Crustal Structure of the Northeastern United States: Contrasts Between Grenville and Appalachian Provinces

Abstract. *Average crustal models for the northeastern United States are computed on the basis of the travel times of P and S waves from regional earthquakes. The Precambrian Grenville Province in New York State has a relatively homogeneous crust. The Paleozoic New England Appalachians have a well-defined, two-layer crust that is slightly thicker and shows a high-velocity lower layer relative to the Grenville. A time-term analysis based on P_n data (waves refracted from the Moho) shows that a relatively thick or low-velocity crust parallels northeast-trending geologic structures in central New England. The observed differences between the two orogenic belts may reflect contrasts in their tectonic evolution.*

Recognition that mountain belts are places where oceans have closed implies that continental structure differs across them. Using the northeastern United States seismic network, we show that this applies to the northern Appalachians by investigating the crustal structure of the Precambrian Grenville Province in New York State and the New England Paleozoic Appalachian Province. The Grenville Province (1.0×10^9 years old) is mainly remobilized older basement of Superior or Hudsonian age and in much of New York State is overlain by an early Paleozoic platform sequence. Rocks of the New England Appalachians are predominantly Paleozoic continental rise or back arc basin metasediments in the synclinoria and island arc metavolcanics with their associated intrusives and older basement in the anticlinoria (Fig. 1). The suture zone separating the two belts is characterized by a linear serpentinite belt trending north to northeast generally found to the east of Precambrian inliers of Grenville basement such as the Green Mountains in Vermont. A Bouguer gravity high of up to 25 mgal is evident along much of the suture (*1*).

We analyzed 1545 P-wave and 546 S-wave readings from 170 regional earth-

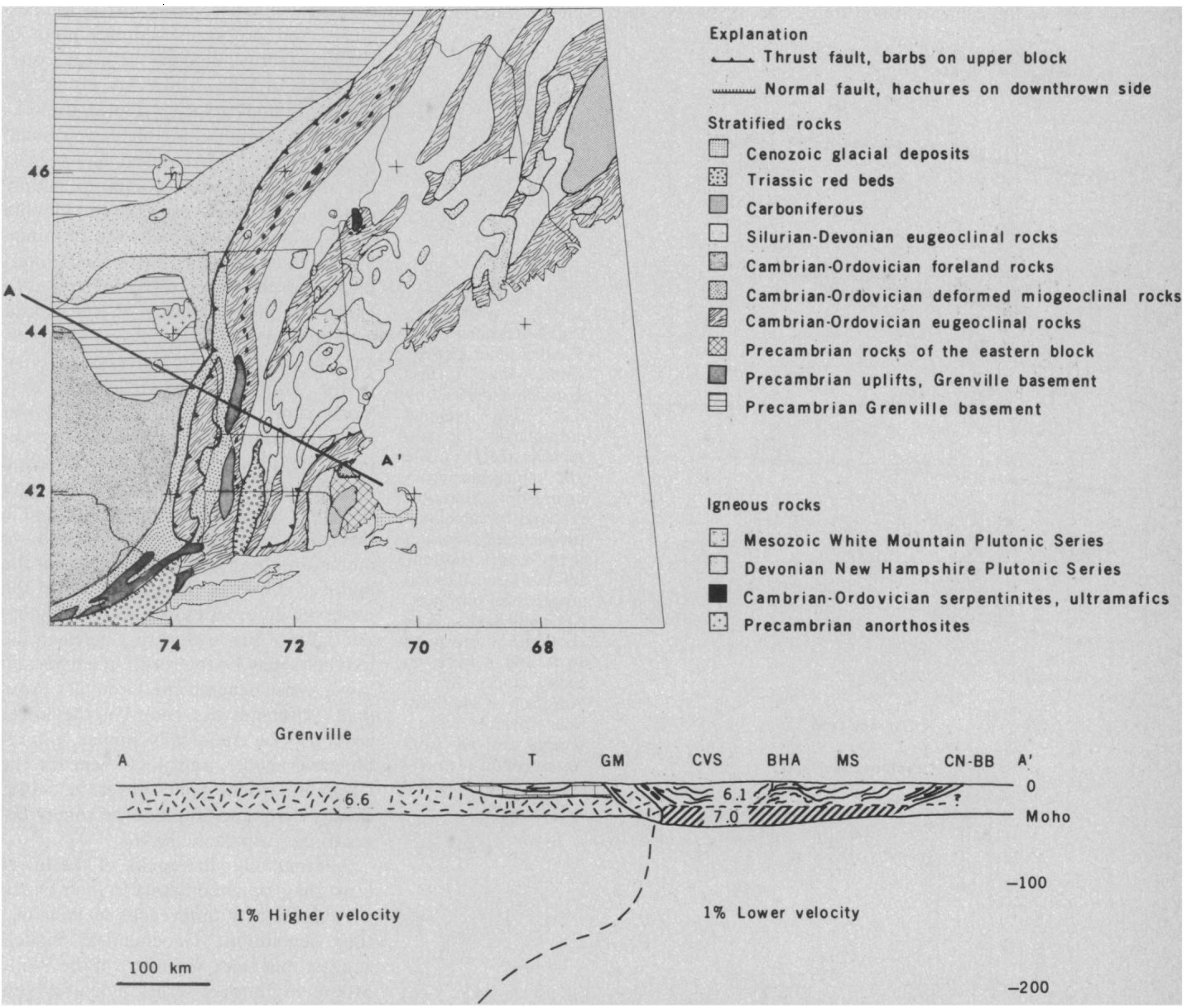

Fig. 1. Generalized geologic map of the northeastern United States (*13*) and schematic structural cross section along profile *AA'*. Abbreviations: *T*, taconic thrust belt; *GM*, Green Mountains; *CVS*, Connecticut Valley synclinorium; *BHA*, Bronson Hill anticlinorium; *MS*, Merrimac synclinorium; and *CN-BB*, Clinton-Newbury-Bloody Bluff fault zone.

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quakes with epicentral distances (D) up to 600 km (*2*). The magnitude range is between 1.5 and 3.8, and small-magnitude events with poor epicentral control were eliminated. Although readings are generally accurate to 0.1 second, scatter in the travel time plots arises from errors in the hypocenter and origin time for each event. Because most events are shallow (less than 10 km), a surface focus is assumed and travel times are computed with respect to the published epicenters and origin times. Reduced travel time plots based on P and S travel times for stations lying above Grenville and Appalachian basement are plotted separately (Fig. 2). The serpentinite belt and Precambrian uplifts are used to separate stations into the two regions (Fig. 1).

We interpreted the travel time curves by using a nonlinear least-squares technique in which apparent velocities, critical distances, and their corresponding times for two or three linear travel time branches are perturbed about an initial model (*3*). The calculated travel times for the P- and S-wave models and the velocity profiles are shown in Fig. 2.

The results obtained from interpretation of the travel time profiles are consistent with previous refraction and surface wave models (*4*, *5*) and show large contrasts between the two orogenic belts. The crust of the Grenville Province appears to be very homogeneous with nearly constant P- and S-wave velocities of about 6.6 and 3.7 km/sec, respectively, with an average crustal thickness of 37 km. In contrast, the Appalachians are characterized by a slightly thicker (approximately 40 km) crust with two well-defined layers. The upper Appalachian crust shows relatively low P and S velocities of about 6.1 and 3.6 km/sec, respectively, to about 15 km where an abrupt increase to 7.0 and 4.1 km/sec occurs. Both regions show similar P_n (waves refracted from the Moho) velocities of approximately 8.1 km/sec.

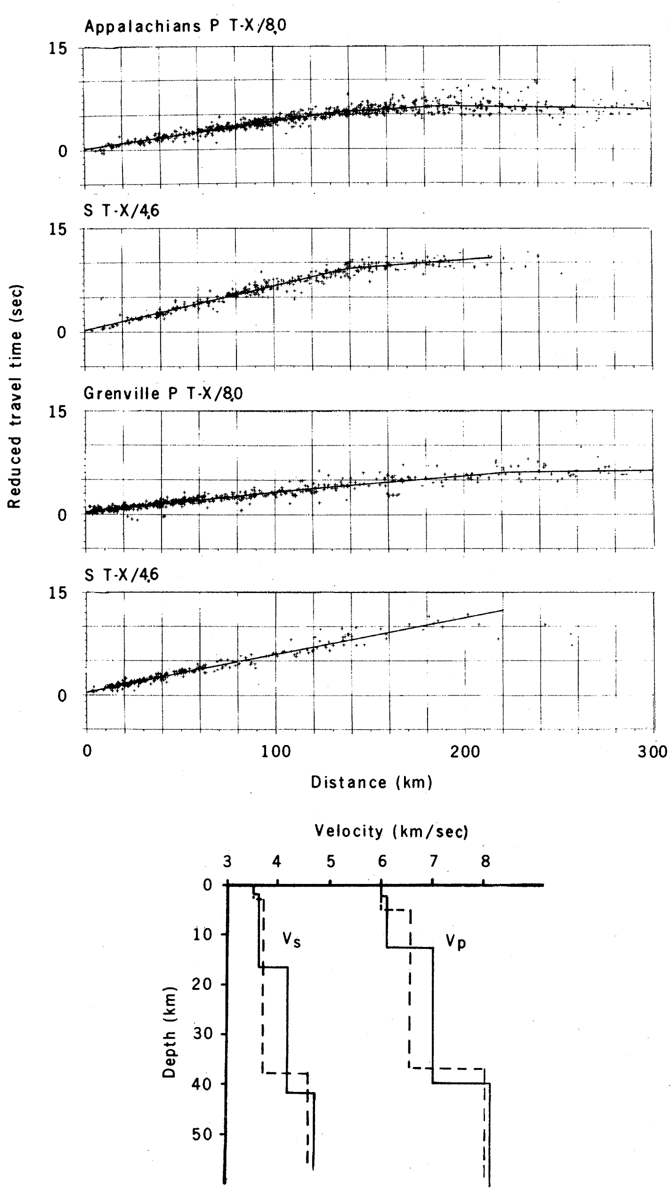

Fig. 2. Reduced P and S travel times (for example, time T less distance X divided by 8.0) from regional earthquakes for stations in the Grenville and Appalachian provinces (top). Lines correspond to calculated travel times from velocity models (bottom) for the Grenville and Appalachian provinces. Solid and dashed lines (bottom) correspond to P- and S-wave velocity models for the Appalachian and Grenville provinces, respectively, derived from an inversion of travel times from regional earthquakes.

The least-squares technique used represents an average crustal model and cannot adequately portray lateral variations in crustal structure. For instance, local travel time studies indicate that a highly variable upper crustal layer with relatively low velocity and a thickness of 5 km or less is present in most regions. To study lateral variations in crustal structure, a time-term analysis was applied to the P_n travel time branch for all stations ($D > 200$ km) (*6*). The calculated P_n velocity is 8.1 km/sec, and the time terms show a good correlation with the pattern of teleseismic P-wave residuals recorded across the network (*4*).

The observed differences in crustal structure between the Grenville and Appalachian orogenic belts are probably the result of variations in the petrology, chemistry, water content, and orogenic history. Temperature differences may affect the velocities, however, at temperatures and pressures representative of the lower crust in older geologic belts; the effect of temperature on seismic velocities is small relative to pressure (*7*).

Recent summaries of geophysical, geological, and geochemical data suggest that the upper crust is composed mainly of schists and gneisses of the amphibolite facies which grade downward into migmatites and finally basic and intermediate granulites in the lower crust (*8*). Electrical measurements in the northeastern United States suggest the presence of a highly conductive lower crust in the Adirondack Mountains in New York State, whereas a resistive lower crust underlies a slightly conductive upper crust 15 km thick in New England (*9*). This upper layer correlates well with the upper layer (15 km thick) observed in this study and probably corresponds to metamorphosed eugeoclinal rocks of the major synclinoria. This implies that the observed differences in velocity and conductivity of the lower crust between the two belts may be the result of a hydrated lower crust beneath the Grenville Province. Although the rocks of the lower crust may be chemically similar, a hornblende-granulite petrology beneath the Grenville would yield lower velocities than a pyroxene-granulite petrology beneath the Appalachians (*10*).

Alternatively, the rocks of the lower crust may show contrasts in their chemistry caused by differences in their tectonic evolution. Geochemical models suggest that some members of the White Mountain Plutonic series in central New Hampshire could have been formed by reaction of fractionated, mantle-derived alkali basalt with metamorphosed tholeiitic (oceanic) basalt at the base of the crust (*11*). A schematic northwest-southeast cross section taken along profile *AA'* is shown in Fig. 1. Also shown are velocity variations in the upper mantle derived from teleseismic P-wave residuals (*4*), which indicate that the upper mantle is characterized by slightly lower velocities beneath the Appalachians. The time-term analysis suggests that the Appalachians have a slightly thicker crust than the Grenville and can be divided into two well-defined layers. The upper 15-km layer probably corresponds to rocks that have been subjected to a high degree of compression and crustal shortening during the Taconic and Acadian orogenies. The rocks of the Appalachian belt probably were associated with a cycle of oceanic opening and closure. It is therefore possible that the chemistry of the lower crust was strongly affected by tectonic interaction of these sediments with the underlying basement during orogeny. Thus, interaction of ocean floor within the Appalachians would account for the higher velocities found in the lower crust relative to the predominantly ensialic crust of the Grenville Province.

The homogeneous character of the crust in this portion of the Grenville Province is consistent with the hypothesis that the crust underwent substantial reactivation, thickened, and became vertically uniform during the Grenville orogeny (*12*). After the thickening, the crust was eroded to relatively deep levels, as evidenced by the surface exposure of granulite terrains (*12*).

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Sexual Characteristics of Adult Female Mice Are Correlated with Their Blood Testosterone Levels During Prenatal Development

Abstract. *Mice produce litters containing many pups, and the female fetuses that develop between male fetuses have significantly higher concentrations of the male sex steroid testosterone in both their blood and amniotic fluid than do females that develop between other female fetuses. These two types of females differ during later life in many sexually related characteristics. Thus, individual variation in sexual characteristics of adult female mice may be traceable to differential exposure to testosterone during prenatal development because of intrauterine proximity to male fetuses.*

Differentiation of mammalian fetuses into the masculine phenotype depends primarily on the secretion of androgens from the testes. The female phenotype is thought to occur if the fetus remains relatively free from the effects of androgens during the time of sexual differentiation (*1*). Inherent in this traditional concept of the "normal" development of a mammalian female is the assumption that females exposed to androgens during fetal life may be abnormal. Indeed, experiments in which female fetuses are exposed to increased concentrations of androgens, either by way of administration of hormones to the mother or because of a metabolic error that results in an increased production of adrenal androgens by the fetus, are often cited as evidence supporting this assumption (*2*).

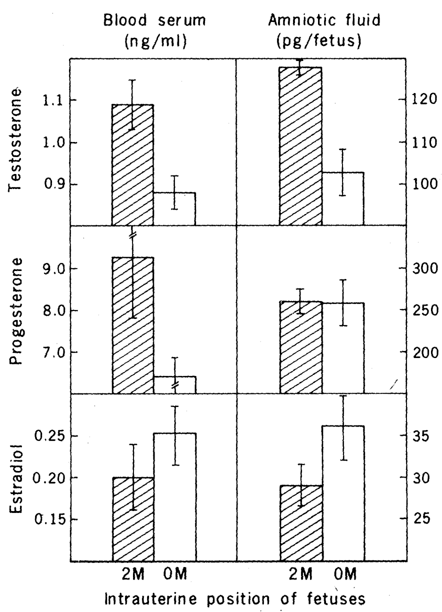

Fig. 1. Concentrations of testosterone, progesterone, and 17β-estradiol in the serum and amniotic fluid of 17-day-old 0M and 2M female fetuses. Hormones in blood serum are expressed as nanograms per milliliter of serum; amniotic fluid values are expressed as picograms of steroid extracted from the amniotic fluid of each fetus.

Recent studies with rodents, which produce litters containing many pups, have shown that in both mice (*3*) and rats (*4*) there is considerable variability among adult females in terms of reproductive characteristics, and that part of this variability can be traced to the former intrauterine proximity of females to male fetuses during prenatal development. For example, female mice that developed in utero between two male fetuses (referred to as 2M females) were found to differ morphologically, physiologically, and behaviorally from females that did not develop next to a male fetus (0M females) (*3*). When these two types of females were compared, 2M females had larger anogenital spaces at birth and in adulthood, were more aggressive in a variety of test situations, marked their environment with urine at a higher rate, and had longer and more irregular adult estrous cycles than 0M females. The 0M females appeared to be more attractive and sexually arousing to males. Prior intrauterine position was also found to interact with housing density in terms of the time of onset of puberty in female mice (*3*). These findings suggest that in species that produce litters containing many pups, the reproductive characteristics of females may vary depending on their intrauterine proximity to male fetuses, and that such variation is normal in polytocous animals.

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