resolution seismic programs. A presentation by Jansen and Jehn-Dellaport (2015) highlighted the possibilities of 3D data in aquifer characterization. Using conventional 3D surveys should allow better structural and stratigraphic resolution and imaging of constituent porous bodies (geobodies) within aquifer systems. High acquisition costs for new data and substantial licensing fees for existing data may have inhibited these studies.

POSSIBLE USES OF CONVENTIONAL SEISMIC DATA

Looking at previous work, and considering the capabilities of seismic reflection data interpretation as used in contemporary hydrocarbon development, we can outline some achievable goals for use of such data in deep groundwater exploration.

- Most 2D lines and 3D data volumes can be used for structural interpretation—identification of faults, folds, and fracture systems that affect the target aquifers. More detailed information on fractures and related anisotropy could be acquired from 3D seismic surveys. Karst development is also identifiable in 2D and 3D surveys.
- Stratigraphic interpretation can be derived from good-quality data, which can extend well-log correlations into undrilled areas.
- Aquifer extents may be estimated within stratigraphic intervals by using reflection strength and continuity, and possibly interval velocity information.
- With 3D surveys, it is possible to image the properties and geometries of individual geobodies (porous aquifer elements) within overall aquifers. This information can allow optimized siting of well fields and improve our modeling of aquifer connectivity and flow paths.

No seismic method can determine water salinity, as the difference between fresh and saline water is small and masked by geologic variations. This information must come from resistivity log analysis, controlled-source electromagnetic methods, and production tests.

SEISMIC DATA AVAILIBILITY

Seismic data available from data libraries is abundant in Texas. To compare this abundance to the distribution of aquifers, we consulted the websites of the major vendors—Seismic Exchange, Inc. (SEI), Seitel Data, Fairfield and CGG—to obtain general lines of 2D profiles and outlines of 3D data extents on a statewide basis. Offshore, the National Archive of Marine Seismic Surveys (NAMSS) operated by the U.S. Geological Survey provides free access to those surveys from the Federal Outer Continental Shelf that are over 25 yr old. Note that considerable amounts of 3D and some 2D data remain proprietary to individual oil and gas companies and would have to be identified and licensed using geophysical data brokers. Thus, all maps presented in Figures 2 and 3 represent minimum coverage.

The distribution of 2D seismic profiles outlines most of the oil and gas producing basins of Texas, except for North Texas (Fig. 2). The majority of onshore lines are available through SEI, but significant amounts are also obtainable from Seitel Data. The offshore is blanketed with 2D profiles available through NAMSS.

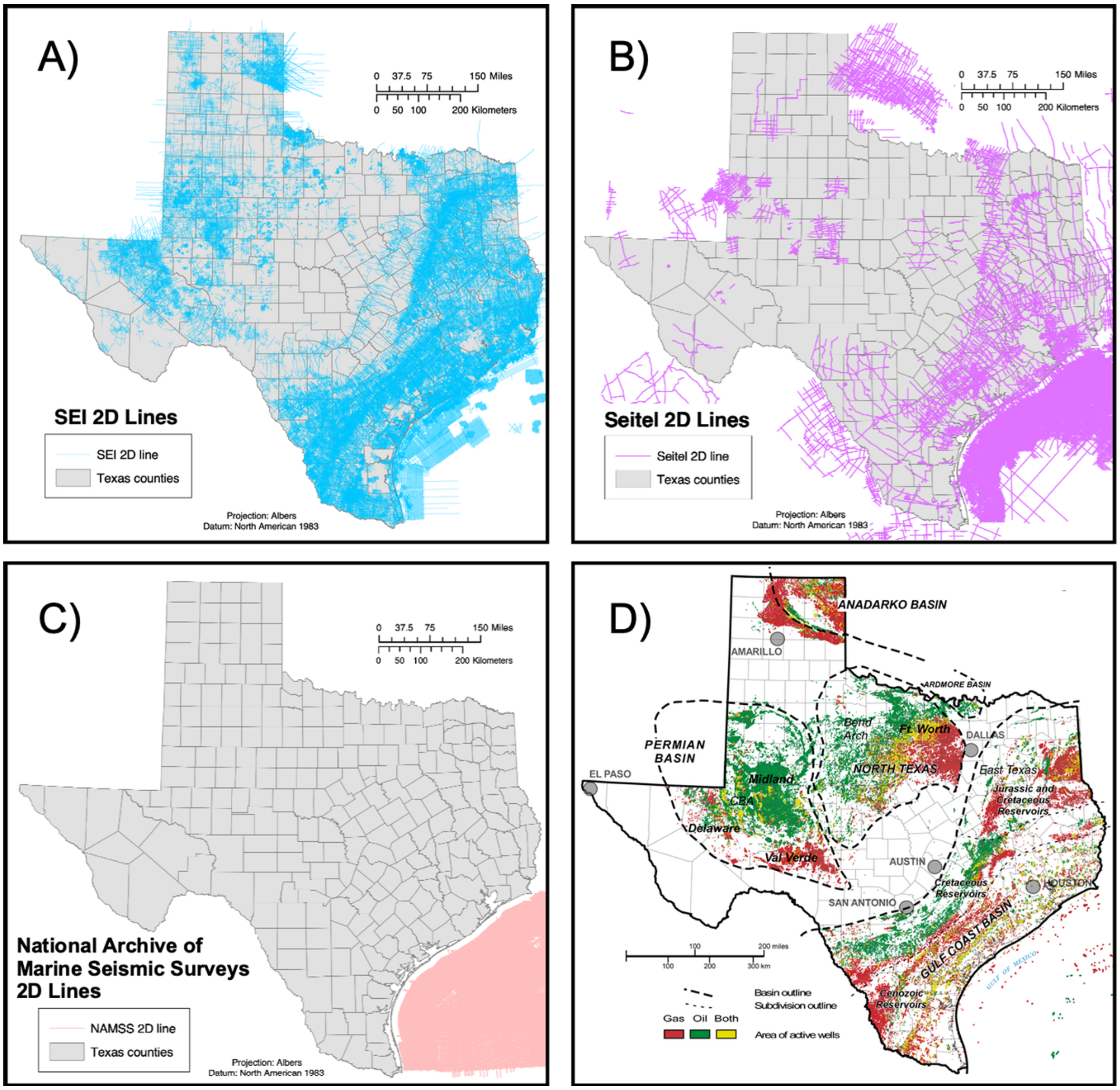


Figure 2. Availability of 2D seismic profiles in Texas and the Federal OCS, by vendors. Map of oil and gas fields and basins is from Ewing (2016). Significant amounts of 2D data are still held proprietary and are not shown.

The distribution of 3D seismic data likewise emphasize areas of interest for hydrocarbon exploration and development (Fig. 3). The Gulf Coast area has almost complete coverage; most gaps are filled with proprietary surveys, or are created by urban areas such as Houston. West Texas is well covered with available surveys and a scattering of surveys exists in North Texas and the Anadarko Basin (Texas Panhandle). Offshore surveys available through NAMSS cover the inner shelf and the Pleistocene shelf-margin areas in offshore Galveston and High Island.

Looking at the major aquifer systems having significant deep and brackish-water extensions, the Gulf Coast aquifer system (Oligocene-Pliocene) and the Carrizo-Wilcox aquifer system

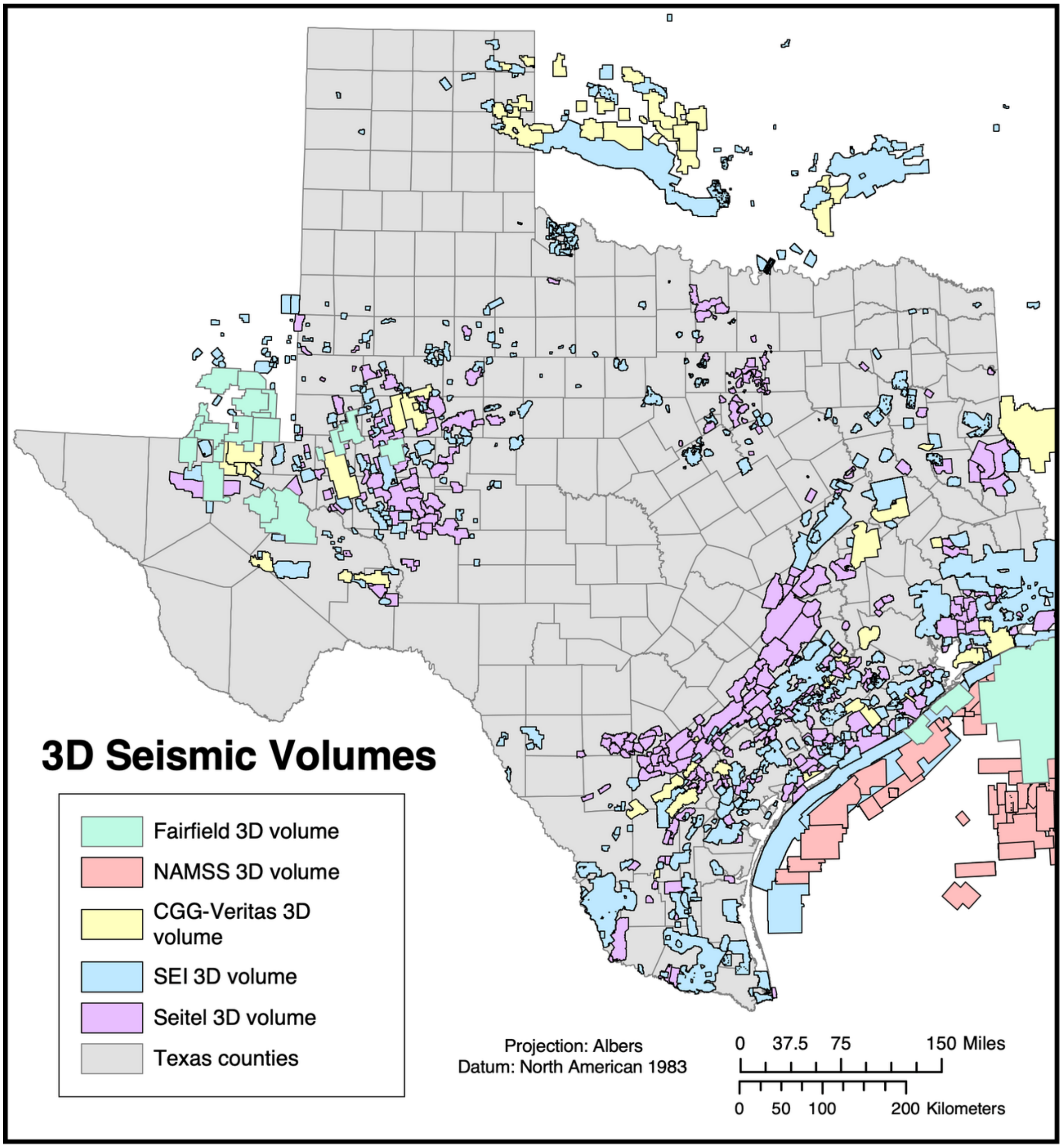


Figure 3. Availability of 3D seismic volumes in Texas and the Federal Outer Continental Shelf (OCS), by vendors. Significant volumes of 3D data are still held proprietary and are not shown.

(Paleocene-Eocene) are covered with 2D profiles and have extensive available 3D coverage (Fig. 4). The Gulf Coast aquifer system generally has fresh water at shallow depths (to hundreds of feet) and an extensive brackish zone as deep as 3000 ft, depending on location. The Carrizo-Wilcox aquifer system has substantial resources of deep fresh water (Carrizo in South

Texas, the Simsboro in Central Texas) that extend to 2500 ft depths; they also have substantial brackish zones. The Cretaceous aquifers, notably the Trinity and Woodbine aquifers of north and central Texas and the Edwards aquifer of south and central Texas, have much more limited coverage, primarily consisting of regional 2D seismic lines (Fig. 5). Such lines can be useful, however, in identifying Balcones faulting and regional correlation of aquifer units.

DATA QUALITY AND LIMITATIONS

Availability is one thing, quality another. Since hydrogeologic use of the data will focus on the top second or less of record, deep penetration is not necessary. But other factors must be examined to decide on appropriate data to license and on the need for reprocessing.

Location is important. The cost of 2D profiles is fairly standardized at the major vendors, but 3D volume license costs vary widely. In any event, expenditure of tens to hundreds of thousands of dollars is likely—and may be beyond the range of many water-development projects. Use of 3D data volumes in particular will be at a subregional (countywide or smaller) scale, including a potential project area or fairway determined from geologic examination. 2D profiles can provide structural data and stratigraphic correlation on more regional scales.

Acquisition geometry and fold are also important. Since the targets are shallow (generally less than the maximum spread offset), true fold will be limited in the target section, which results in less noise rejection and poorer resolution of velocity. Ideally, one would like the closest possible spacing (group interval, shot interval, and line spacing) that is available. In 3D surveys, the distribution of azimuths is often limited which limits the ability to hunt for fracture patterns or anisotropy; but in many aquifers, this is not as significant. Because of shot and receiver spacing, shallow horizons are greatly affected by spatial irregularities called 'footprint' which need to be reduced for interpretation of the shallow section.

Resolution is another key factor. Resolution of individual aquifer elements is determined by the effective frequency of the seismic pulse (itself a function of input signal, attenuation and depth) and the velocity of the rocks involved. Typical conventional 3D surveys have frequency ranges of 10–60 Hz, occasionally up to 120 Hz. Dominant frequencies depend on depth, but usually are 20–40 Hz. By contrast, frequencies of new high-resolution surface surveys may exceed 300 Hz, but with limited depth of penetration. Full resolution of top and base of an aquifer element (tuning thickness) is achieved at 1/4 wavelength, which can range from 10–25 msec (two-way travel time). Detectability (an amplitude representing the element) is much less, perhaps a few milliseconds depending on noise. Lateral resolution is also frequency dependent.

Translation of time resolution to depth depends on velocity of the rocks involved. A 50 Hz frequency within a 6000 ft/sec rock would give a tuning thickness of some 30 ft, whereas the same frequency in a 13,000 ft/sec rock (as in West Texas) would give a tuning thickness of 65 ft. Thus, lower velocity sections yield better resolution of individual aquifer elements. Shallow horizons in the Gulf Coast generally are low velocity sandstone and shale and are therefore ideally suited for detailed aquifer characterization. High-velocity carbonate or evaporite rocks, as in west Texas, will give more general results.

Reflection strength may be a problem. Seismic acquisition images reflections from boundaries between units having significant contrast in acoustic impedance (velocity x density). Is there enough contrast in the shallow section to image the aquifer? This question is particularly relevant to sand-shale sequences, such as the Gulf Coast aquifer system. Neidell and Berry (1989) discussed a sand-shale 'crossover' in shallow Louisiana sections, which would make sands nearly invisible on imaging. However, this effect is mainly observed in very young (Pleistocene) sands that have lower density than and comparable velocity to the surrounding shales. Data from the Texas Gulf Coast (Loucks et al., 1979; and the Stratton area) show distinctly higher velocity, density, and acoustic impedance at all depths sampled (Fig. 6). It should be noted, however, that data above about 1500 ft is scarce or absent. The inference is that, at least below 1500 ft, sands should have positive impedance contrast at their top, unless the sand has some gas saturation or high organic content. Thin carbonate stringers, if present, may create strong reflectors that could mask or imitate sand presence.

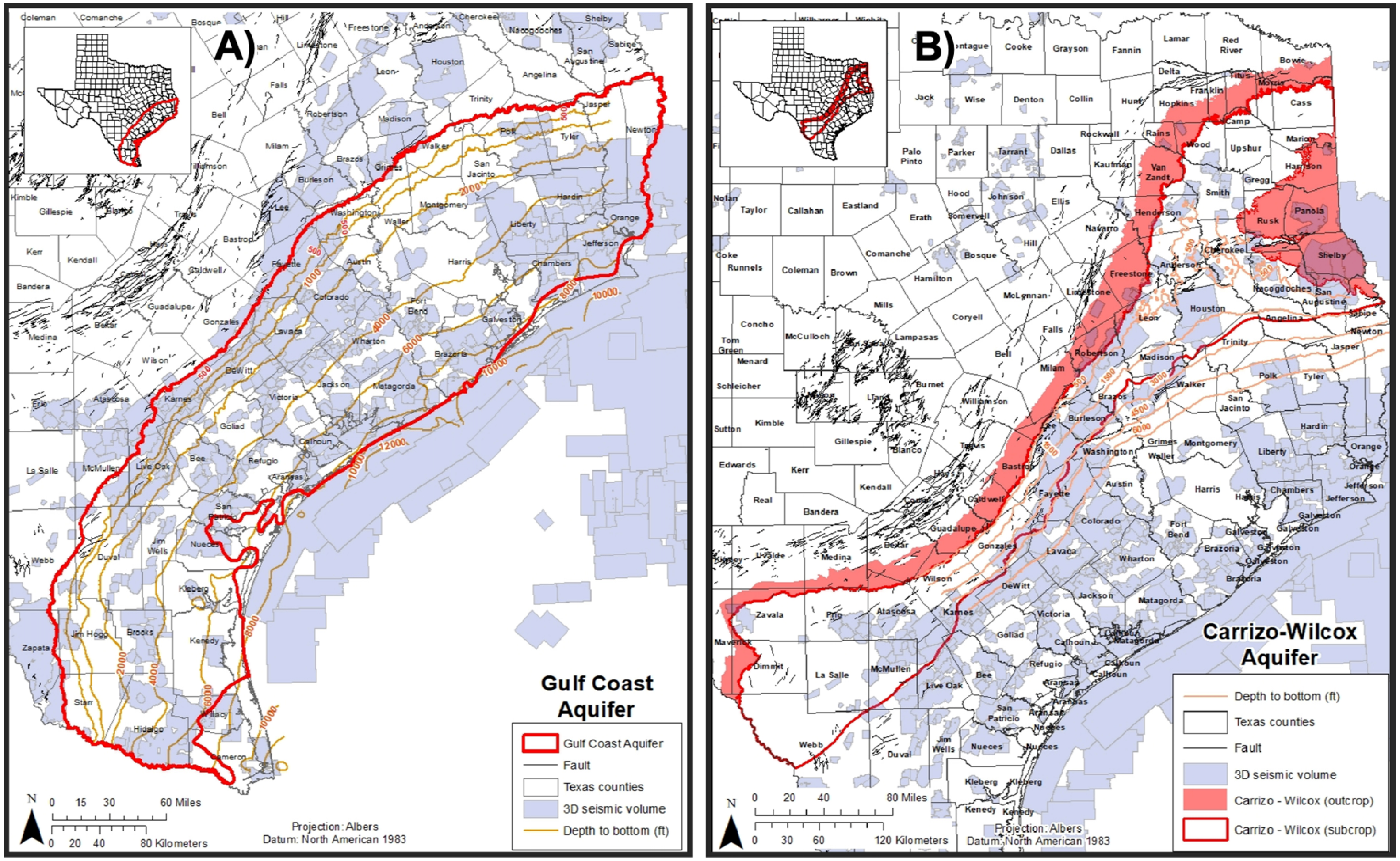


Figure 4. Comparison of 3D seismic availability to the extents of (A) the Gulf Coast aquifer system (Oligocene-Pliocene) and (B) the Carrizo-Wilcox aquifer system (Paleocene-Eocene). Both systems have essentially complete 2D coverage as well.

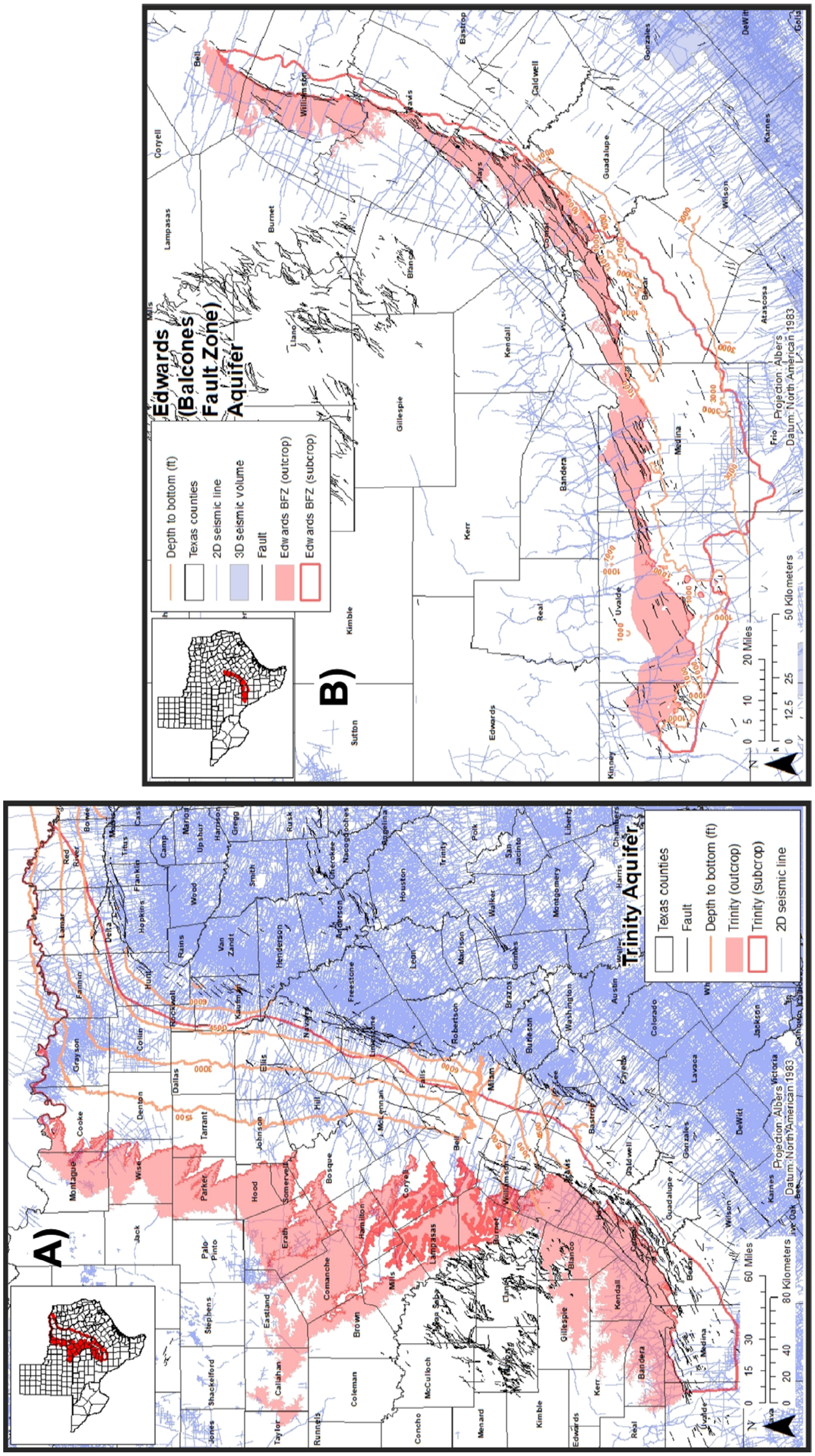


Figure 5. 2D seismic availability over the (A) Trinity aquifer and (B) the Edwards aquifer. There is no 3D availability over these aquifer areas.

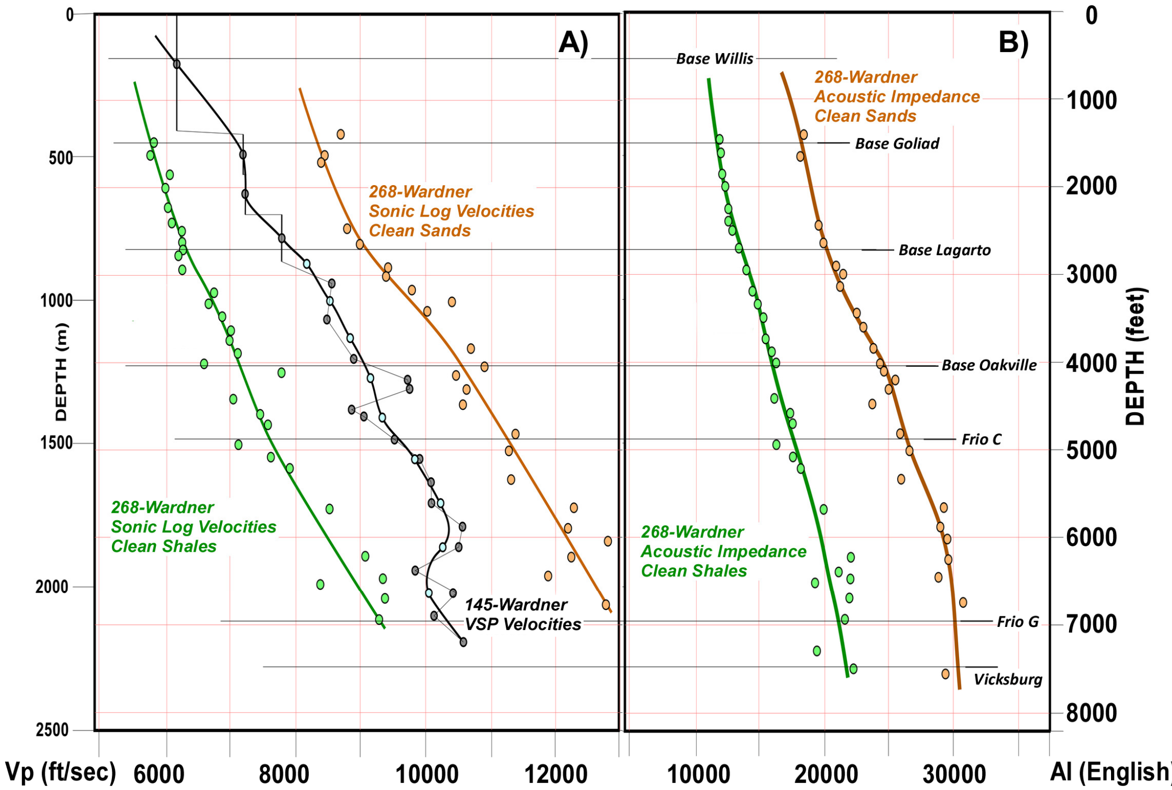


Figure 6. (A) Velocity vs. depth and (B) acoustic impedance vs. depth for clean Gulf Coast sands and shales in the Stratton area, Nueces County, Texas. Sandstones are faster and higher impedance than shales, with difference remaining fairly constant with depth.

AN INTERGRATED WORKFLOW FOR SEISMIC USE IN HYDROGEOLOGY

Given the objectives and limitations of seismic usage, we have proposed an integrated workflow for seismic and hydrogeologic work. In general, it is similar to typical workflows in hydrocarbon exploration. A detailed flowchart of all steps is found in the contract report, as submitted to the TWDB (Draper et al., 2021).

In the first section, the project is scoped and objectives outlined. All relevant geologic and hydrologic information is collected, including regional context from previous studies and geophysical logs from many wells, including sonic and density information when available and nearby velocity surveys or vertical seismic profiles (VSPs). The wells are studied to determine the depth distribution of salinities, primarily from resistivity and spontaneous potential (SP) log data, as well as the distribution of target aquifer elements of interest and possible aquifer dynamics—a typical hydrogeologic workflow. In addition, a seismic data search is conducted, and quality checks of prospective data are made, to identify surveys having sufficient quality and coverage to be useful in fairway or project delineation. At the close, a decision is made to license the data.

With the seismic data in hand, a seismic project is set up and a quick interpretation of structure and reflection character is made using previous well tops and velocity data. Depending on the goals of the study and the nature of the data, a decision to reprocess is made. If reprocessing is not feasible or permitted by budget, the existing data is then interpreted fully.

If reprocessing proceeds, using an experienced data processing establishment, the workflow is a conventional state-of-the-art procedure, with careful attention to the top second of the data. Preprocessing steps are standard, but care must be taken in velocity estimation, noise removal, and statics. Refraction statics are key; in high-velocity environments, refraction residuals may become significant in interpretation. Data may also be checked for anisotropy. Because of the limited number and irregular distribution of traces at shallow depths, interpolation of data is key for maximizing velocity estimation and geologic signal in 3D volumes; the amount of data in the bin gather is greatly increased. The interpolated dataset is again interpreted for stacking velocities, preferably on a bin-by-bin basis, and prestack time migration processes are applied to generate a final stack and migrated volume ready for interpretation. Depth migration or depth conversion are probably not necessary in Gulf Coast environments without shallow salt.

Interpretation is a complex process. Initial interpretation correlates formation tops in wells to seismic reflectors, and carries them beyond the area penetrated by wells, allowing identification of key structural elements and estimation of their continuity toward the surface. Intervals may be characterized by reflection content and stacking velocity. Detailed calibration of reflectors to wells by either VSPs or synthetic seismograms derived from sonic and density logs leads to initial assessment of seismic facies and horizons of interest. Time slices, on 3D volumes flattened to picked regional reflectors, image laterally variable lithologies including reservoir elements, and these variations can be compared to well information. Attribute calculations may assist in this work; however, most attributes are based on difference calculations, which are sensitive to noise and become very unreliable as the footprint increases in the shallow section.

If additional, more quantitative information is desired on the distribution and character of aquifer elements, the seismic data can proceed to inversion to yield volumes or sections of acoustic impedance, which can be related to important aquifer elements. For this work, we require at least one and preferably more wells with velocity and density logs through the horizon of interest. This can be a problem, as many oil and gas operators are not interested in the shallow water-bearing zones and do not run these logs in the shallow interval. Based on this log data, an initial model of acoustic impedance with depth is established, which can also use stacking velocities from 3D survey bins. The impedance inversion proceeds using near-trace data to yield acoustic impedance as a function of travel time. Use of far-trace data can estimate shear velocities and lead to a comprehensive estimation of rock parameters. If compaction trends are strong, a relative acoustic impedance (RAI) can be calculated, which removes the compaction trend and gives a more interpretable volume. For greater detail, statistical and artificial intelligence (AI) methods can yield flags of distribution of sandstone or other aquifer bodies (at additional cost).

A TEST CASE: STRATTON 3D, NUECES COUNTY, TEXAS

This workflow, along the general concept of seismic data informing hydrogeology, was tested using the Stratton 3D dataset. This is a 7.65 mi^2 3D survey acquired in 1992 by the Texas Bureau of Economic Geology with funding from the Gas Research Institute (Hardage et al., 1996). The full dataset was released in 2014 'for worldwide education and training' and is available on the Wiki site of the Society of Exploration Geophysicists (wiki.seg.org). The dataset has been used for several studies, notably by Al-Gain et al. (2020), who reprocessed the data using a similar workflow, but focused on the Frio hydrocarbon reservoirs.

The Stratton dataset lies within Stratton Field in southwestern Nueces and adjoining counties, along the Vicksburg Flexure producing trend (Fig. 7). The field lies within the Gulf Coast aquifer system and contains Miocene brackish to moderately saline sandstones without hydrocarbon accumulations, overlying Frio and Vicksburg intervals that contain significant gas and oil reservoirs. For this study, 255 wells with raster logs were identified within and adjacent to the survey; of these, only four wells had sonic logs covering the Miocene interval below 1,500 ft and one had a density log. A VSP is present in the public dataset but was not used as such infor-

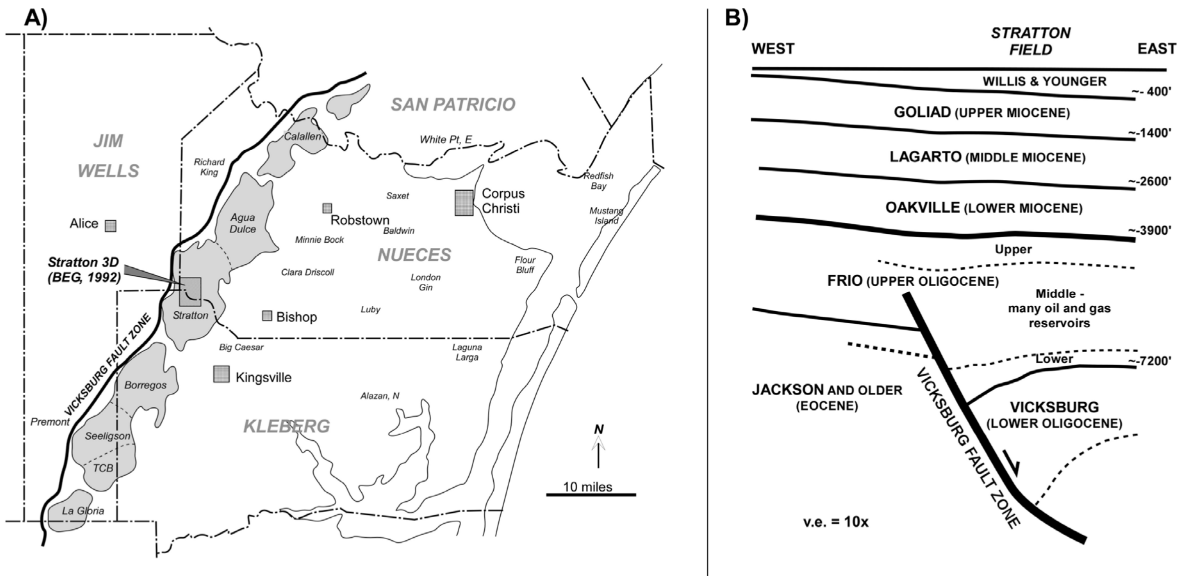


Figure 7. Location of the Stratton 3D survey, southwest of Corpus Christi; and a general cross-section through the field. Brackish water resources occur in the Goliad and Lagarto sections of the Miocene; fresh water is restricted to the shallow Plio-Pleistocene (Willis and younger) section.

mation is unlikely to be present in datasets of hydrogeologic interest. The seismic data were reprocessed through seismic inversion following the workflow outlined above.

Interpretation of this dataset is ongoing and will be reported later. Here we will summarize the results and what they tell us about the usefulness of this sort of data for hydrogeologic work.

A typical line of the reprocessed seismic data can be compared with the original processing to show the substantial improvement that was achieved (Fig. 8). The original line is indefinite above 600 msec, and has some mistie effects below that. The new version of the line shows strong and geologically meaningful reflectors up to the shallowest levels, about 100 msec. The 'footprint' of the acquisition signal is present and increases upward, but does not overwhelm the signal. We judge that about half of the improvement comes from increased care during statics and velocity estimation and half comes from the interpolation process. Lack of attention to shallow imaging is common in Gulf Coast 3D surveys, which focus on deeper oil and gas targets. The effect of interpolation on the quality of gathers is shown in Figure 9, comparing a typical gather before and after interpolation. The process produces a rich set of traces that allows much more confident velocity estimation and noise rejection.

The Miocene contains a number of fairly continuous sandy intervals (Oakville and basal Lagarto, lower Miocene), a relatively small number of isolated channels, and abundant mudstone (Lagarto, middle Miocene), overlain by a sandier Goliad interval (upper Miocene) and shallow Plio-Pleistocene deposits containing fresh water. These sandy and muddy intervals correspond well with the stronger, more continuous seismic facies and irregular and generally weaker reflectivity facies that are seen on the data. Isolated channels are well imaged at several levels (Fig. 10), from the upper Oakville (942 msec, 3260 ft) up to the shallow upper Goliad (260 msec, 800 ft). In the deeper parts of the Miocene section, attributes such as coherence can outline channel margins; however, in the shallower intervals, the footprint noise effectively overwhelms the geologic signal in attribute displays.

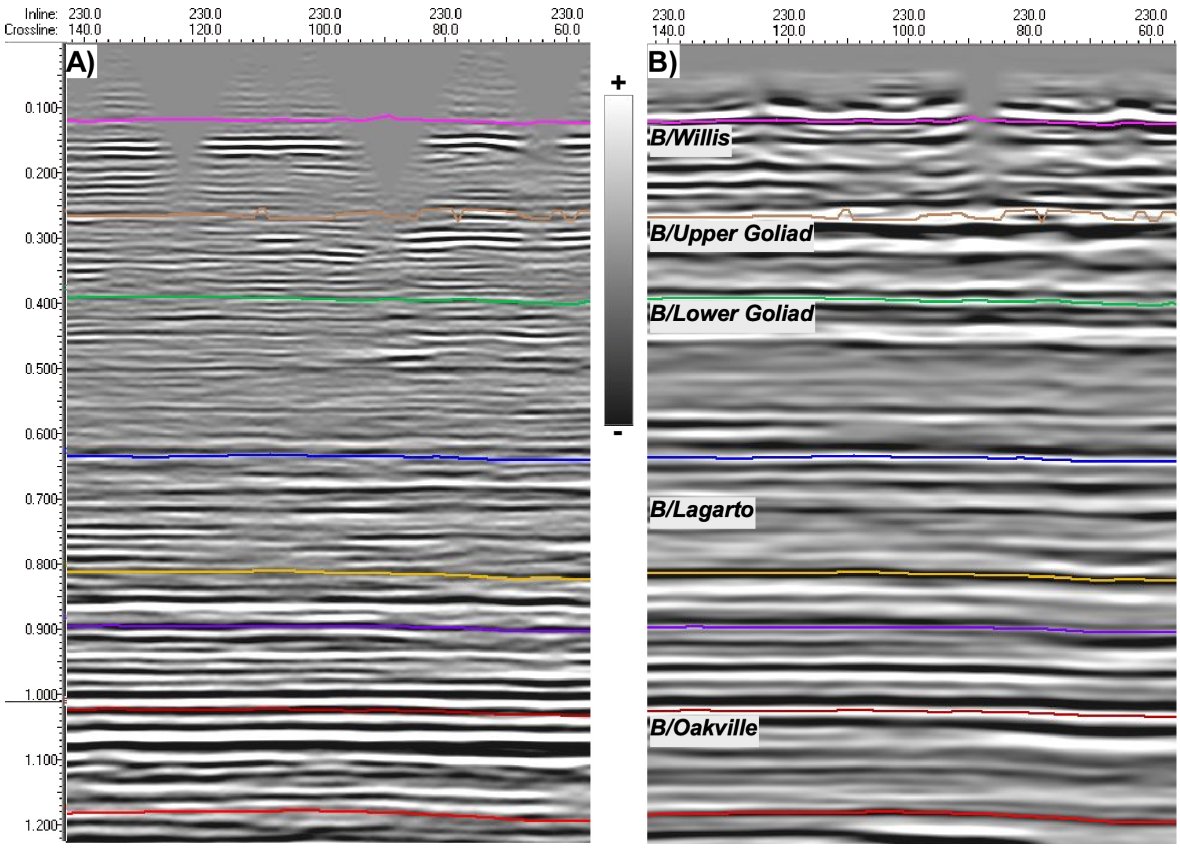


Figure 8. Comparison of original processing vs. 2021 reprocessing; note great improvements above 600 msec to about 100 msec (two-way travel time).

For use in inversion, we were able to combine the one density log available in the Miocene section with a sonic log in a well 800 ft distant (Wardner #268), in order to prepare a full petrophysical analysis that resulted in acoustic impedance, shear impedance, and other rock physics parameters being estimated at the well. This information, together with the detailed stacking velocity information from reprocessing, created the initial model for inversion. Given the small survey and nearly flat geology, one composited well was sufficient for the inversion of the survey.

The final acoustic impedance volume shows good resolution of high-impedance sandy intervals; however, this is masked by a strong compaction trend from low to high impedance that makes detailed examination of larger intervals difficult (Fig. 11A). For this reason, an RAI volume was obtained by subtracting the initial model from the final volume. This volume allows consistent scaling through the Miocene, and better recognition of higher-impedance aquifer elements (Fig. 11B).

CONCLUSIONS

Seismic reflection datasets acquired for oil and gas exploration and development form an abundant resource that can be used in evaluation and development of deep groundwater re-

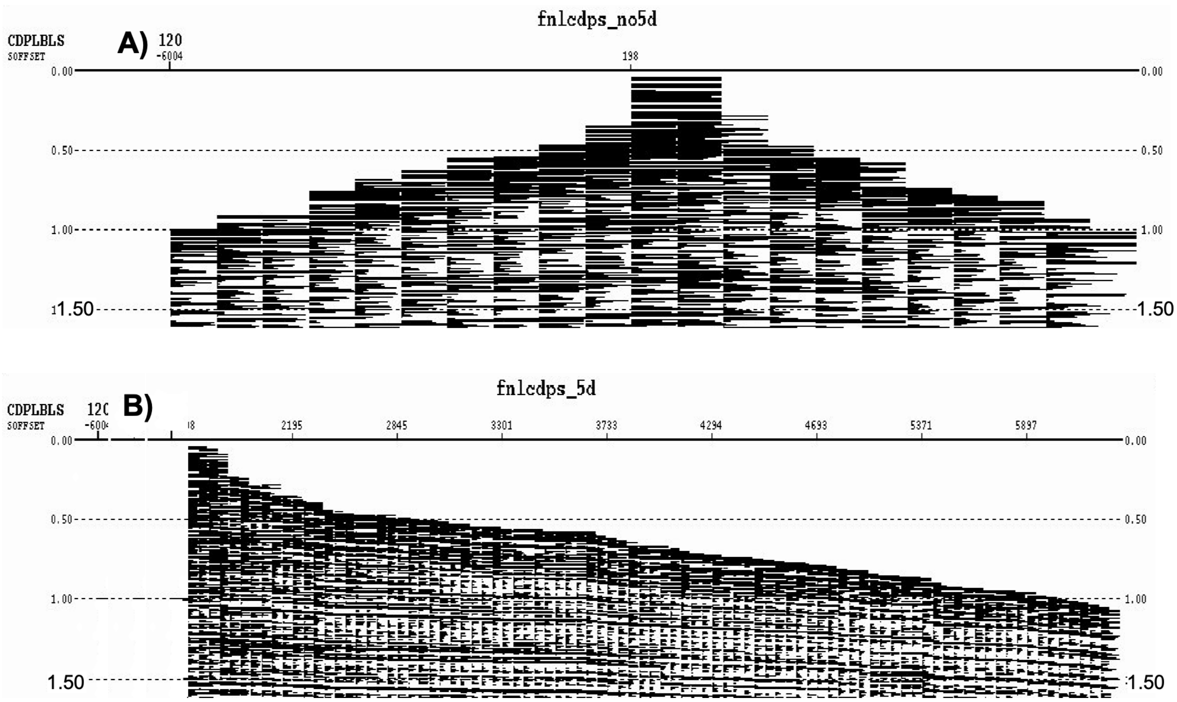


Figure 9. Typical bin gather (A) after rebinning to square bins but before interpolation; and (B) after interpolation (only half the spread shown), showing increase in data and increased ability to determine velocities.

sources, both fresh and brackish, in many parts of Texas. As reprocessing at Stratton shows, great improvements in interpretable data can be obtained, especially in the low velocity Gulf Coast aquifers that overlie deeper hydrocarbon targets. Seismic data can visualize aquifer elements and their connectivity, extend information into undrilled areas, and optimize targets for evaluative wells. Full usage of 3D reprocessed data requires sonic and density log data over the aquifer intervals that may not be available. Deep groundwater evaluation wells should consider running these logs to improve the seismic imaging.

The key question in actually using seismic reflection data is cost versus benefit: what do we learn that is useful given the costs of licensing, interpreting and reprocessing? The Stratton dataset was freely available; if it were licensed, project costs might exceed $200,000. However, in the process of evaluating production fairways and developing a major well-based desalination project, these costs appear quite manageable. Lesser sums spent on 2D seismic profiles can answer important structural questions in faulted aquifers.

ACKNOWLEDGMENTS

Thanks to the Bureau of Economic Geology for the 2014 release of the 3D survey and related information. Seismic processing of the Stratton 3D dataset was carried out by Tricon Geophysical: David Williams, VP; James Sobczak, processor; Vlad Rabinovich, petrophysicist; and Francisco Bolivar, inversion specialist. Thanks to all of them. The project was funded by Texas Water Development Board by a contract to INTERA. A careful review by Bonnie Weise has improved this manuscript.

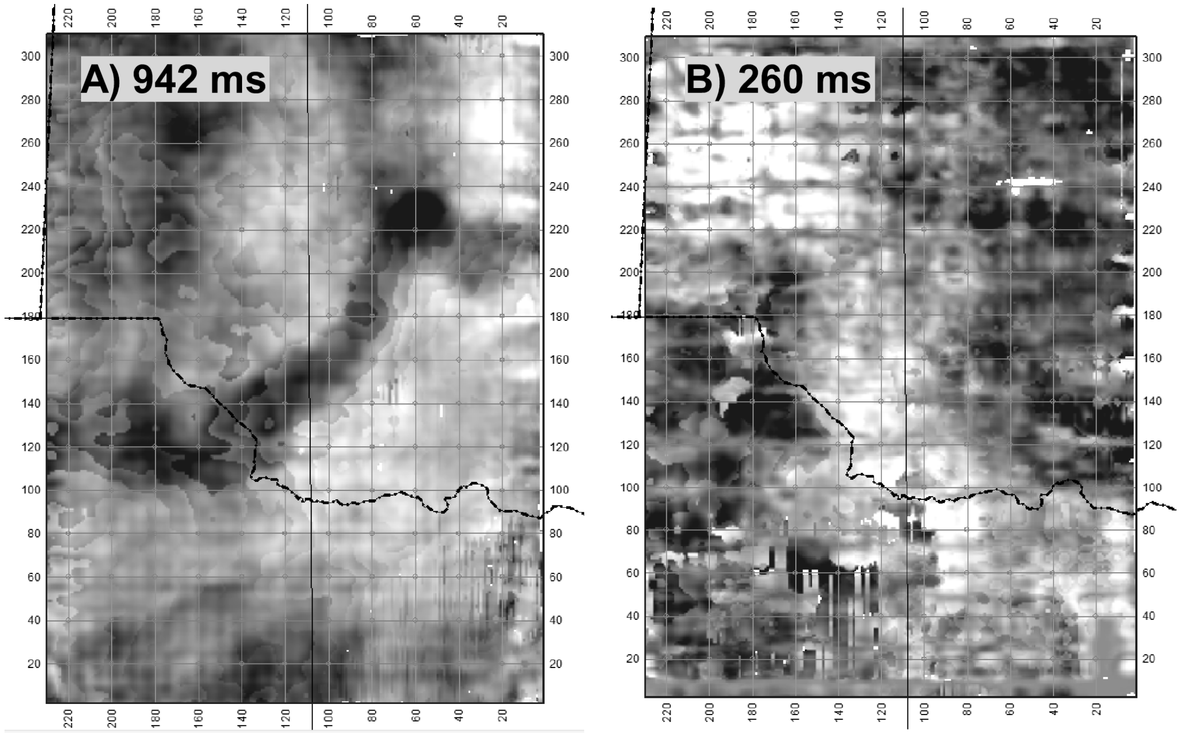


Figure 10. Geologic channel features in the Miocene imaged on the reprocessed data; time slices are flattened on nearby high-quality reflectors. (A) Channel in the Upper Oakville (942 msec, 3260 ft); (B) channel in the Upper Goliad (260 msec, 800 ft), which appears to be the shallowest geologic feature imaged.

REFERENCES CITED

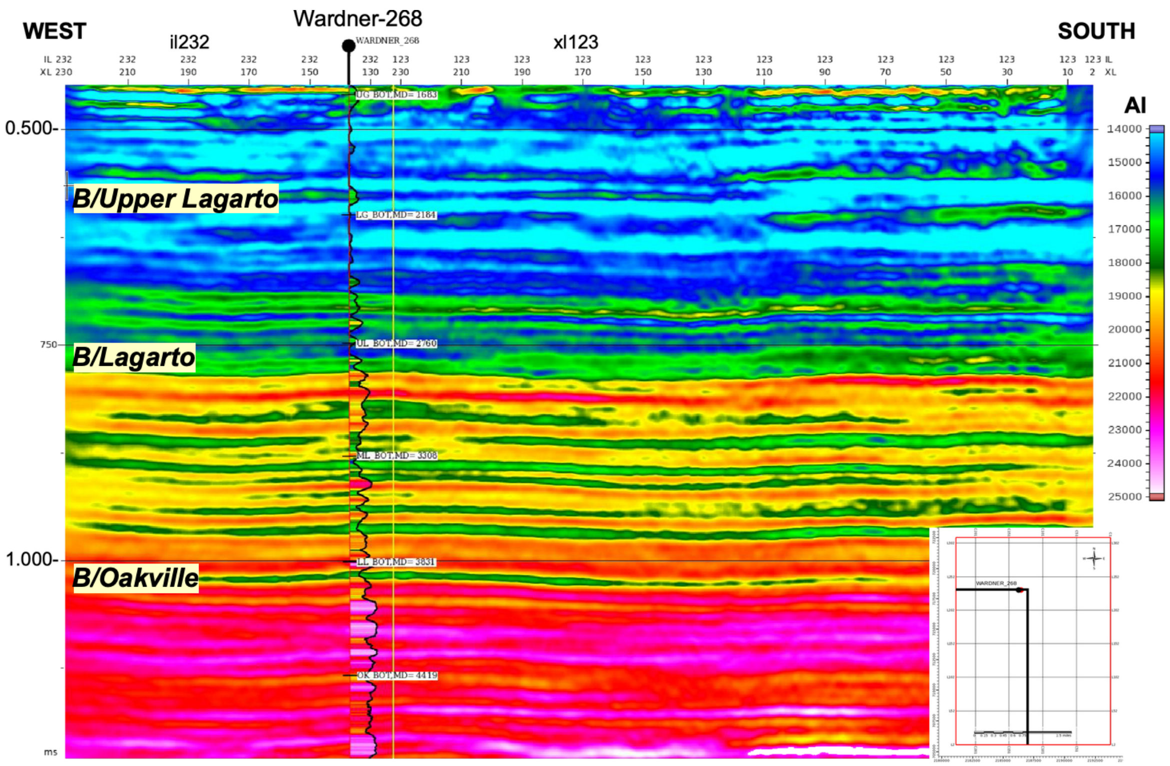
Al-Gain, M., K. Abdelrahman, A. Kahal, S. Al-Zahrani, E. Ibrahim, and N. Al-Otaibi, 2020, Impact of 5D regularization and interpolation on subsurface imaging: A case study of Stratton Field, South Texas, United States of America: Journal of King Saud University–Science, v. 32, p. 2733–2740.

Bertoni, C., J. Lofi, A. Micallef, and H. Moe, 2020, Seismic reflection methods in offshore groundwater research: Geosciences (Switzerland), v. 10, p. 1–34,

Cunningham, K. J., J. W. Kluesner, R. L. Wescott, E. Robinson, C. Walker, and S. A. Khan, 2018, Sequence stratigraphy, seismic stratigraphy, and seismic structures of the lower intermediate confining unit and most of the Floridan aquifer system, Broward County, Florida: U.S. Geological Survey Scientific Investigations Report 2017–5109, 86p.

Draper, C. H., T. E. Ewing, and D. M. Lupton, 2021, Final report: Seismic interpretation: Report to Texas Water Development Board under Contract 580–20–RFQ–0008, Austin, Texas, 220 p.

Ewing, T. E., 2016, Texas through time: Lone Star geology, landscapes and resources: Bureau of Economic Geology Udden Series 6, Austin, Texas, 431 p.



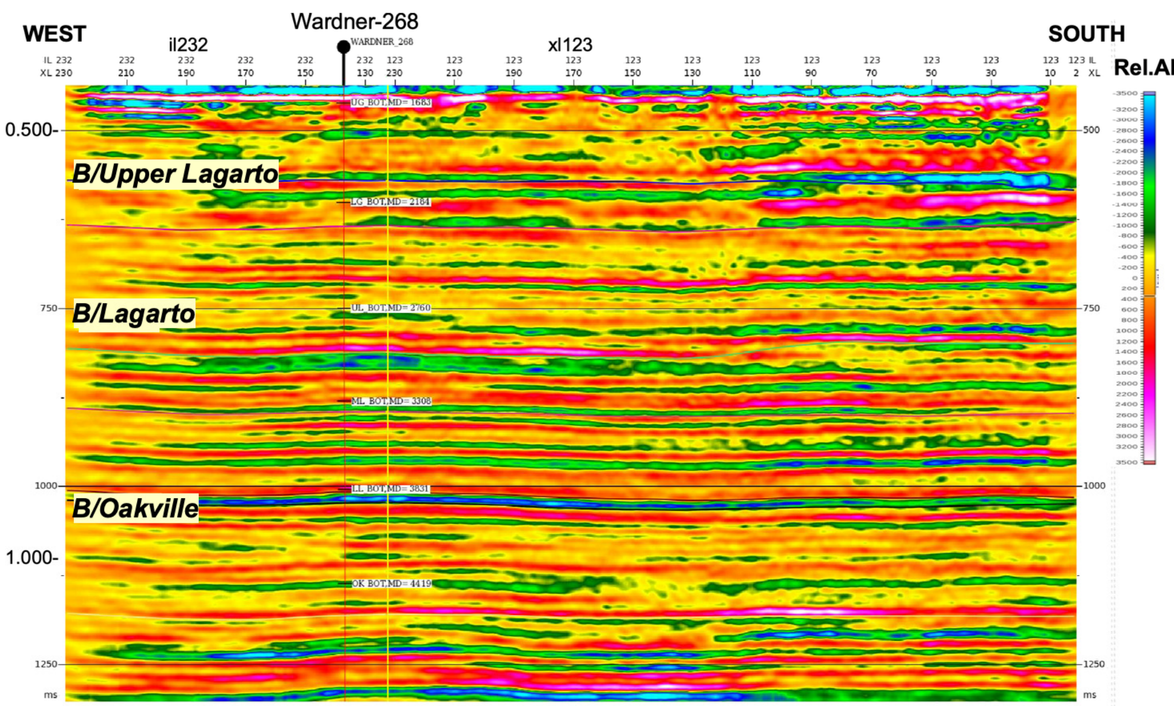


Figure 11. Typical line (combination of inline and crossline) showing results of inversion: (A) Acoustic impedance, showing the strong compaction trend and (B) relative acoustic impedance (RAI), with the compaction trend removed.

Flores Capetillo., R., J. R. Vera Sanchez, G. Pardo Castro, A. E. Oviedo Perez, F. Cuevas Rivera, R. Chavez Guillen, F. A. Avila Luna, and M. Vazquez Garcia, 2014, Deep groundwater prospecting in Mexico City through seismic reflection methodology: The Leading Edge. v. 33, p. 758–763.

Hanot, F., N. Quisel, S. Thomas, and N. Rampnoux, 2011, Pertinence of the seismic reprocessing using existing seismic profiles in the Paris Basin: Energy Procedia. v. 4. p. 4607–4616.

Hardage, B. A., R. A. Levey, V. Pendleton, J. Simmons, and R. Edson, 1996, 3-D seismic imaging and interpretation of fluvially deposited thin-bed reservoirs, *in* P. Weimer and T. L. Davis, eds., Applications of 3-D seismic data to exploration and production: American Association of Petroleum Geologists Studies in Geology 42, Tulsa, Oklahoma, p. 27–34.

Jansen, J., and T. Jehn-Dellaport, 2015, Repurposing petroleum seismic reflection data to characterize deep aquifers: Presentation from National Ground Water Association Groundwater Expo and Annual Meeting.

Loucks, R. G., M. M. Dodge, and W. E. Galloway, 1979, Sandstone consolidation analysis to delineate areas of high-quality reservoirs suitable for production of geopressured geothermal energy along the Texas Gulf Coast: Report prepared by the Bureau of Economic Geology (Austin, Texas) for the U.S. Department of Energy Division of Geothermal Energy (Washington, D.C.) under Contract EG–77–5–05–5554, Report ORO–5554–1, 101 p.

Neidell, N. S., and N. Berry, 1989, Documenting the sand/shale crossover: Geophysics, v. 54, p. 1430–1434.

Thomas, A. T., S. Reiche, M. Riedel, and C. Clauser, 2019, The fate of submarine fresh groundwater reservoirs at the New Jersey shelf, USA: Hydrogeology Journal. v. 27, p. 2673–2694.

Woodward, D. G., and A. H. Al-Jeelani, 1993, Application of reprocessed seismic sections from petroleum exploration surveys for groundwater studies, Eastern Abu Dhabi, UAE: Proceedings of the Middle East Oil Show, v. 1, p. 257–266.

NOTES