Reports

The Giles County, Virginia, Seismic Zone

Abstract. *A well-defined seismic zone recently detected in Virginia has an orientation that is not related to the surrounding geologic structures. The orientation of the zone appears to be related to features below the Appalachian overthrust belt. A damaging earthquake that is important in evaluating seismic hazard in the southeastern United States may have occurred in the zone in 1897.*

Damaging earthquakes are rare in the eastern United States, but they have the potential of causing damage over large areas. Although much of the East has a relatively high population density, seismic hazards have generally been poorly evaluated in comparison with those in the West. For example, few areas in the East are covered by seismograph networks that are dense enough to allow accurate calculation (± 5 km) of locations and especially depths of earthquake foci. In most of the East, earthquakes large enough to be reliably located are too infrequent to allow the spatial and temporal patterns of seismicity to be accurately defined. Finally in large portions of the East, the rocks that may contain structures such as ancient faults that are activated in modern stress fields, are hidden by overlying younger sediments, sedimentary rocks, or overthrust masses.

Results obtained from 3 years of monitoring microearthquakes with a seismograph network indicate the probable epicenter of a damaging earthquake that occurred in 1897. The evidence (*1*) allows us to infer the type of fault or fault zone most probably responsible for most of the detected microearthquakes, and perhaps for the 1897 shock as well.

The 31 May 1897 earthquake in Giles County, southwestern Virginia [modified Mercalli intensity (MMI), VIII; body wave magnitude (m_b) = 5.8] (*2, 3*) is the largest shock known to have occurred in Virginia and the second largest known in the Southeast. The 1897 earthquake serves as the design earthquake for some engineering projects in the Appalachian highlands. The main shock was accompanied by a foreshock-aftershock sequence (*2, 4*). The aftershocks strong enough to be felt apparently ended as early as 1902 or perhaps as late as 1917 (*4*). A quiescence of four to six decades ended in 1959 with three shocks that were felt in the Giles County locale. Within 50 km of Pearisburg, the county seat of Giles County and the presumed epicenter of the 1897 earthquake, six more earthquakes were reported in the last two decades. The largest shock during the period was the event of $m_b = 4.6$, MMI = VI, on 20 November 1969. We do not know how to interpret this apparent renewal of seismic activity (nine earthquakes reported in the last 22 years) in or near Giles County in terms of another possible event like that of 1897.

Since 1962, a worldwide standard seismograph network observatory has operated at Blacksburg, 35 km southeast of Pearisburg. Late in 1977, a network of five seismograph stations was installed (Fig. 1a) to enclose the concentration of historical and recent epicenters.

Using local quarries and regional earthquakes as seismic sources, Moore (*5*) employed conventional refraction techniques to develop a crustal velocity model specific to the Giles County network. He also used a modification of the tripartite technique, perturbed to account for curvature of wave-front signals

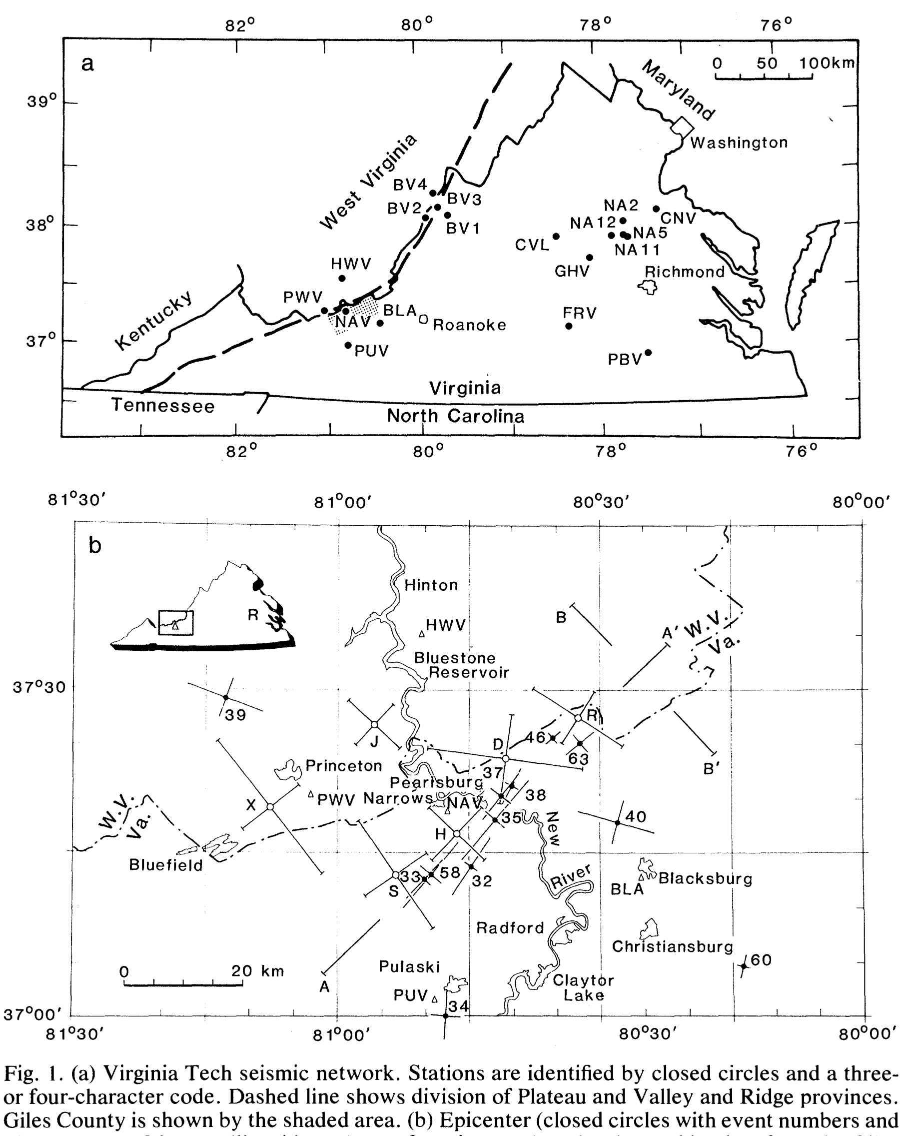

Fig. 1. (a) Virginia Tech seismic network. Stations are identified by closed circles and a three- or four-character code. Dashed line shows division of Plateau and Valley and Ridge provinces. Giles County is shown by the shaded area. (b) Epicenter (closed circles with event numbers and 68 percent confidence–ellipsoid axes) map for microearthquakes located by data from the Giles County subnetwork. JHD relocated epicenters (*7*) are shown by open circles with event letter designators and 90 percent confidence–ellipsoid axes. Network seismic stations are shown by open triangles with three-letter codes. The locations of vertical profiles A-A′ and B-B′ are also indicated. Inset map shows area of this figure (shaded portion) and locations of the Narrows seismic station (NAV, open triangle symbol) and Richmond (R).

Table 1. Earthquakes that occurred after 1977 in the Giles County seismic zone and were located with network data and the Hypoellipse program (*17*). Average network magnitude is calculated as $MD = -3.38 + 2.74\log D$, where D is the average duration in seconds at network stations from the onset of the *P*-wave until return of vibrations to background microseismic level. The root mean square (r.m.s.) error of the travel-time residuals is the observed seismic wave travel time minus the calculated seismic wave travel time. The quality factor according to Hypoellipse uses the lengths and azimuths of the axes of the error ellipsoid; the quality factor is based on the largest of the three semiaxes, with A ≤ 2.5 km, B ≤ 5.0 km, C ≤ 10 km, and D ≥ 100 km.

Event	Date	Magnitude (*MD*)	r.m.s. error of travel-time residuals (seconds)	Number of phases	Largest gap between stations (deg)	Quality factor code
32	28 January 1978	1.6	0.10	6	243	C
33	10 May 1978	0.3	0.09	6	268	B
35	1 June 1978	−0.2	0.17	6	170	C
37	28 July 1978	0.6	0.27	7	146	C
38	30 August 1978	0.5	0.09	6	158	C
46	18 February 1980	1.1	0.25	14	199	B
58	9 October 1980	−0.2	0.25	5	345	C
63	2 December 1980	0.4	0.34	10	113	C

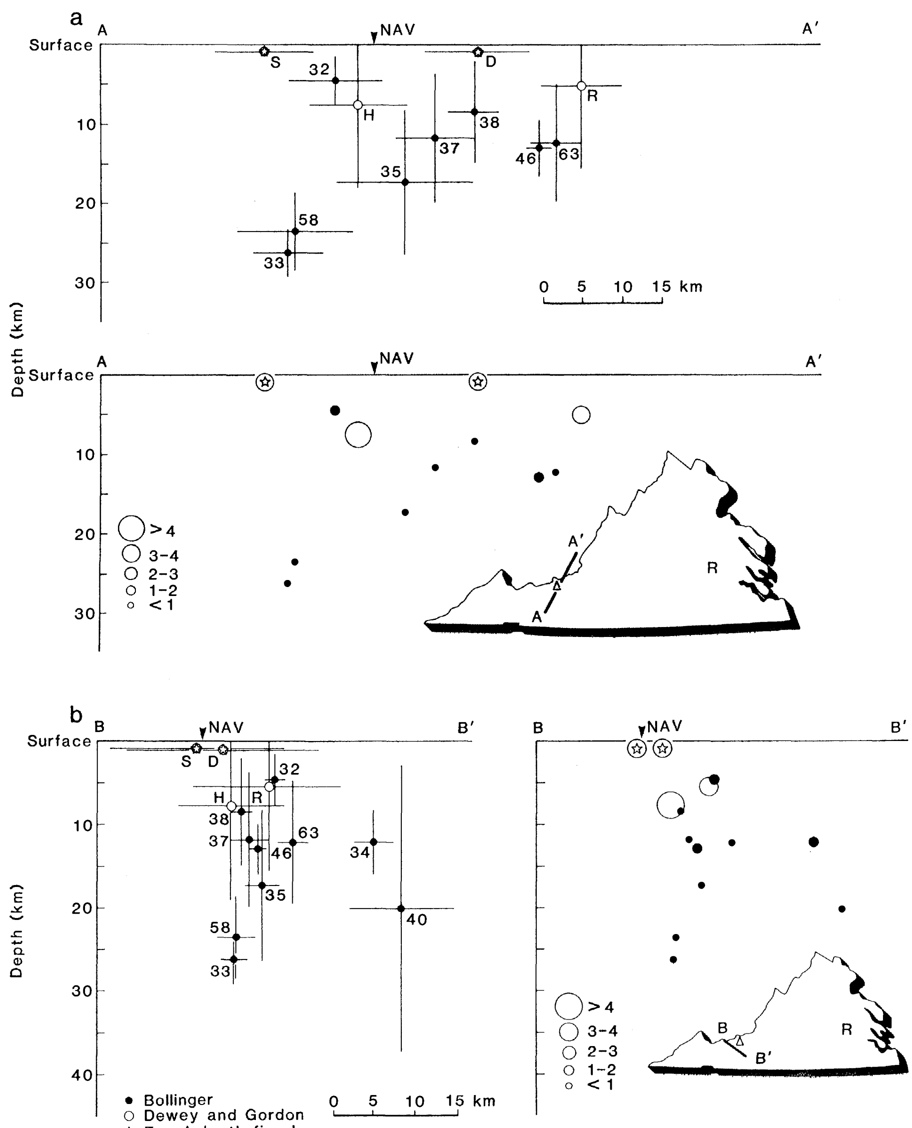

Fig. 2. (a) Vertical distribution of hypocenters along a northeasterly striking plane A-A′ shown in Fig. 1b (no vertical exaggeration). Hypocenters are also shown by circles whose sizes are proportional to earthquake magnitude. (b) Vertical distribution of hypocenters along a northwesterly striking plane B-B′ shown in Fig. 1b (no vertical exaggeration).

from blasts in quarries and mines (*6*), to help determine the local velocity structure. We used his three-layer velocity model (TPM2).

The close station spacing and locale-specific velocity model allow determination of accurate locations. Locations calculated for blasts from three known quarries differ from the actual locations of 0.5, 0.9, and 2.0 km. With TPM2, 8 of 12 microearthquake epicenters coalesced to form a northeast trending alignment (Fig. 1b and Table 1). The depth distribution of the foci defines a nearly vertical, tabular zone extending from 5 to 25 km (Fig. 2, a and b).

Dewey and Gordon (*7*) corroborated our zone. They used joint-hypocenter-determination (JHD) techniques to relocate historical earthquakes, including six in Giles County. The six, with m_b between 2.1 and 4.6 occurred between 1959 and 1976, and four are located in our zone (Fig. 1b). Thus, between 1959 and 1980, there have been 12 earthquakes in the Giles County seismic zone with magnitudes between 0 and 4.

Geologically, Giles County has mostly east-northeast-trending structures of the Valley and Ridge province, with unmetamorphosed, diverse sedimentary rocks of Cambrian through Pennsylvanian ages exposed. The upper several kilometers of rocks are complexly folded and faulted and detached from underlying rocks by thrusting many kilometers to the northwest; depth of the detachment ranges from about 3 km in the northwestern portion to about 6 km in the southeast (*8*). The trend of detached structures (ENE) varies little, and the detached rocks pass above the northeast-oriented seismic zone without significant disruption. Thus, structures in rocks shallower than 3 to 6 km are probably largely unrelated to deeper structures and the zone of seismicity.

The microearthquakes now recorded in Giles County are produced in a tabular zone in the metamorphic and igneous basement beneath the thrust masses (Fig. 2). The 1897 earthquake may have been triggered in the same zone and it is possible that the zone will be found to contain a reactivated fault or fault zone. There are only a few times in the geologic history of the region when such faulted basement could have been produced.

1) Although pertinent data are sparse, it seems unlikely that the large, tabular, steeply dipping seismic zone occurs on a fault older than late Precambrian age. An older fault would probably have been healed, deformed, or both, during the Grenville orogeny ($\sim 1.1 \times 10^9$ years ago).

2) As the Iapetus Ocean (predecessor of the Atlantic) opened in latest Precambrian or early Cambrian time, extensional faults formed. Most were probably normal faults, forming both west of Giles County and at least as far east as a large gravity gradient that passes about 50 km to the southeast (*1, 9*). Such a fault is the most likely candidate to be active under Giles County today.

3) After a period of thrusting, the Atlantic Ocean opened in Mesozoic time. Additional northeast-oriented extensional faults formed, many as sedimentary basin border faults, but these faults are not known as far to the northwest as Giles County.

From seismologic and core data, the upper crust in Giles County appears to be subject to roughly homogeneous, northeast- to east-trending compressive stress (*10*). Thus, a midcontinent stress province (*11*) may extend eastward into the basement under the thrust faults of the Valley and Ridge province. A fault striking northeast that was reactivated in such a stress regime would be a right-reverse fault, consistent with but not required by the sparse first-motion data from Giles County (*1, 10*).

We have assumed that the seismic zone we have defined was the source of the 1897 shock, but the assumption cannot be tested. The intensity data demonstrate that the meizoseismal area was, indeed, in Giles County (*2, 12, 13*). Campbell (*14*) reported, "The shock of May 31 was probably more severe in and about Pearisburg than any other point from which I have information." Pearisburg, being the largest town in the county, may have produced the most and more detailed intensity reports. The earthquakes of 1886 in Charleston, South Carolina, and 1811–1812 in New Madrid, Missouri, are also associated with zones of continuing earthquake activity (*15*).

Our results provide direct instrumental evidence of a tabular seismic zone in Virginia and an active zone in the Southeast that does not parallel the surficial tectonic fabric. Whether they are representative or atypical of a larger region is not yet known.

We draw four main conclusions (*1*).

1) The Giles County seismic zone, centered at Pearisburg, strikes northeast and dips nearly vertically. It is about 40 km long, 10 km wide, and 5 to 25 km deep.

2) The seismic zone is in the basement beneath the rocks detached by thrusting. It lies 20° counterclockwise to the trend of the detached structures of the southern Appalachian region.

3) Although low-dip thrust faults have been found to, or suggested to, produce large earthquakes elsewhere (*16*), such is not the case for the Giles County seismic zone.

4) Although conclusive evidence is lacking, it is likely that (i) this seismic zone is the same one that produced the 1897 shock and that the events felt in the last two decades suggest an apparent resumption of strain energy release after a seismic quiescence of four to five decades and (ii) the northeast-trending seismic zone is most probably the result of reactivation of one or more normal faults from Iapetan time.

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Zeolite Molecular Sieve 4A: Anomalous Compressibility and Volume Discontinuities at High Pressure

Abstract. *Unit cell parameters of synthetic zeolite 4A were measured at several pressures to 40 kilobars with both water and an alcohol mixture as hydrostatic pressure media. Compression in water was normal, with no observed phase transitions. Compression in alcohols was twice as great as in water, and three volume discontinuities were observed. These volume changes in alcohol were rapid with increasing pressure but sluggish in reverse. High-pressure "phases," all of which are dimensionally cubic, are progressively more compressible at high pressure. These unusual high-pressure phenomena, which indicate significant interactions between zeolite 4A and the hydrostatic media, are consistent with differences in zeolite adsorption of water and alcohols.*

A-type zeolites are synthetic, hydrous, alkali aluminosilicates, with exceptionally large structural channels and cavities (*1*). This cubic framework structure has been employed extensively as a selective sorbent for drying gases and solvents. Aluminosilicate framework compounds, especially those of high symmetry, commonly display "polyhedral tilt" transitions, in which corner-linked networks of AlO_4 and SiO_4 tetrahedra distort at high pressure (*2*). Zeolite A was selected for crystallographic study at high pressure on the basis of the prediction that the unusually open cubic framework would undergo such reversible tilt transitions. The zeolite crystals instead displayed a series of gradual transitions of a type not previously recorded. In particular, the high-pressure behavior of zeolite A was found to be dependent on the nature of the hydrostatic, pressure-transmitting fluid. These striking and unexpected phenomena are described in this report.

Cube-shaped crystals of fully hydrated zeolite A (Linde Molecular Sieve 4A, space group *Fm3c*, a = 24.55 Å, $12NaAlSiO_4 \cdot 27H_2O$) were provided by J. V. Smith (Department of Geophysical Sciences, University of Chicago). A 70-μm cube was selected for high-pressure