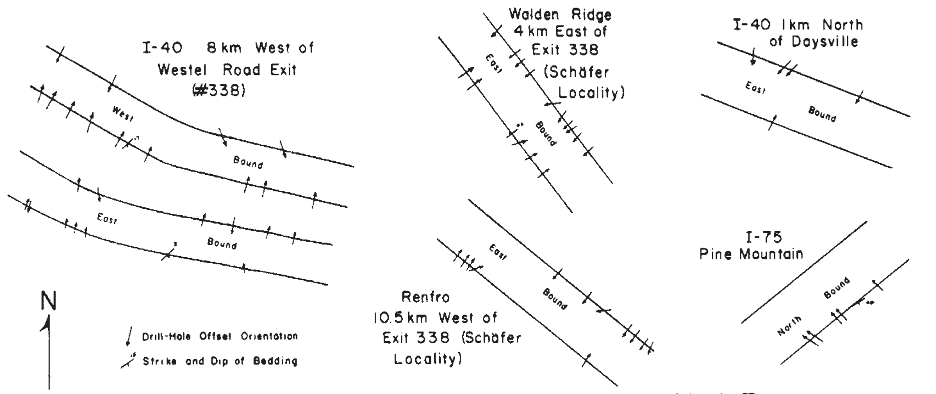

Fig. 1 Orientations of displacement for drill holes at the localities in Tennessee.

the base to the top of a cut in the Tennessee localities, the amount of offset increases upwards. Also, in most drill holes in which there are multiple offsets, the offset vectors are nearly parallel. Where offset vectors are not parallel, differences in motion may generally be explained by relative rotation of one of the upper blocks during blasting, later slumping, readjustment across major joints, or some other local process. At the West Virginia locality south-west of Oak Flat, the sense of movement is reversed from the base to the top of the cut on the north side of the highway. On a lower-to intermediate-level fracture the drill holes are offset away from the highway, whereas on an upper-level fracture the offset vectors have moved towards the highway.

A consistent relationship between offset vectors and highway cut orientation was noted. Orientation vectors are consistently oriented approximately normal to highway cuts. Most vectors symmetrically converge towards the centre of the highway (Fig. 1). At one locality in Tennessee, measurements were made in two parallel cuts of westbound and eastbound lanes separated by 30–50 m of rock. Offset vectors converge symmetrically towards the centre of the westbound lane, but vectors on both the north and south sides of the eastbound lane point north (Fig. 1). Using an elastic rebound mechanism, this pattern may be explained by excavation of the westbound lane first, initiating rebound and release of elastic strain energy throughout the mass. The differential in total or average offset of drill holes from the westbound to the eastbound lane (consistently greater effects in the westbound lane) favours a difference in time of excavation for the two lanes.

Offsets may cease to exist from one side of prominent joints (properly oriented) to another. One side of a joint may be offset as much as 30 cm whereas drill holes on the other side of the joint may be offset only 0 to <2 cm.

Stresses which produce observed strains, such as offset drill holes, may be simply interpreted as having a tectonic origin[2]. However, relatively high near-surface *in situ* stresses may also originate from non-tectonic processes[3].

Static loads derived from the weight of rock material composing a topographic high may become resolved into shearing stresses directed along properly oriented existing planar discontinuities, such as subhorizontal bedding. As long as these stresses are less than the shearing strengths of the rocks involved or less than the stresses necessary to reactivate existing planar discontinuities, no permanent strain would result. There would also be some dependence of storage of elastic strain energy on the elastic moduli of the rock mass. The most favourable orientations for static load-derived shearing stresses to be relieved would obviously be those which would permit movement outwards from the source of stress. A downward-directed static load may be relieved effectively by horizontal motion, provided this otherwise normal stress may be transformed into shearing stresses (Fig. 2). Existing subhorizontal planar discontinuities (bedding or fractures) may provide shear surfaces along which the stresses may be relieved. Motion along these surfaces may be accelerated during blasting where rapidly expanding gases are forced along bedding or fracture surfaces. The gases separate the rock mass and effectively lubricate it to overcome the coefficient of internal friction along the surfaces, so that accumulated elastic strain energy is released. Further strain may be caused by subsequent creep along discontinuities.

Blocks which are surrounded by properly oriented joints may contain no stored energy. Joints generally dip 70° or more. Those which are sufficiently open (not locked) and are oriented at low to moderate angles to the outward-directed shearing stresses may be relieved without offsetting drill holes.

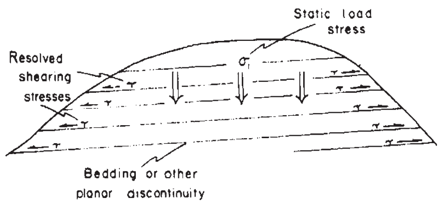

Fig. 2 Possible mechanism for producing subhorizontal shearing stresses from a nontectonic source.

We conclude that offset drill holes are a common phenomenon in the Cumberland–Allegheny Plateau of Tennessee and West Virginia where bedding is nearly horizontal. Drill holes are offset by release of stored elastic strain energy produced by static load. Offset drill holes in the Cumberland–Allegheny Plateau and in the Valley and Ridge are not related to recent tectonism. All tectonic structures present here predate highway construction and are probably Palaeozoic structures.

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2. Schäfer, K. *Nature* **280**, 223 (1979).
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SCHÄFER REPLIES—Hatcher and Webb have observed additional offsets of drill-holes with vectors oriented normal or oblique to the highway cuts. I agree that many of these displacements result from the release of static load-derived strain which is a common feature in the Appalachians and in other mountainous areas.

hatcher and Webb stated that I simply interpreted those offsets as having a tectonic origin. However, I did not consider any offset vector which was directed towards or away from a highway, although a tectonic component could also be involved. Offset vectors oriented parallel to the highway cuts were not included, either, in myanalysis when the excavation of the raod was directed radially to a topographic high. As of sites 1 and 2 at Interstate highway 40, Tennessee, which is NW–SE-oriented, a topographic high is located north-east of the highway. Also at the West Virginia site the highway cut runs tangentially to a topogkraphic high in the north-west. Thus, it is not surprising that Hatcher and Webb observed numerous drillholes with offset vectors normal or oblique to the road cuts. Other non-tectonic offset vectors may even run in the direction of the road-cut when static load-derived tangential tensile stresses induce dip-slip movements.

The borehole offsets which I considered, however, are all parallel (in one case sub-parallel) to the highway cuts revealing considerable rock masses to be upthrusted by tectonic forces and not by blasting. The tectonic origin of these faults evidently is not doubted by Hatcher and Webb as they did not mention any of these borehold offsets in their discussion.

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