Geothermal Technologies Program 2010 Peer Review

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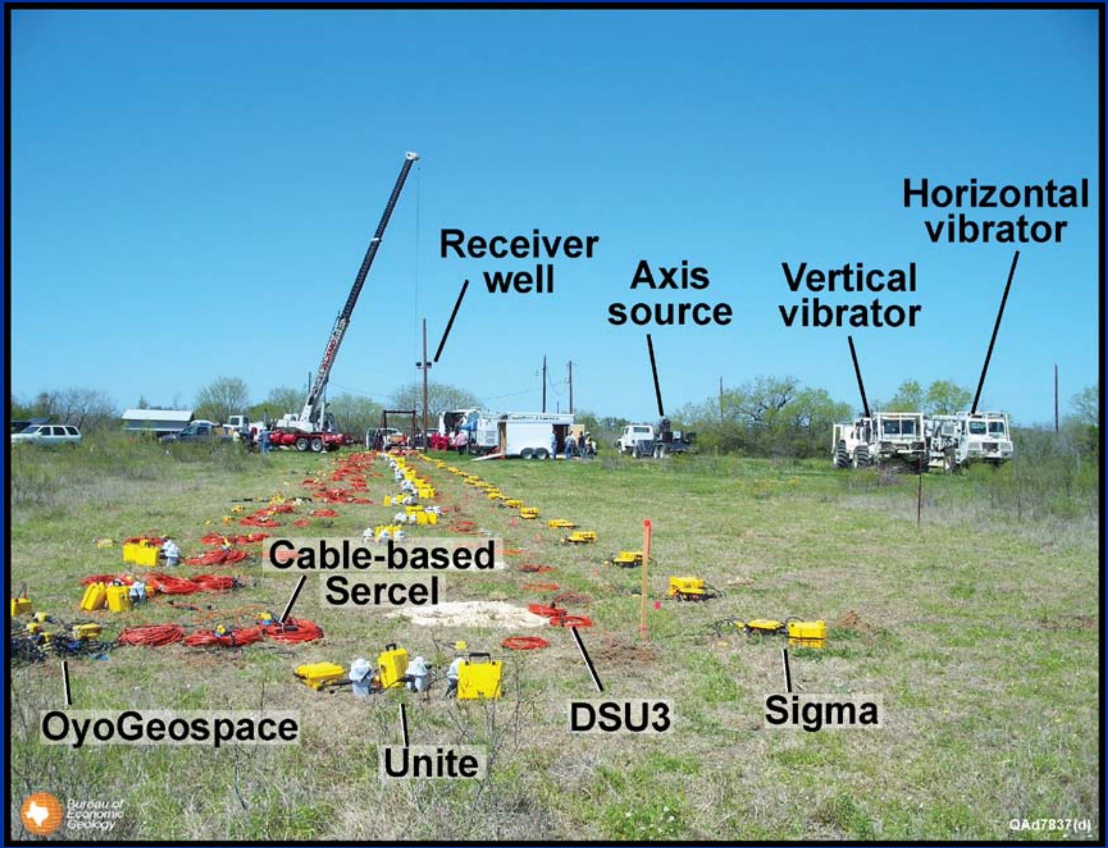

Seismic Technology Adapted to Analyzing and Developing Geothermal Systems Below Surface-Exposed High-Velocity Rocks

May 3, 2010

Principal Investigator: Bob A. Hardage

Bureau of Economic Geology
The University of Texas at Austin

TIMELINE

- Project start date – February, 2010 (?)
- Project end date – February, 2013 (?)
  (Uncertainty exists because "restrictions" are not yet "lifted")
- Percent complete – 10 percent (work done under funding "risk")

BUDGET

- Total project – $1,749,170
- DOE share – $1,397,170
- Awardee share – $352,000
- Funding received in FT09 – zero
- Funding received in FY10 – zero

BARRIERS

- None once "restrictions" are lifted.

PARTNERS

- AOA Geophysics
- AscendGeo
- Austin Powder Company
- Dawson Geophysical
- GEDCO
- Mitcham Industries
- RARE Technology
- Sercel
- United Service Alliance

Relevance/Impact of Research

- Improved seismic imaging of geology across high-velocity Earth surfaces will allow more rigorous evaluation of geothermal prospects beneath volcanic outcrops.
- Seismic-based quantification of fracture orientation and intensity will result in optimal positioning of geothermal wells.
- Field tests will define the relative merits of S-wave seismic sources needed for geothermal seismic applications.
- Rock physics theory describing P-wave and S-wave reflectivities across orthorhombic media will allow methodology to be applied to geothermal reservoirs that are fractured and thin bedded, in addition to being thick, massive fracture units.

Scientific/Technical Approach

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- Record, process, and analyze P-wave and S-wave seismic data along profiles that traverse high-velocity-rock outcrops and low-velocity sediment cover in Brewster County, Texas – an area with volcanic rock outcrops and geothermal springs.
- Perform field tests that define the geometrical patterns and relative strengths of P-wave and S-wave seismic modes radiating away from vertical vibrators, horizontal vibrators, vertical-impact sources, inclined-impact sources, and shot-hole explosives.
- Participate in the design, acquisition, processing, and interpretation of 9C3D seismic data across Soda Lake Geothermal Field, Nevada.
- Develop rock physics theory describing P-wave and S-wave reflectivities from fractured geothermal units and compare theory against real seismic data.

Accomplishments, Expected Outcomes and Progress

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ACCOMPLISHMENTS

- On hold until DOE removes “restrictions” and funds can be expended. The process of “lifting conditions” has been underway since January 2010.

EXPECTED OUTCOMES

- Technology that will improve seismic data quality across high-velocity outcrops common to geothermal areas.
- Quantitative evaluation and comparison of seismic S-wave sources for geothermal exploitation.
- Demonstration of physics of P-wave and S-wave propagation in high-velocity outcrop areas.
- Seismic methodology for quantifying fracture orientation and intensity in geothermal reservoirs.

PROGRESS

- Selected locations for seismic test sites on 430-mi^2 O-2 Ranch, Brewster County, Texas, an area of volcanic outcrops and geothermal springs.
- Scope of study has been expanded to include analysis of 9C3D seismic data acquired across Soda Lake Geothermal Field, Nevada.
- Initiated petrophysics analysis of well log data across Soda Lake Field, Nevada.
- Assisted Magma Energy in design of Soda Lake 9C3D seismic survey and in selection and deployment strategy of high-temperature downhole geophones.
- Completed first field tests of S-wave seismic sources.

TEAM QUALIFICATIONS

- Research staff = 10 scientists.
- 20 sponsoring companies support laboratory work.
- Three senior scientists – average of 51 years of research experience.
- Key scientists – average of 16 years of research experience.
- Awards: Kaufman Gold Medal, Conrad Schlumberger Award, Hollis Hedberg Award, SEG Honorary Members (3), SEG Life Members (3), SEG Special Commendations (3), AAPG Distinguished Service (1), Best Paper (6), SEG President (2), SEG Editor (1), SEG First VP (1), and many lesser awards and honors.

EQUIPMENT

- Cable-free seismic data acquisition systems (3).
- 2400 strings of 3C geophones.
- Sercel 428 seismic recorder.
- 70 licenses of commercial software for geoscience applications.
- Seismic sources (vibrators, accelerated weight drops, explosives).
- VSP receiver array (24 stations).
- 100-acre seismic test site with three monitor wells.

Project Management/Coordination

- Research staff of 10 scientists report directly to the Principal Investigator.
- Consultants hired to assist research effort report to Principal Investigator.
- Principal investigator coordinates with eight partner companies who supply seismic sources, seismic data recorders, downhole seismic sensors, shot-hole drilling, and seismic data processing.
- Project is part of the multicomponent seismic research done at the Exploration Geophysics Laboratory (EGL), Austin, Texas. Progress is reviewed annually with the 20 companies who sponsor EGL, as are all other research studies in progress at the lab.

Project Management/Coordination

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- Exchange of digital data files between research team and Magma Energy, operator of Soda Lake Geothermal Field (Nevada), is frequent and efficient.
- Principal Investigator receives weekly Email status report from each team member.
- Graphical documentation of research progress in terms of PowerPoint, tif, or jpeg formats is done continuously by professionals in the Bureau's Graphics Section, who provide the Principal Investigator weekly status reports.
- Financial accounting is handled by the Bureau's Accounting Section, who provides the Principal Investigator monthly reports.
- Amassed 4X more cost-share than needed from 10 companies, allowing replacement cost-share to be brought forward if any first-choice candidate for cost-share undergoes financial stress.

FY2010 Tasks

- Acquire seismic data across Test Site 1, O2 Ranch, Brewster County, Texas.
- Initiate processing of P-wave and S-wave data across Test Site 1.
- Amass well-log database describing subsurface geology at Test Site 1.
- Develop rock physics model for Soda Lake Field, Nevada.
- Initiate extraction of fracture-sensitive attributes from 9C3D seismic data acquired across Soda Lake Field, Nevada.

FY2011 Tasks

- Complete processing and interpretation of P and S seismic data across Test Site 1.
- Acquire seismic data across Test Site 2, O2 Ranch, Brewster County, Texas.
- Initiate processing of P-wave and S-wave data across Test Site 2.
- Document value of 9C3D seismic data for quantifying fracture systems across Soda Lake Field, Nevada.

Milestones (FY2010 and FY2011)

- Select at least five seismic test sites across O2 Ranch, Brewster County, Texas.
- Acquire and process seismic data at Test Site 1.
- Amass well-log database describing geology at Test Site 1.
- Acquire and process data that define P-wave and S-wave radiation patterns emitted by a variety of seismic sources.
- Analyze 9C3D prestack data acquired across Soda Lake Field, Nevada.

Decision Points (FY2010 and FY2011)

- Decide whether seismic data acquired at Test Site 1 are appropriate for research. If data are inappropriate, proceed to Test Site 2.
- Determine whether seismic-source test was flawed. If test weaknesses are found, correct the test procedure, and repeat the test.

Summary

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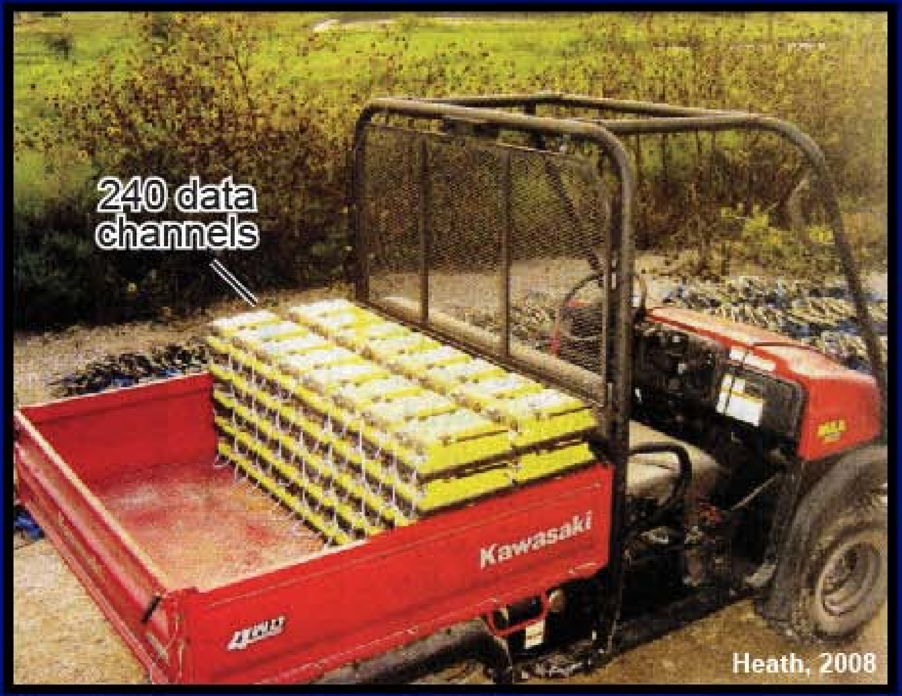
- Cable-free seismic data acquisition will be important for exploiting geothermal energy.
- Theory implies the SH shear wave mode can image geothermal systems beneath surface outcrops of high-velocity rocks when other seismic modes cannot.
  Is this theory correct?
- P-wave and S-wave radiation patterns emitted by seismic sources need to be measured and quantified to determine optimal source types for evaluating geothermal prospects.
- Seismic technology can be developed that will characterize fracture systems in geothermal environments.

CABLE-FREE SEISMIC DATA ACQUISITION



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P-WAVE PROFILE: VAL VERDE BASIN, TEXAS (Vertical Impact Source and Vertical Geophones)

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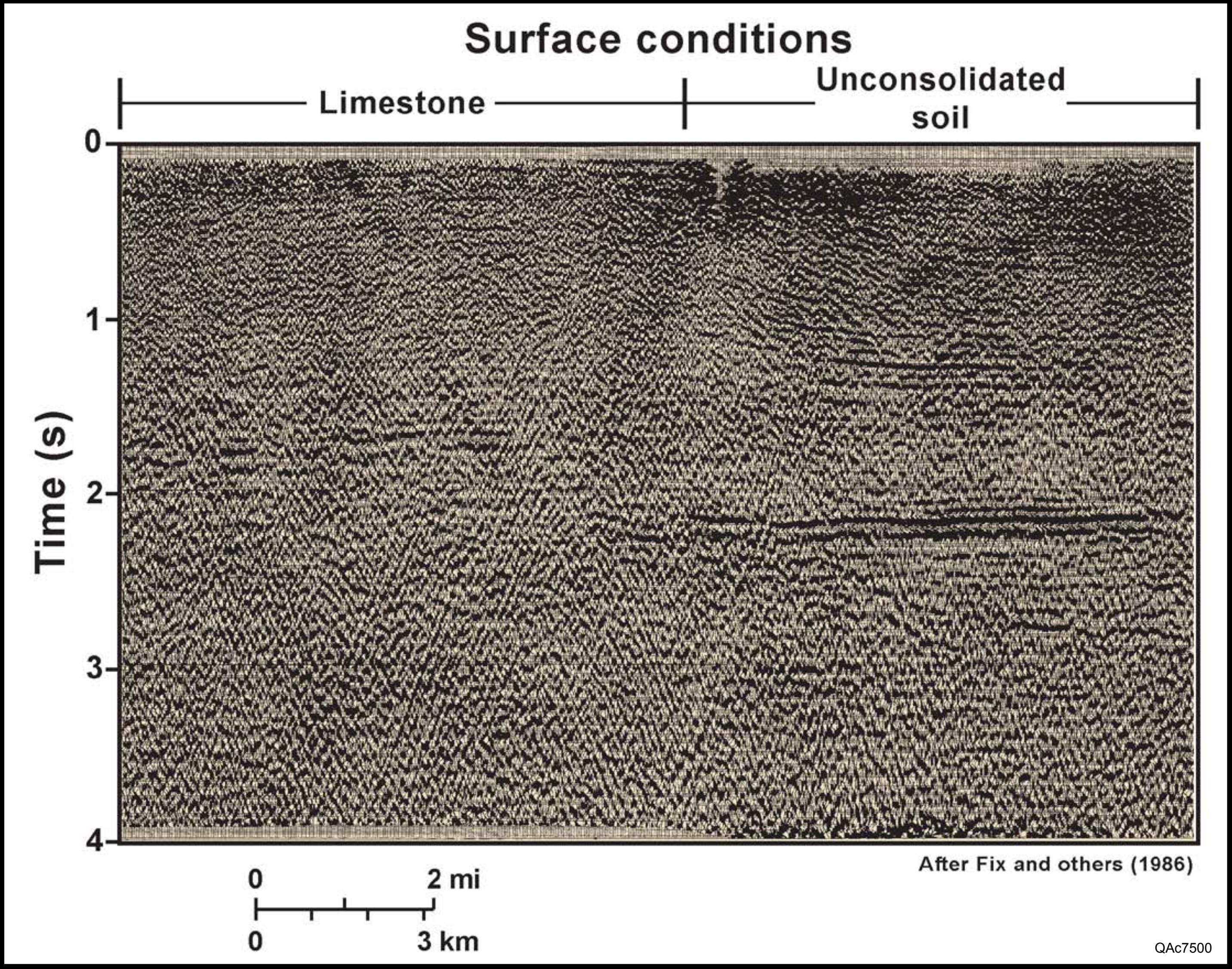

SH PROFILE: VAL VERDE BASIN, TEXAS (Horizontal Vibrators and Horizontal Geophones)

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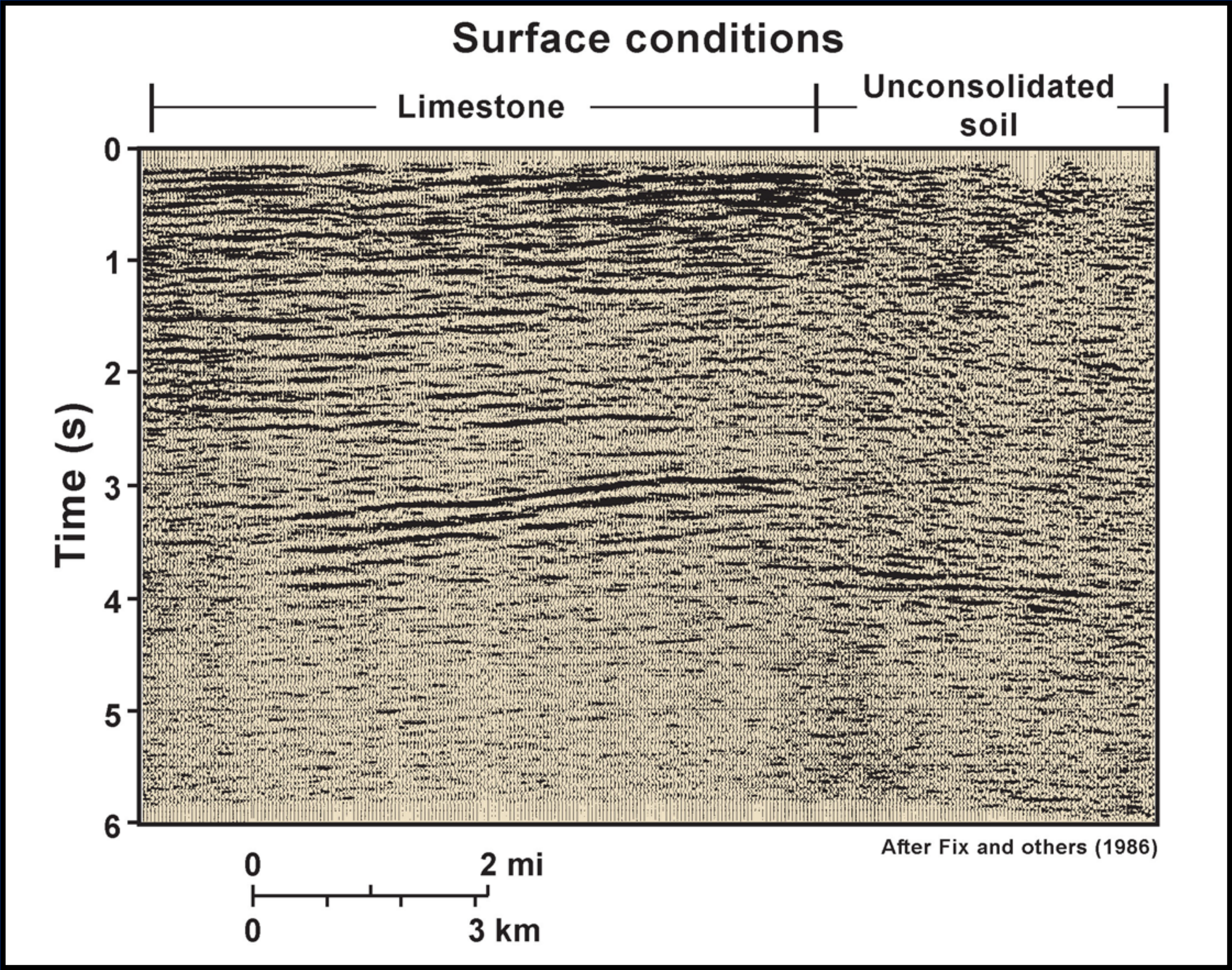
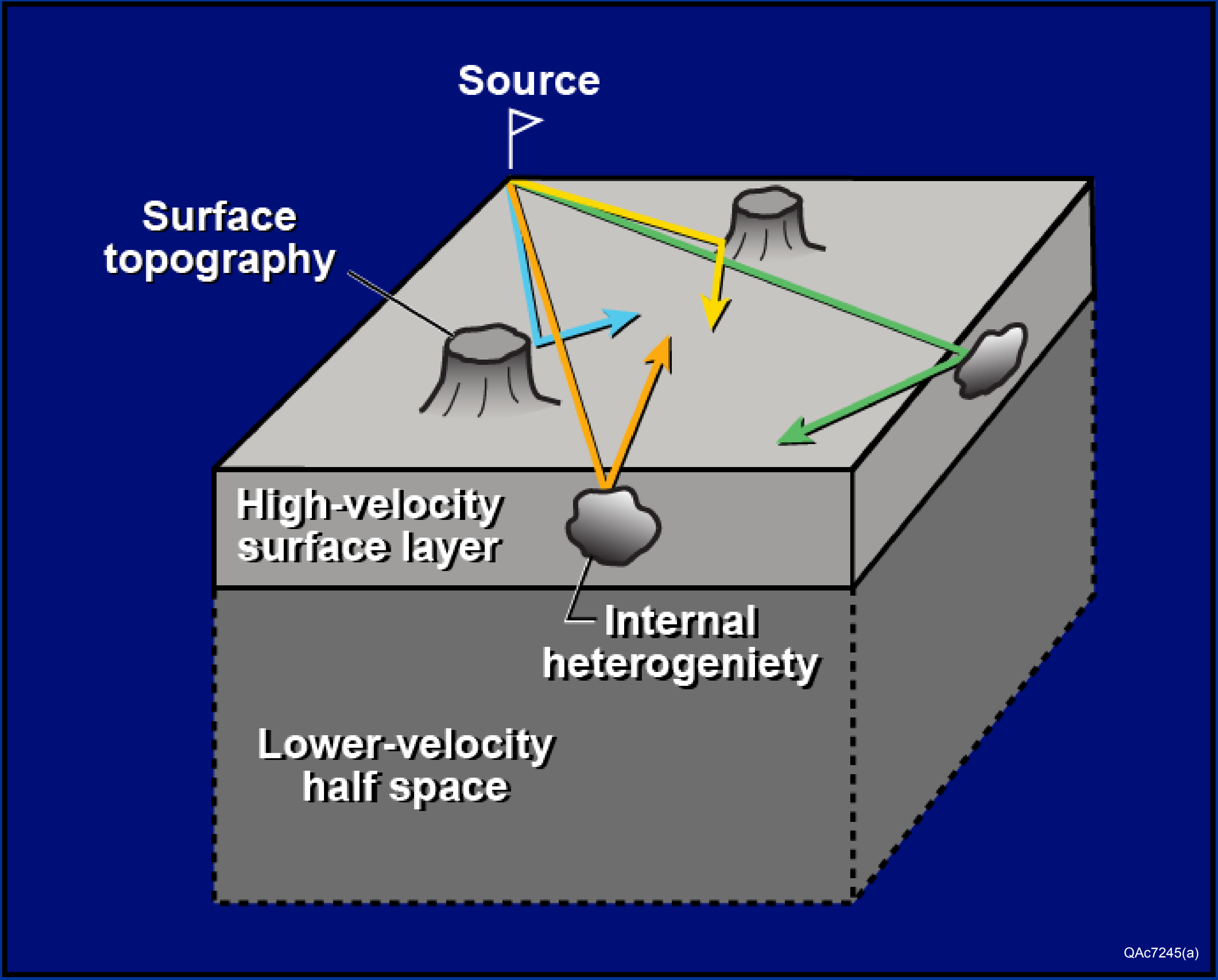
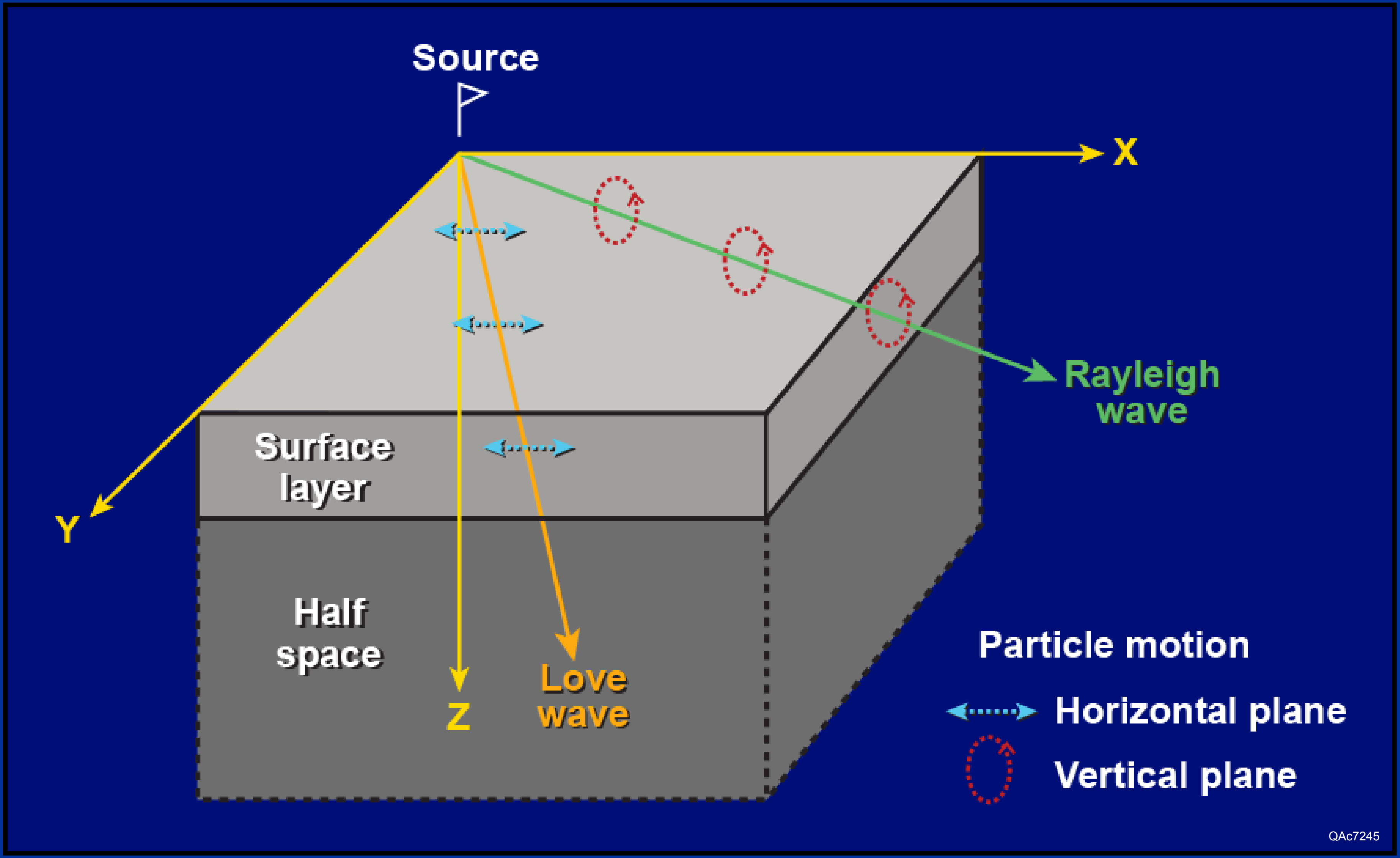


HIGH-VELOCITY OUTCROPS = UNORGANIZED RAYLEIGH WAVE NOISE



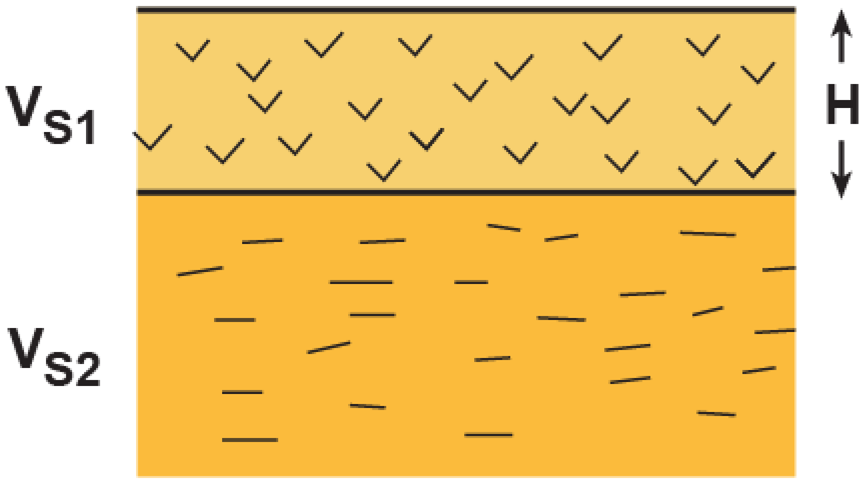
SEISMIC SURFACE WAVES



LOVE WAVE MODES

Frequencies allowed:

$$\omega_\eta = \frac{\eta \pi V_{S1}}{H}\left[1 - \left(\frac{V_{S1}}{V_{S2}}\right)^2\right]^{1/2}$$



After Aki & Richards, (1980), p. 264

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3-C VSP DATA AFTER HORIZONTAL AND VERTICAL ROTATIONS

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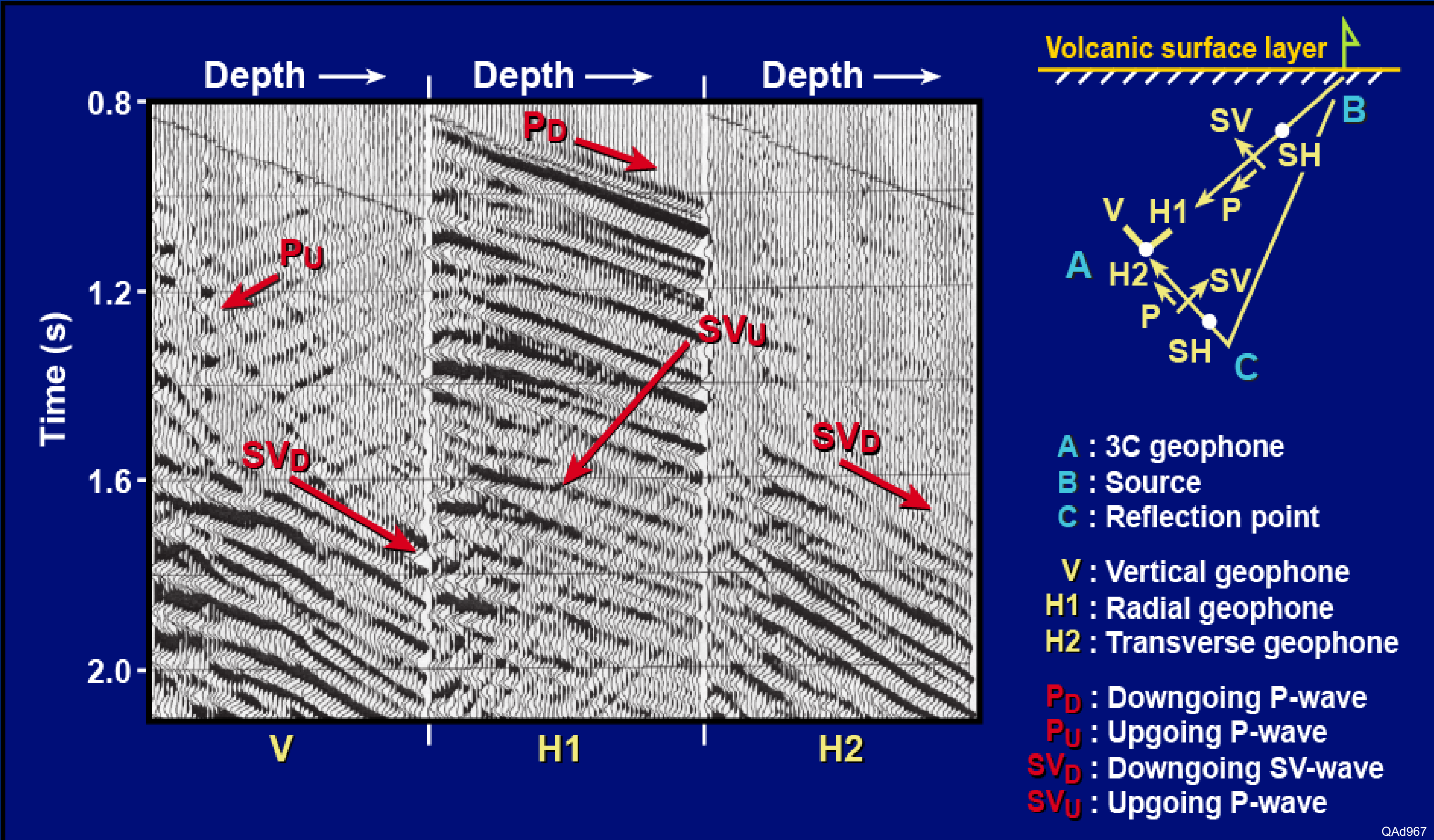

UPGOING WAVEFIELDS AFTER HORIZONTAL AND VERTICAL ROTATIONS

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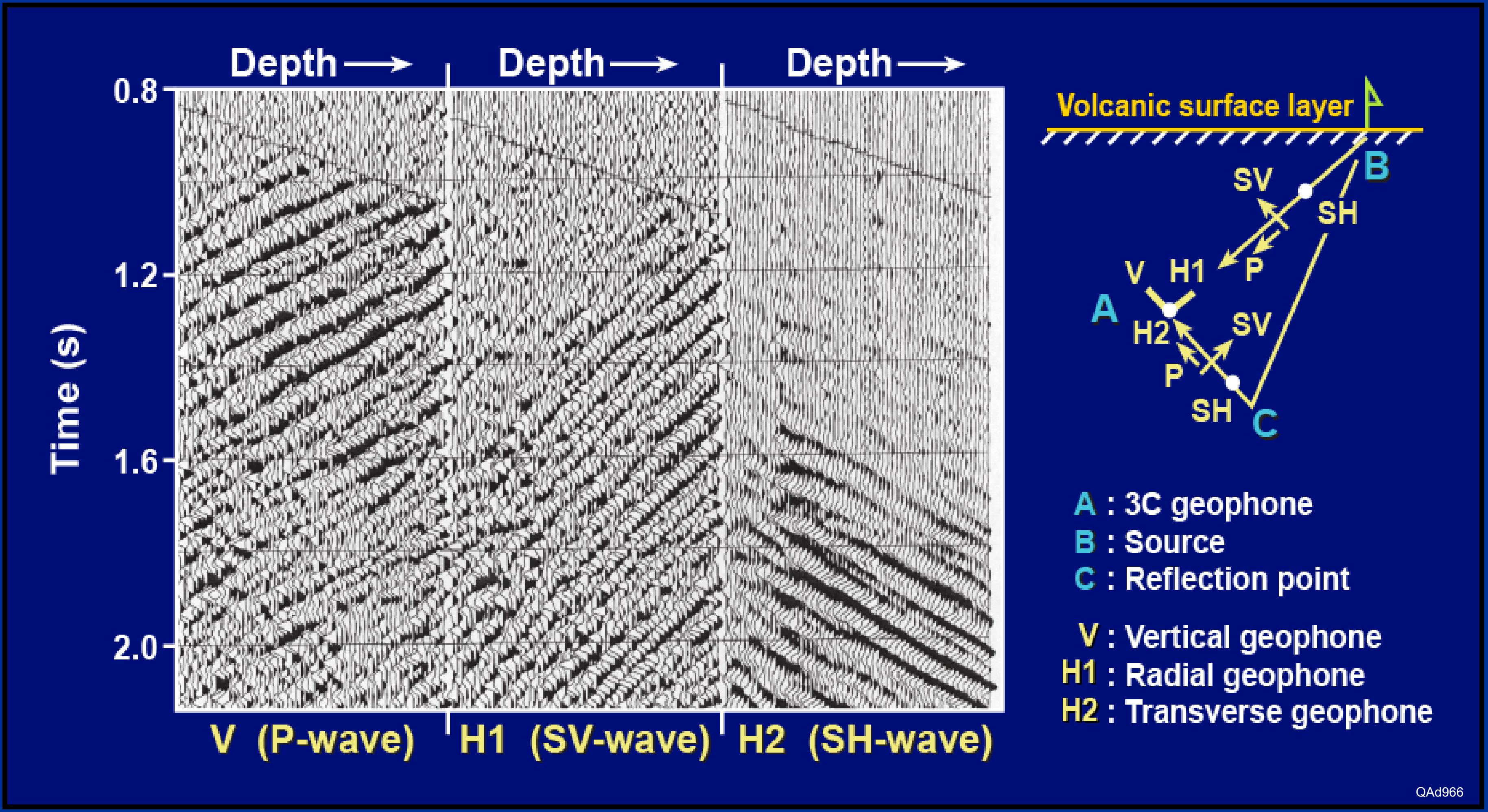

GENERAL LOCATION OF STUDY SITES IN THE PERMIAN AND VAL VERDE BASINS

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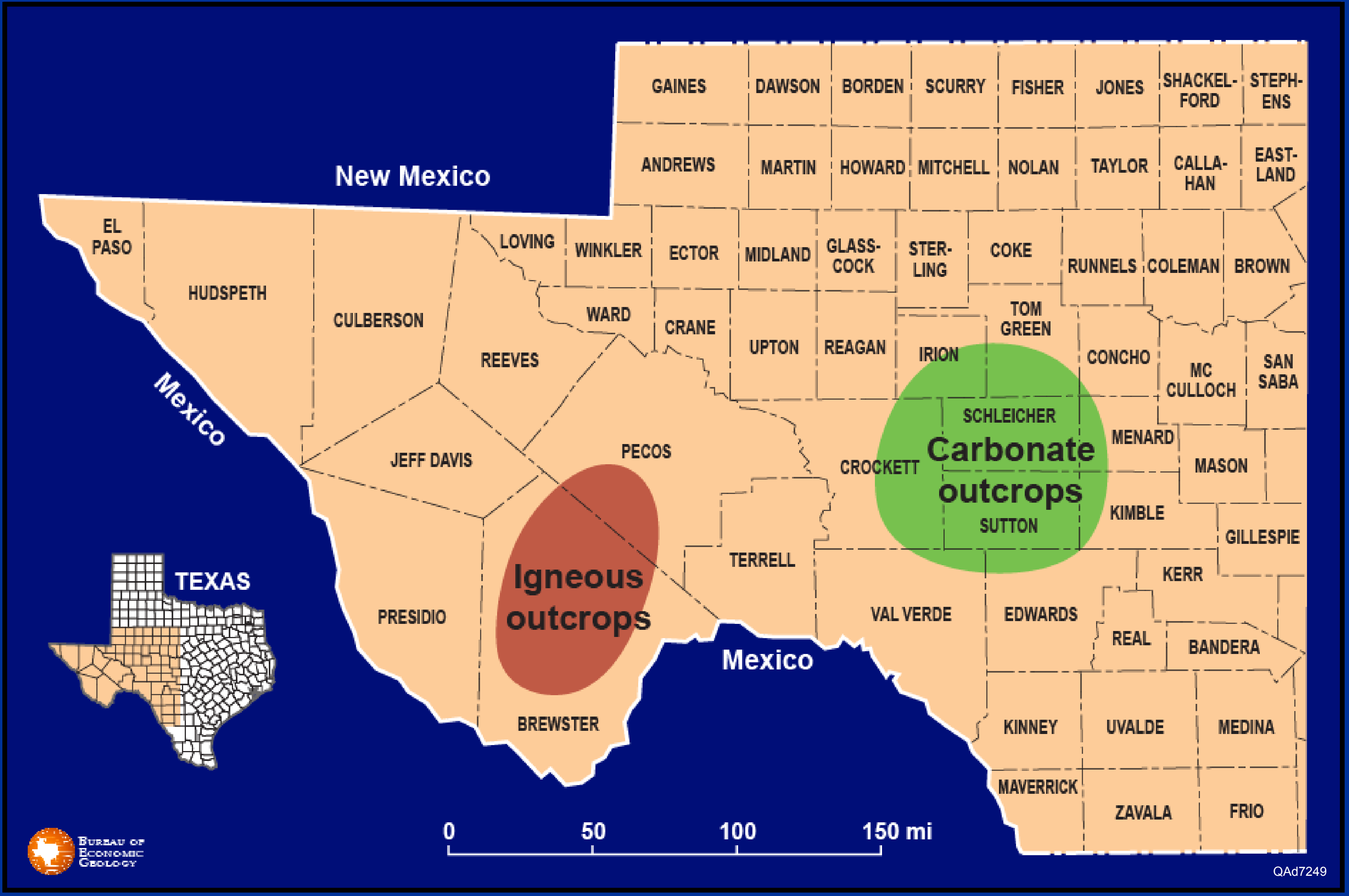

GEOLOGIC SETTING AND GEOTHERMAL EVIDENCE
Presidio County, Texas

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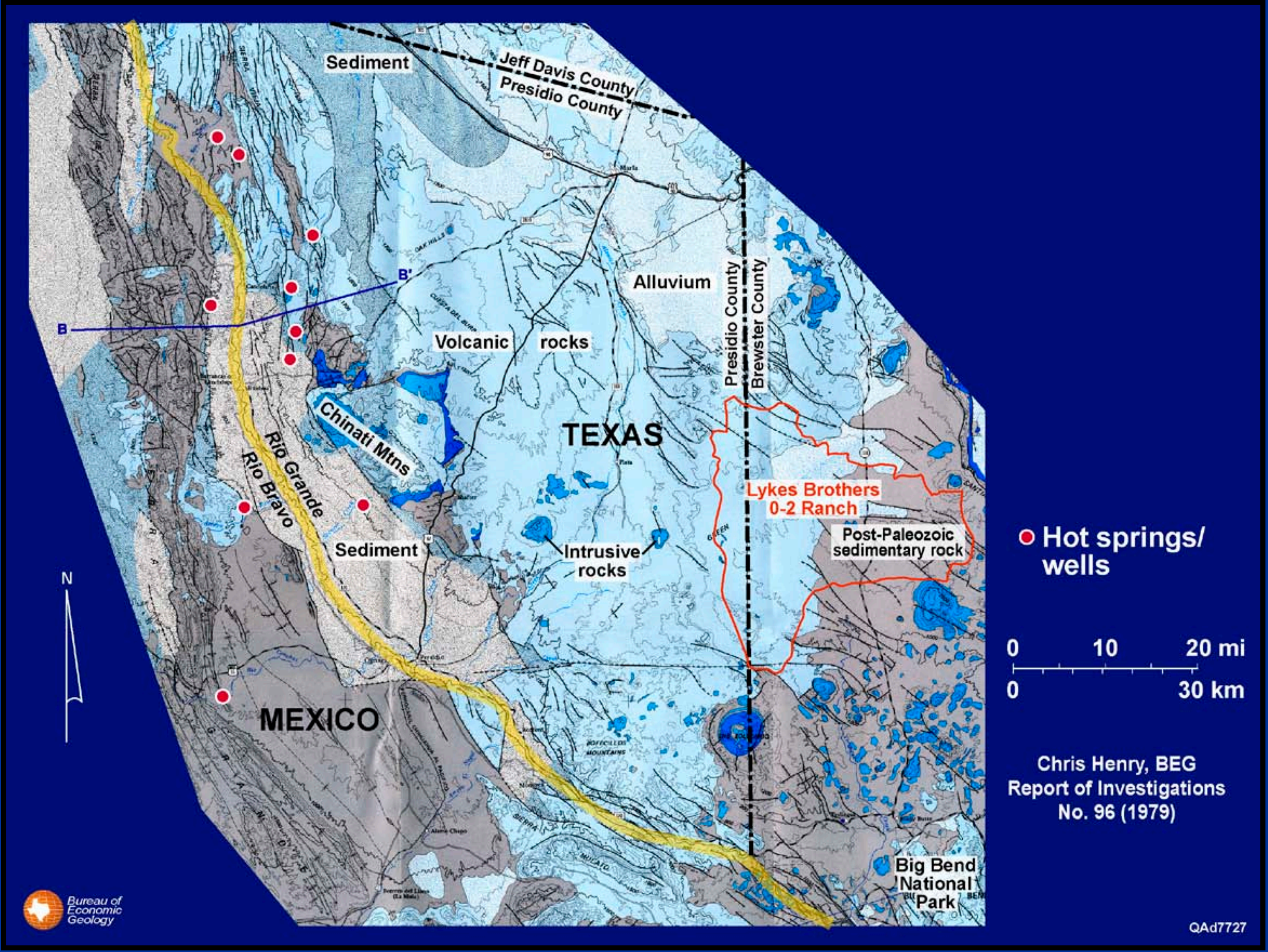

O2 RANCH AND SURFACE GEOLOGY

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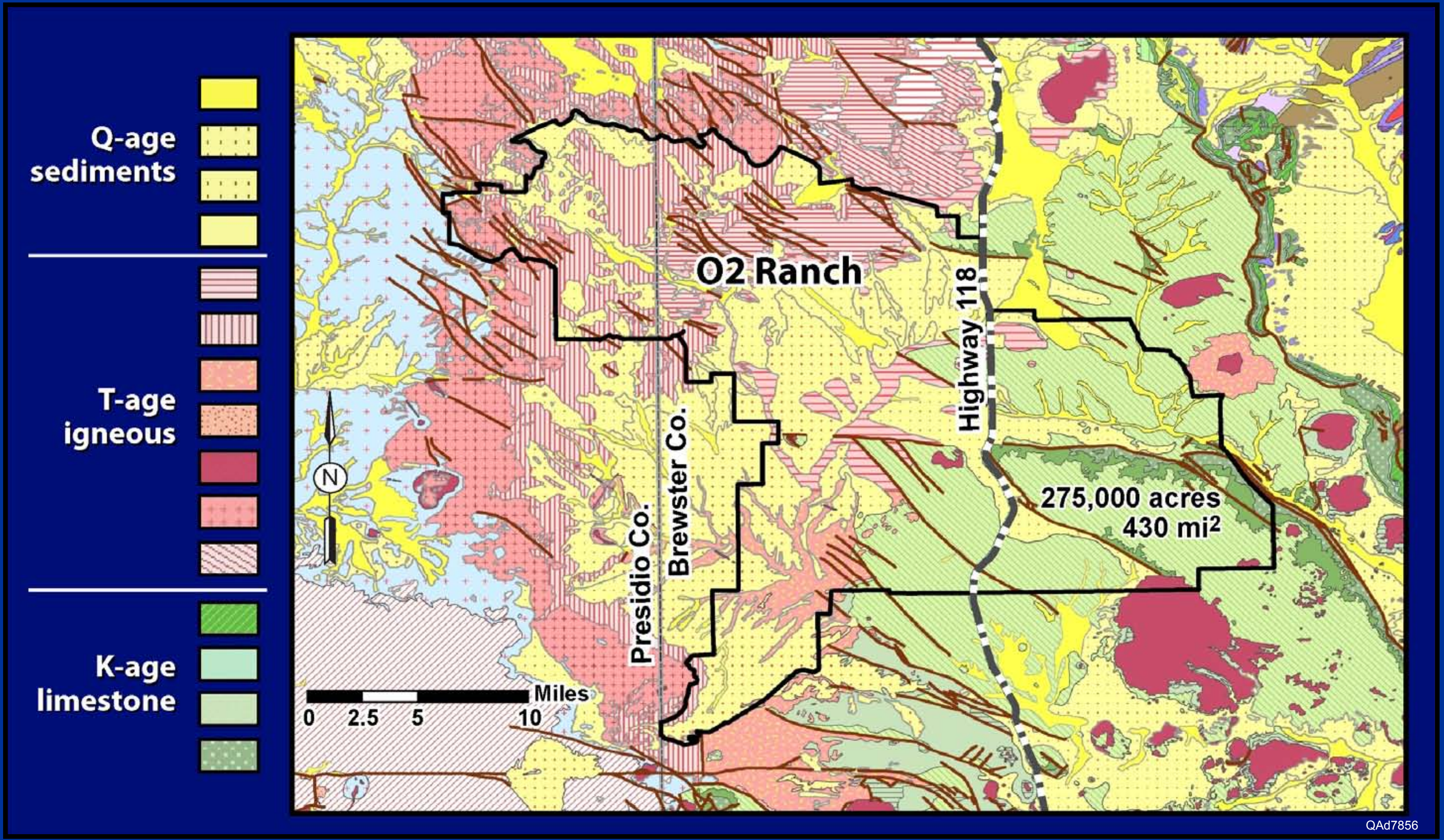
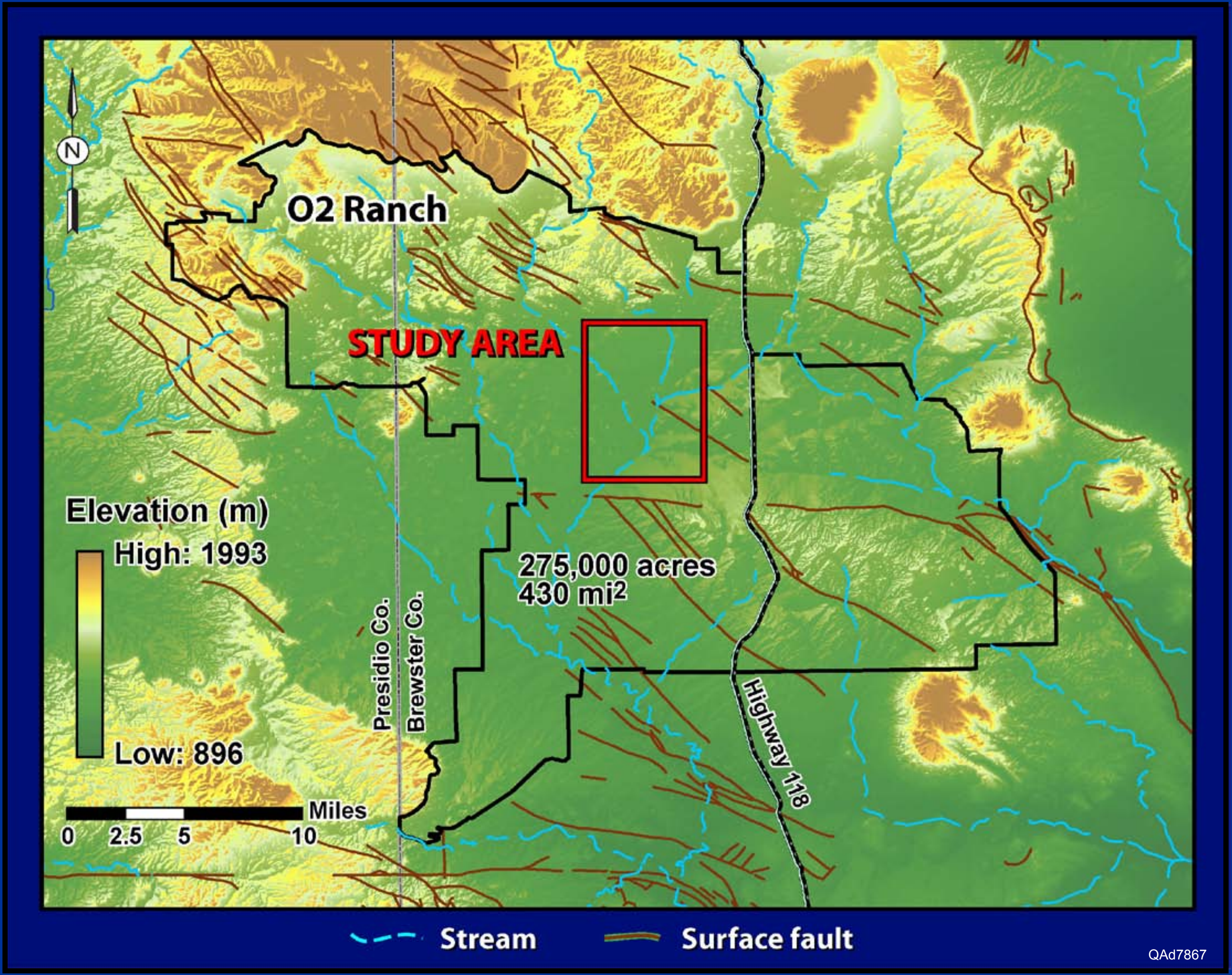


O2 RANCH AND TOPOGRAPHY



TARGETED SEISMIC TEST AREA

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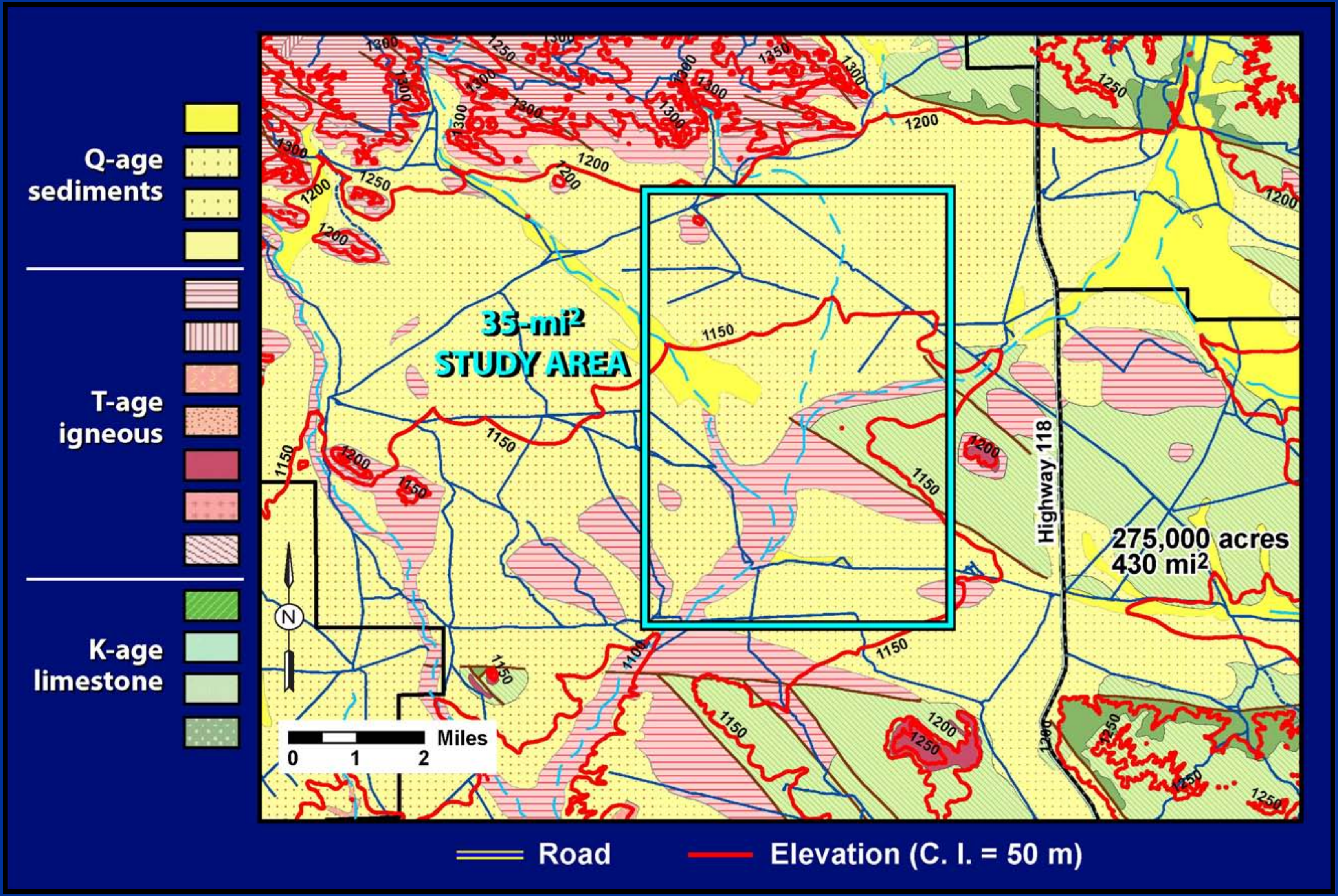

NONE

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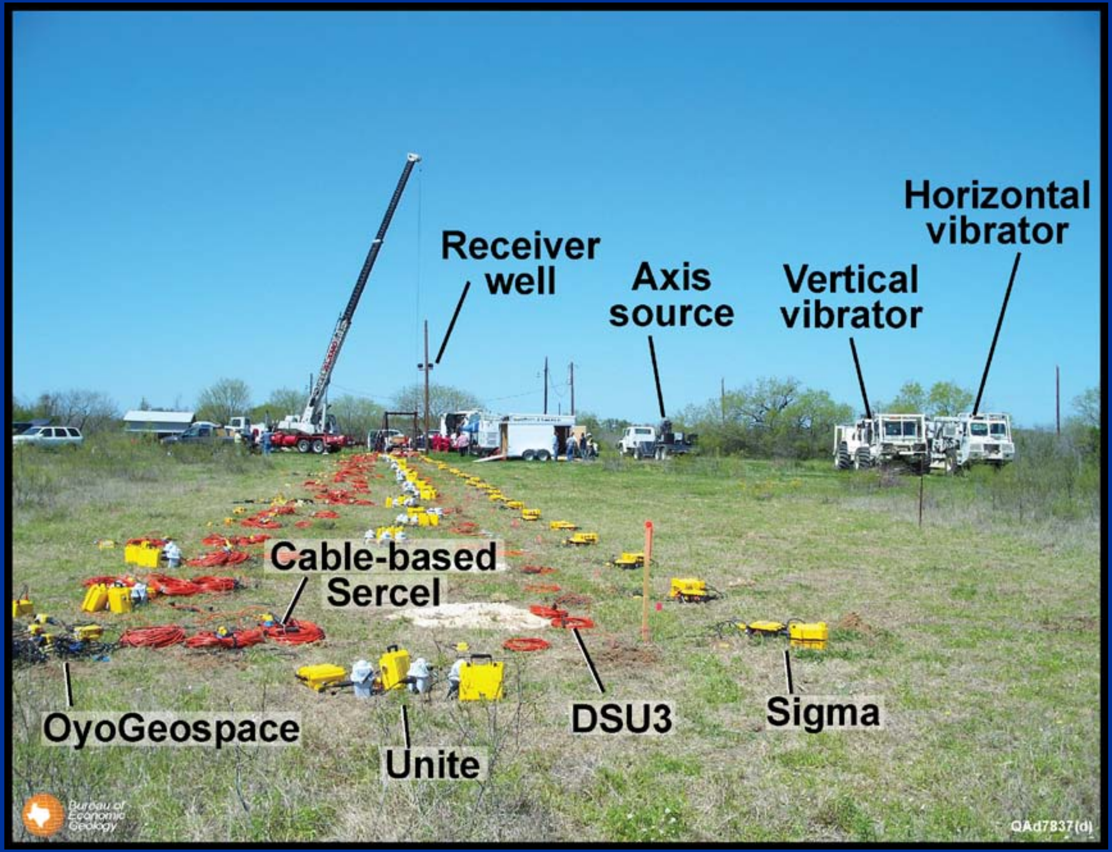

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