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# Seismic Imaging of Upper Crustal Structure Using Travel Times From the PASSCAL Ouachita Experiment

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A first arrival travel time inversion applied to the 1986 PASSCAL Ouachita experiment has been used to image upper crustal structure. Twenty-one shot points every 10 km were recorded along two 100-km-long segments with 400 seismographs on each segment. A splined velocity model parameterization allowed for the inversion of laterally inhomogeneous models but not velocity discontinuities. Over 800 travel times were used in the inversion with a variable data covariance weighting. The multiple source nature of the experiment design allowed the use of reciprocity relationships among the 21 shot points to enhance data correlation. A succession of models with velocities specified at 30, 90, 171, and 221 nodes were inverted for whose horizontal node spacing decreased from 100 to 12.5 km in the final 221 node model. Vertical node spacings of 3.0 and 1.5 km were used. The results of the inversions indicate changes in depth of isovelocity lines which are interpreted as Triassic fault structure based on nearby well data. The final RMS travel time residual is 0.045 s. Resolution using first arrivals deteriorates rapidly below 9 km depth. Three distinct velocity gradients can be correlated with geologic units. Surface exposed Cretaceous and Jurassic sediments with velocities from 2.0 to 3.5 km/s extend to 1.5 km depth. Triassic rift fill sediments, which do not outcrop, have inverted velocities ranging from 3.5 to 4.75 km/s between depths of 1.5-3.0 km. Paleozoic sediments are imaged by a decreased velocity gradient below a depth of 3.0 km. Lack of resolution at depths greater than 9 km necessitates detailed modeling of wide-angle reflected phases to further constrain deeper crustal structure.

## INTRODUCTION

Imaging crustal structure from surface seismic observations has led to the development of new techniques and experiment design. Simultaneous inversion of earthquake data for velocity structure and hypocenter have been implemented by numerous authors [*Wesson*, 1971; *Aki and Lee*, 1976; *Pavlis and Booker*, 1980; *Thurber*, 1983]. More recently, *Huang et al.* [1986] implemented an inversion of refraction and reflection travel times. The design of the 1986 PASSCAL Ouachita Lithospheric Seismology experiment shown in Figures 1 and 2 featured close station spacing and multiple sources to allow for imaging of the earth's crust by travel time, amplitude, and waveform techniques using reflection and refraction information. In this paper, a first arrival travel time method is described and applied to the PASSCAL Ouachita experiment.

The study area of the PASSCAL Ouachita experiment is along a major Paleozoic convergent continental margin shown in Figure 1. The experiment overlays the southern third of a COCORP reflection profile across the Ouachita Mountains and the Benton uplift in Arkansas. Four hundred seismographs were deployed in two separate profiles each 100 km in length. The 21 explosive sources of the experiment, shown in Figure 2, were at an average interval of 10 km along the profile and allowed the recording of near-vertical offset information as well as refracted and wide-angle reflected information. The experiment design, a prototype of future PASSCAL experiments, is an attempt to image crustal structure on the scale of geologic interest. The location of the experiment improves velocity control for the COCORP Ouachita experiment and the determination of deep crustal structure associated with the southern midcontinent convergent plate margin.



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A first arrival travel time inversion has been used to model the PASSCAL Ouachita data set and complement other forward modeling and reflection processing based studies. Advantages of a first arrival inversion include increased velocity control, assuming that first arrivals are clearly discernible, as well as estimation of model resolution and model parameter errors. The inversion requires only correlations of first arrivals and covariance weights to produce an inverted model eliminating the trial and error process of forward modeling. The multiplicity of sources provides the necessary ray coverage to adequately image subsurface structure.

Cultural noise in the data necessitates the use of reciprocity relationships amongst the 21 shot points to facilitate travel time picks. Consequently, a covariance weighted inversion scheme has been used to weight the data according to an estimate of its uncertainty. A series of models with an increasing number of nodes are inverted for in an effort to delineate subsurface fault structures, to match first arrival travel time information and to estimate both model resolution and model parameter covariance.

## TRAVEL TIME INVERSION

Until recently, seismologists have analyzed refraction profiles by the calculation of flat and dipping layer earth models. *Steinhart and Meyer* [1961] provide formulas for the estimation of standard error of model parameters for such models. Advances in theoretical techniques and their computer implementation have led to analysis based on accurate forward modeling of refracted travel time data. Many authors have pointed out the nonuniqueness of such modeling and the need for their refinement by the utilization of amplitude information [e.g., *Healy*, 1963; *Fuchs*, 1970; *Braile and Smith*, 1975 and *Banda et al.*, 1982]. For all the good points of forward modeling, there are also drawbacks. The time and manpower needed to coordinate modeling of multiple source large experiments are considerable. After modeling, error bounds on model parameters can only be estimated by using a Monte Carlo approach. Different model parameterizations and individual