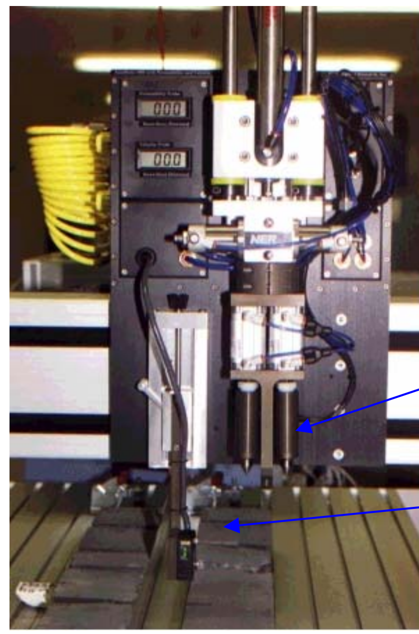
Laboratory Petrophysics Measurements

AutoScan-II: Multi-Probe Core Scanner for Petrophysical Measurements

AutoScan-II Applications

- Detailed Core-Based Logs for Log Calibration
- Rapid Core Screening for Plug Selection
- Quick Determination of Relationships Between Petrophysical Properties
- Resistivity and FMI Log Calibration and Interpretation
- Quantification of Anisotropy for Calibration of New Induction Logs
- Improved Linkage Between Well-Logs and Petrology
- Improved Interpretation of CT and MRI Data

A laboratory core scanner that allows the fully-coupled scanning of core or table-top samples for gas permeability, resistivity, and ultrasonic compressional and shear-wave velocities. The **AutoScan-II** system replaces NER's AutoScan 1000 product, with the addition of all new software for motion control, data acquisition, and data management, and the introduction of the **Z-Probe** complex resistivity probe for resistivity scanning. Combined with the velocity **V-Probe**, and permeability scanning capability or **SS-Probe**, the addition of this resistivity probe provides unique capability for core selection and screening, log calibration, and petrophysical facies identification. This system emphasizes characterization of heterogeneity at scales that are currently most difficult to quantify from log and core analysis.



The scanner involves an X-Y test bed, which positions the desired probe on the sample. Multiple probe heads are mounted on a high-precision computer assisted XY table-top system. Physical properties measurements are made on user defined grids, lines, and or points at spacings as small as 0.1 mm, over a large scan area, which permits the detailed study of multiple meters of core in a single setup. The system is fully automated both for positioning and data acquisition.

NER's **AutoScan-II** permeability system is based on a probe permeameter design developed and tested in earlier versions. Significant reengineering of the apparatus and data acquisition software, provides new flexibility for adding a wide variety of new probes.

For all measurement types, the surface of a slabbed core can be scanned using a laser ranging device to avoid making measurements in the vicinity of fracture, vugs, or other irregularities, and to detect the edges of the specimen. This minimizes setup time and avoids the need for editing large data files after the measurements are completed, a feature which is particularly important when multiple cores are measured in parallel. The entire process is computer-controlled using a workstation and data is acquired, processed, and plotted with minimal user intervention.

NER's ***Data Miner*** software allows for interactive plotting and data analysis, including petrophysical modeling, geostatistical model building, and rock type identification through cluster analysis. Simple ASCII data files are also available for specialized processing and databasing.

AutoScan-II Probe Options

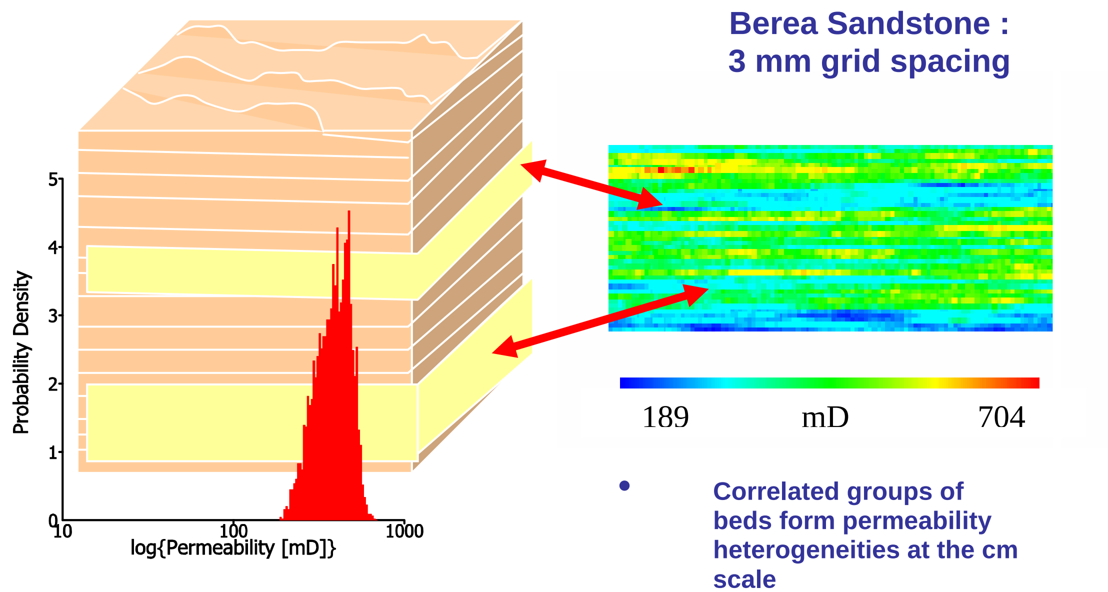
Permeability: The SS-Probe

Capabilities

- Easily Characterize Spatial Variability in Permeability
- Automated Apparatus Suitable for Routine and Specialized Core Analysis
- Fully Integrated with **V-Probe** Velocity Option for Simultaneous Scanning
- Laser Scanning for Automated Flaw Detection and Sample Boundaries
- *Smart-Flow* Data Acquisition for Improved Range, Precision, and Speed
- Real-Time Graphical Display of Measurement Process
- Real-Time Corrections for Klinkenberg and Inertial Effects

NER's **SS-Probe** offers a reliable and convenient method to determine the permeability as a function of position in whole and slabbed cores. Permeability is measured using a steady-state gas injection technique. Permeabilities ranging from 0.1 milliDarcys to 3 Darcys are measured with the standard 4mm probe tip. Measurement control and acquisition software allow user selection of pressure control or flow control based measurements, enabling detailed studies of Klinkenberg effects at low pressures and inertial and turbulence effects at high flow rates. NER's *Smart-Flow* technology allows the system to optimize measurement control parameters during the actual measurement to increase measurement speed, available range, and precision.

Example permeability data collected with the SS-Probe.



Velocity: The **V-Probe**

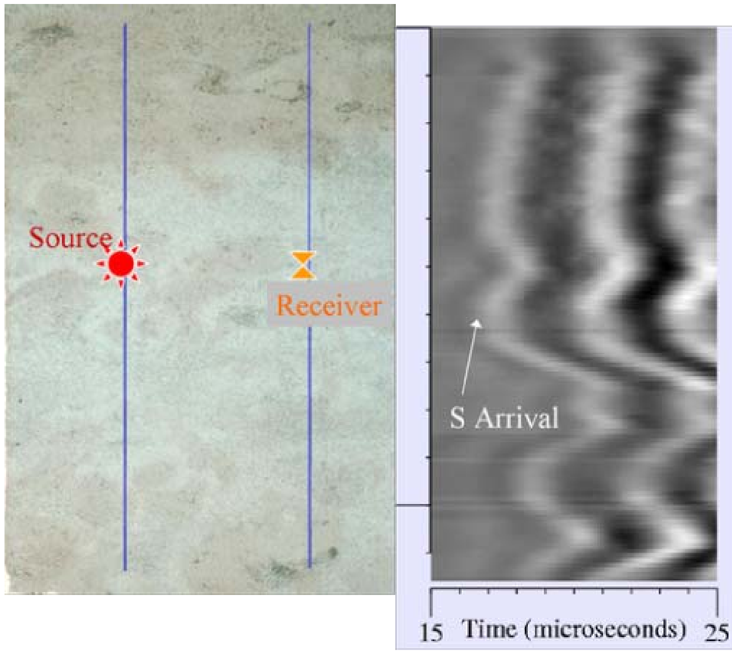
Capabilities

- Easily Characterize Spatial Variability in Compressional and Shear Velocity.
- Automated Apparatus Suitable for Routine and Specialized Core Analysis.
- Two Orthogonal Propagation Directions for Characterization of Anisotropy.
- Fully Integrated with **SS-Probe** for Simultaneous Use.

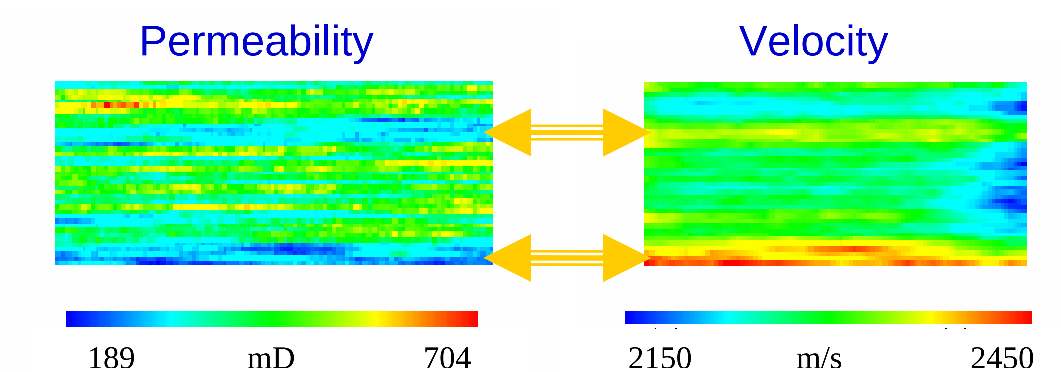
NER's **V-Probe** provides a means to measure ultrasonic compressional and shear velocities. The probe is fully integrated with the **SS-Probe**, and thus the two measurements can be made sequentially during the same scan. Both compressional and shear velocities can be measured in two orthogonal orientations on the core, providing a means to quantify anisotropy in elastic properties.

For many permeametry applications it is advantageous to relate permeability to porosity. Measuring porosity directly on a slabbed core is not feasible, however, there are well established correlations between acoustic wave velocities (P and S wave) and porosity. The fully integrated nature of the **V-Probe** and the **SS-Probe** allows for convenient constraint on permeability/porosity correlations using a single scan on a rock core.

The combined V-Probe/SS-Probe assembly allows for measurement of permeability and velocities during a single scan, providing improved speed and data integration.



Example waveforms from a linear shear velocity scan on a limestone core. Despite the cores visual homogeneity, significant shear velocity variation is detected.



Comparison of permeability and p-velocity maps of Berea Sandstone. In the plane of bedding, low permeability correlates with high velocity: This is an indicator of a spatial variation in porosity, grain size, and cementation attributes.

Resistivity: The Z-Probe

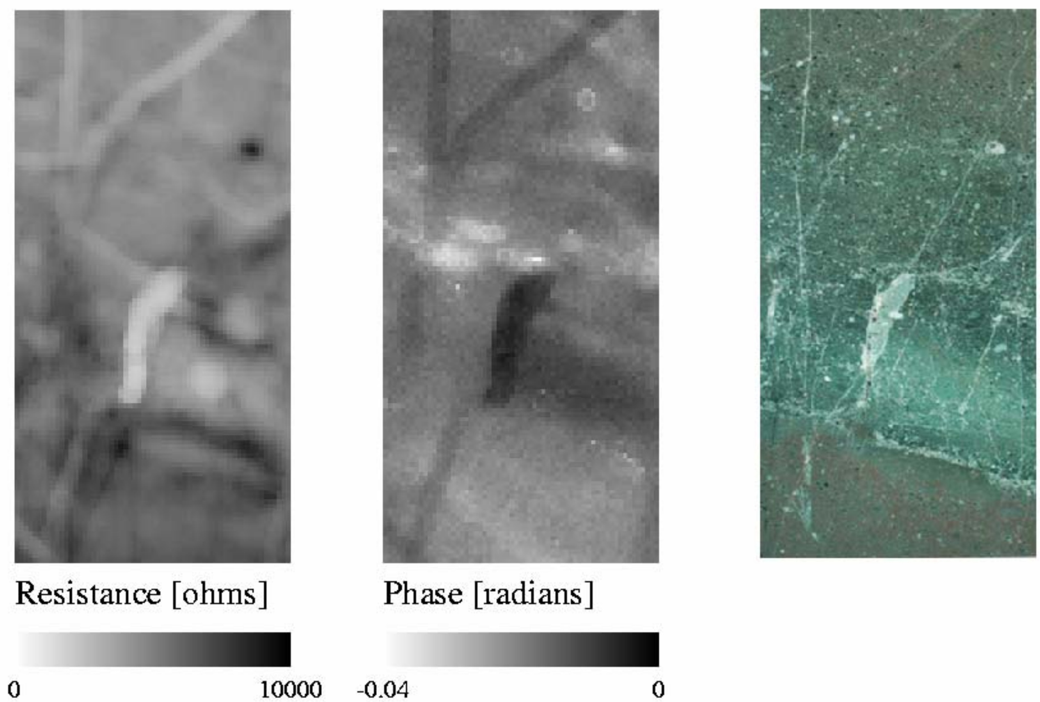
Capabilities

- Easily Characterize Spatial Variability in Complex Resistivity.
- Automated Suitable for Routine and Specialized Core Analysis.
- Used on Both Preserved and Brine-Saturated Cores.
- Through-Brine Laser Scanning for Automated Flaw Detection and Sample Boundaries.

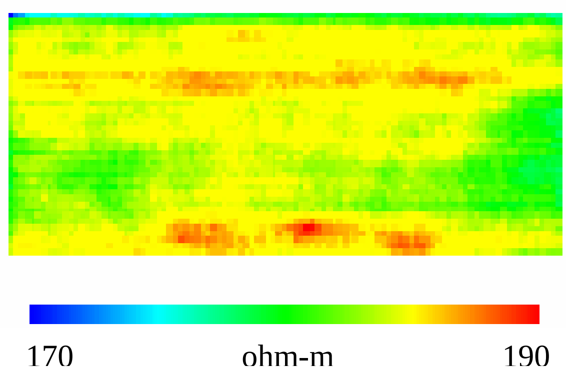
The Z-Probe has been designed and tested to measure spatial variability in electrical properties. The probe consists of a hollow rubber tip with an outer diameter of 1 cm and an inner diameter of 3 mm. The probe is a true four electrode device, with an electrode pair located in the central cavity and an electrode pair configured as rings around the outside of the rubber tip. The probe is pressed against the face of the slabbed core such that the rubber tip seals off conduction through the brine and along the surface, effectively forcing the current to flow through the sample. The probe is moved to different positions on the slab, and the electrical impedance is measured at each point.

An example resistivity map is shown along-side a photograph of the core surface. Note that the resistivity map is rich in detail, showing a wide variety of heterogeneities associated with veins, fractures, and petrographic variations. While some of the heterogeneities correspond to noticeable visual features in the sample, others are less obvious as to their origin. This type of information can be used for a number of applications. First, an understanding of the degree and spatial correlation in electrical properties provides a better context within which to interpret laboratory data on core samples (i.e., understanding scatter in core data). The data also allows for robust identification of petrographic controls on the electrical properties. In addition, the results are valuable in interpreting and calibrating electrical logs. FMI log calibration and interpretation will be significantly enhanced by such data.

Acquiring phase information in addition to resistivity provides a unique and powerful data set that cannot be acquired by other means. For example, areas of high conductivity and low phase shift are indicative of regions dominated by ionic conduction through pores, while regions of high phase shift can be associated with either concentrations of electrically conductive minerals such as pyrite and hematite or areas where surface conduction on clays is the dominant charge transfer mechanism. This type of information is very helpful in facies identification and classification.



An electrical impedance map of a rock sample. Image dimensions are 6 cm by 12 cm. On the left is the real part of the impedance, with light indicating conductive and dark being resistive. In the center is the phase shift with dark indicating little phase shift and light indicating high phase shift. On the right is a photograph of the mapped surface. Note the wide variety of features present in the resistance map.



Example Resistivity map of Berea sandstone, using simulated ground water as the pore fluid. Note the similar structure to that seen in the permeability and velocity maps shown previously.

Data Analysis: DataMiner

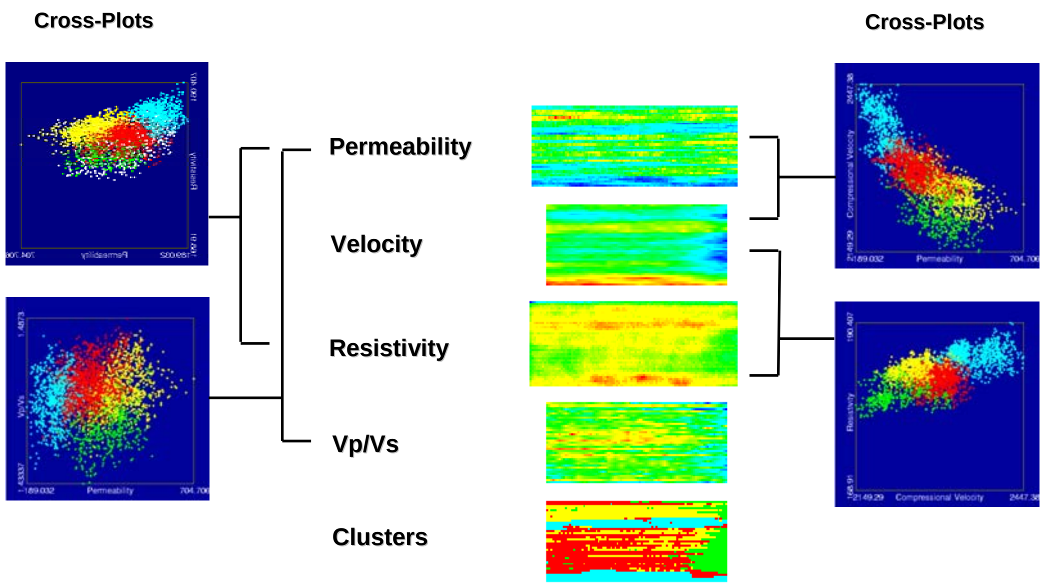
Capabilities

- ❖ Interactive plotting
- ❖ Interpretation software with effective media models for upscaling.
- ❖ Analysis software for crossplotting and facies classifications.
- ❖ Import photographs and ascii log or core data for comparison.

Theoretical developments aimed at understanding the consequences of heterogeneity are fairly well advanced, with an abundance of effective medium theories for various properties being available. However, data collection detailing heterogeneity in physical properties is notably lacking, making it difficult to make use of these theories. The ability to combine measurements of heterogeneity of multiple properties in a single apparatus, and in some cases at the same time, greatly enhances the value of any one such measurement. Knowledge of how heterogeneities in different properties correlate spatially with one another will be helpful in developing interpretations of what controls each property. For example, permeability variations can be influenced by clay content, degree of cementation, porosity, grain size, and grain packing variations. In any given rock, many of these processes may be active and may be either correlated or uncorrelated with each other. Unraveling these dependencies can be important for many applications, such as assessing the potential of enhanced recovery methods in a given formation.

NER's DataMiner data analysis package offers support for handling and interpreting the AutoScan data. The analysis software option provides a package implementing effective media models for upscaling measured properties (i.e. predictions of log scale resistivity, permeability tensors, and scaling of seismic response using traditional volume averaging approaches). In addition, the analysis package provides links to NER's Pore Structure Inversion (**PSI**) software and AutoLab data files, providing ties to laboratory data collected and analyzed using NER's equipment and software product line.

Cluster Analysis: Identifying Facies and Length Scales



Using NER's DataMiner software, permeability, velocity, and resistivity maps can be analyzed to build petrophysical and/or geostatistical models of the observed heterogeneity. In this example, geostatistical cluster analysis is used to find regions of the sample that are petrophysically similar.