AI Sharpens Seismic in Complex Terrain

Geoscientists use AI, imaging technologies and integrated workflows to reduce uncertainty in complex structural areas.

By EMILY SMITH LLINÁS, EXPLORER Correspondent

Conducting 3-D seismic acquisition operations in 2005 in the Piedemonte, a complex area in the Andes Foothills of Colombia. Teams had to overcome numerous challenges to achieve the desired high-density standards of today's 3-D seismic. Photo provided by Jaime Checa.

Jaime Checa (second from the left) helped members of the Casanare Community in Eastern Colombia to feel vibrations generated by a Vibroseis source during an early social outreach project led by SierraCol and ACGGP. These hands-on dialogue sessions bring transparency and build trust among stakeholders. Photo provided by Jaime Checa.

To be competitive, oil and gas companies must have the best information available to make operational and investment decisions. A key component for decision making comes through seismic data – images of Earth's subsurface that help geoscientists identify reservoirs, map underground structures and make drilling decisions to maximize accuracy while minimizing environmental impact.

Securing accurate information can be difficult in complex structural environments, like those in fold and thrust belts, where challenging terrain, difficult surface access, high elevation changes and variable near-surface velocities limit companies' access to quality data.

These environments present challenges both for seismic acquisition – obtaining the data in the field – and for seismic processing – finding actionable insights toward decisions about where to drill for oil and gas or other resources.

Fortunately, decades of technological advances, collaborative workflows and artificial intelligence are making it easier for companies to obtain and process their data.

Step Changes in Seismic Acquisition

Jaime Checa, geophysicist, AAPG member and president of the Colombian Association of Energy Geologists and Geophysicists (ACGGP), has followed advances in seismic acquisition technologies over his 35-year career.

"Seismic acquisition has undergone a step change over the past decade, mainly due to the combination of autonomous nodes and simultaneous vibroseis sources. Trace density has reached the tens and even hundreds of millions of traces per square kilometer, while bin size has decreased to 6.25 meters or less. Bandwidth has been extended towards the low frequencies to obtain one or more critical octaves," he said.

Part of the evolution has been driven by full Waveform inversion, a processing technique that inverts the entire seismic waveform to generate high-resolution volumes of seismic impedance. FWI has been used primarily for marine environments, though companies are testing land applications.

"The deployment of receiver nodes in the field now makes it possible to acquire cost-effective, long-offset, wide-azimuth data – a dream come true for geophysical explorationists," he said.

Above-ground Challenges

Checa noted that while technological advances bring promise, they face significant implementation challenges in complex environments.

"Rough topography and complex shallow geology continue to be very

difficult issues to solve in seismic processing, despite the amazing progress of the current techniques," he said.

And complexity extends beyond the geology.

Checa shared a series of other above-ground conditions that affect companies' ability to acquire high-quality seismic data:

- On the receiver side, while the advent of nodes has greatly reduced logistics and HSE (health, safety and environment) exposure, the effort and labor required to deploy and relocate tens of thousands of units remain extremely demanding – especially in rough terrain and areas with limited access.
- Permitting costs – traditionally tied to the length and width of receiver lines – can rise dramatically in dense geometries, requiring a fundamentally new approach to landowner negotiations.
- Road access for large vibrator sources is often far from ideal. In many areas, the use of explosive sources is still essential, with the resulting increase in cost due to the associated drilling.
- The abundance of environmentally sensitive features heavily constrains the number of sources that can be implemented, and in turn introduces significant irregularities in the desired geometry, which limits the performance of modern imaging algorithms.

Checa noted that involving an experienced seismic company in the planning phase is a best practice that helps companies anticipate and solve critical issues – l lack of surface water, limited availability of explosives, constraints on camp installation, and others – long before field deployment.

Making the Best of Limited Data

Once seismic companies obtain the data, they turn it over to companies like Thrust Belt Imaging, a Calgary-based data processing company that specializes in fold-and-thrust belts, faulted zones and other complex environments in South America and Southeast Asia.

Greg Cameron, AAPG member and TBI president, said the company specializes in workflows designed to facilitate decision-making for companies working in environments with limited or poor-quality data.

"We must work with the data available to our clients. Complex structure land data is often coarsely sampled due to the high cost of acquisition and land access issues," he said.

"Sometimes, acquiring new data is not possible, and we are asked to make improvements to older vintage seismic data. Additionally, many of the areas we work are frontier exploration environments, where there is limited well information or other geologic constraints to calibrate our processing."

Developing Workflows

Over the last 20 years, TBI has developed experience and workflows tailored to the challenges of complex-structure land data.

"In areas filled with data challenges, local geological knowledge and collaboration with structural geologists are key levers for success, Cameron said. "We focus on areas where our interpretive and collaborative workflow adds value to our client's data and continue to evaluate new technologies to see where they can add value."

Clients see the value of the hands-on approach. In its 20-year history, TBI has processed data from more than 40 countries on six continents. Their largest markets are Colombia, Peru, Pakistan, Papua New Guinea and Indonesia.

"Most of our work is for oil and gas exploration," Cameron said. "However, we have recently been involved in hydrogen exploration in France, lithium exploration in the U.S. and geothermal projects in Turkey."

Technology and AI

Cameron said that TBI's time-tested workflow benefits from artificial intelligence.

"Historically, automated processing methods have not performed well on the challenging data we typically work with. However, as algorithms mature and computers become more powerful, we have had success implementing new technologies into our workflow," he said.

"It is an exciting time as we see machine learning and full waveform inversion add value to complex-structure land data."

Cameron noted two major trends in seismic data processing over the past decade: the integration of machine learning, especially convolutional neural networks, and full-waveform inversion methods.

"TBI is at the forefront of both. We are using CNNs to predict PSDM (pre-stack depth migration) velocity models directly from migrated data and are developing a land-focused FWI," he said.

"These technologies both integrate seamlessly with the geologically constrained velocity model building method we have refined over the last 20 years."

AI Applications for Exploration and Production

Cameron said several AI tools have been developed to help geophysicists process and interpret seismic data. Processing tools include noise attenuation, interpolation, and velocity model prediction. He added that the most widely adopted tools are for interpretation, particularly horizon picking and fault interpretation.

"AI tools automate some of the more mundane tasks, accelerating workflows while allowing geoscientists to spend more time focused on other challenges," he said.

"Importantly, all these AI methods require human knowledge to get good results. The AI is only as good as the data it was trained on, which is still the domain of the human."

Adapting to the New Reality

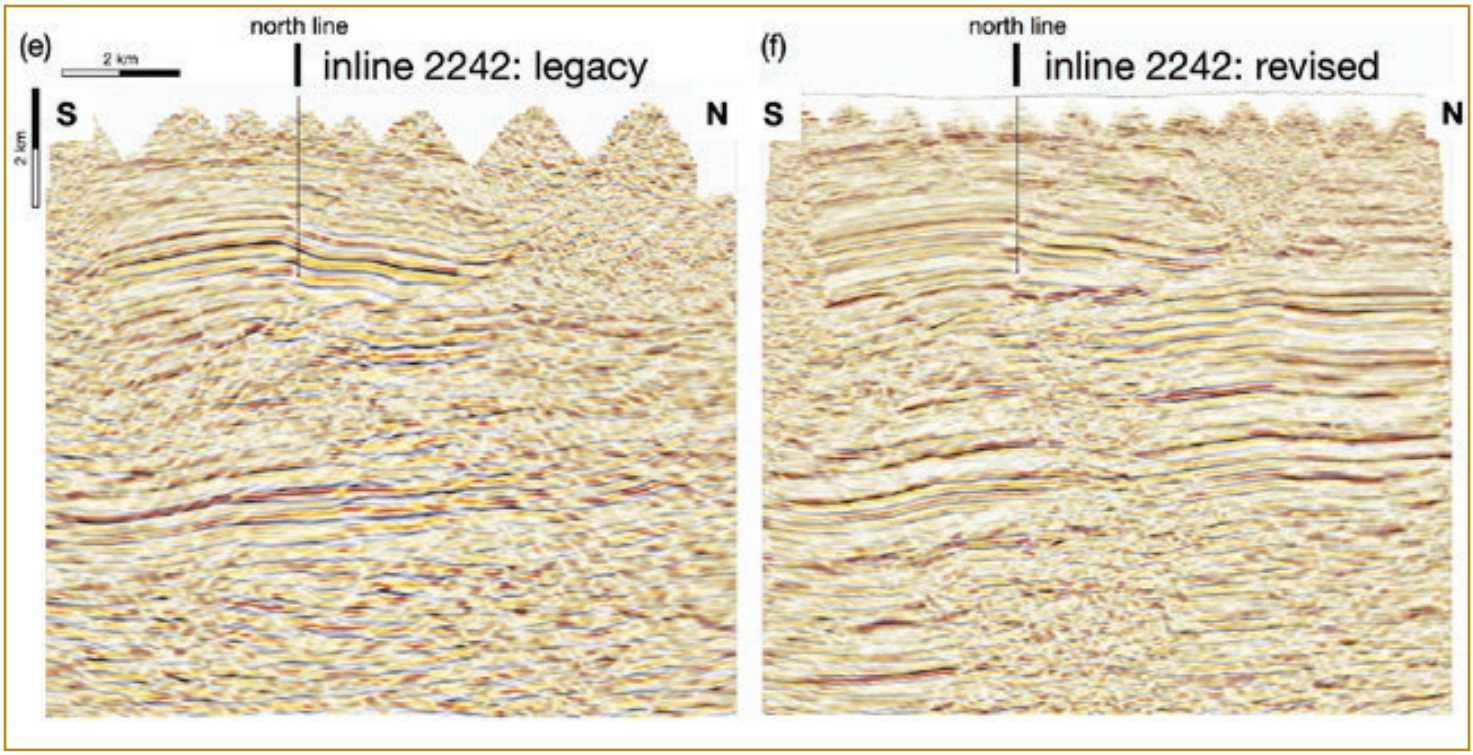
Cameron said while the last 10 years have been difficult for the oil and gas industry, he sees better times ahead.

"Our clients' processing budgets have decreased, and we have been asked to do more for less. We have adapted to this new reality, using our experience to understand how we can be more efficient and still deliver the results our clients have come to expect," said.

"I am optimistic that we will see the market improve for seismic data processing in the short- to mid-term. We will continue to focus on being efficient and incorporating new technology where it adds value to our workflow," he said.

Advances in processing technologies will

To next page



Reprocessing example from Camisea, Peru. Correcting for anisotropy improved the well tie, while building a geologically constrained velocity model in close collaboration with the client improved the footwall and foreland imaging as shown in the box. (Vestrum, R.W., Soldo, J., Zunino, E., Muzzio, M.E., Chung, J.F., 2023, Geologically constrained model building for seismic depth imaging in Camisea, Peru. The International Meeting for Applied Geoscience and Energy, Houston, United States.)

◂ *From previous page*

help to make that possible.

"With the advancement of FWI for onshore data, I expect our clients will be able to get more out of their seismic data, adding value to both new acquisition and older vintage seismic data," he said.

Other 'Above-ground' Challenges

Checa shared how, though technological advances are helpful, companies need more than technology to be successful in complex environments, especially those home to local and Indigenous communities and other rural populations.

"Social unrest remains a persistent, day-to-day challenge," he said. "Hiring people and procuring goods and services continue to be cumbersome processes, undermining efforts to achieve high operational efficiency," he said.

The current socio-economic context underscores an unprecedented need for a rigorous and comprehensive planning process to acquire data within expected timeframes and budgets, while accounting for the full range of potential issues inherent to operations in challenging environments, he explained.

"Establishing early relationships with authorities, regulators and local communities is a critical component of the overall strategy, which needs to include a robust communication strategy," he said.

Community Engagement

Checa developed corporate strategies while working as seismic project manager at several companies in Colombia.

Successful community relations are critical for onshore operations success in the Andean nation marked by armed conflict, protected natural environments and Indigenous sites, and an underlying disconnect between the national government and big city populations and populations living in the territories.

"Ecopetrol, Canacol, Parex, Geopark and SierraCol have conducted early engagement activities through hands-on field exercises, where communities receive clear answers to their concerns and gain first-hand familiarity with equipment such as vibroseis sources," he said.

"These practices help build trust and foster inclusive dialogue, encouraging communities to reflect on their own future development."

Checa shared how similar workshops held with local and national environmental authorities contribute to the creation of harmonized regulations that balance operational needs with environmental protection.

The Role of Professional Associations

The best practices in Colombia come not only from companies, but also from professional societies, particularly the ACGGP, the local society that Checa has supported over decades.

"Professional associations act as credible bridges between stakeholders, with strong potential to foster early and sustained relationships based on education and transparent communication," he said.

He cited ACGGP's Regional Pedagogy Program, an initiative that has reached more than 40,000 people across the country with tailored, science-based content and direct interaction with technical experts.

"These efforts have contributed to a better-informed public dialogue around geoscience, energy, and environmental topics, while promoting trust and transparency," Checa said.

"Through partnerships with universities, local leaders, teachers and students, the program has helped demystify the technical aspects of the energy industry and foster constructive engagement. This type of sustained outreach is essential to building the long-term social foundations needed to successfully implement complex operations like 3-D seismic acquisition in geologically promising, yet socially sensitive regions."

AAPG Rockies and Andes Workshop

Checa will share his expertise, both in seismic and in community outreach, as a committee member for the AAPG Rockies and Andes Workshop: "Navigating Energy Frontiers: Innovations in Oil and Gas for Complex Environments, taking place in Lima, Peru on March 4-5, 2026.

The Rockies and Andes Workshop is the second event organized jointly by AAPG's Canada and Latin America and Caribbean Regions.

The first edition, held in Calgary in May 2024, convened experts from seven countries for cross-regional, multidisciplinary discussions around the exploration and development of hydrocarbons and renewable energy resources, as well as the application of subsurface skills to geological storage.

The 2026 workshop themes include strategies for gas reserve replacement and enhancement; technologies for exploration in fold and thrust belts; geoscience solutions to revitalize mature fields; and community relations and regulatory considerations for operations in sensitive environments.

Cameron attended the inaugural Rockies and Andes Workshop in Calgary and looks forward to continuing the discussion in Lima next year.

"TBI has extensive experience in both the Rockies and Andes, so the event is a natural fit for us," he said. "We will be sharing our experience imaging complex-structure land data and the technologies we are developing to further enhance our workflow. I look forward to listening to my fellow attendees to understand the challenges they are facing and how we can work together to solve them."

Cameron said he enjoys focused, single-session workshops that facilitate provide in-personal interaction with a single group of people over two days.

"This format allows you to form stronger connections than you would at larger events. The tailored content of the GTW leads to meaningful discussions during and after the event," he said, encouraging colleagues from both Canada and Latin America to join him in Lima.

For additional information and to register for the Rockies and Andes workshop visit aapg.to/rockiesandes2026.