WHERE AND WHY OF PINE MOUNTAIN
AND OTHER MAJOR FAULT PLANES,
VIRGINIA, KENTUCKY, AND TENNESSEE*

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ABSTRACT. The Pine Mountain overthrust fault at the base of the Cumberland
overthrust block in southwest Virginia, southeast Kentucky, and northeast Tennessee
is consistently at one of four different stratigraphic positions. In the highest position,
deep drilling has established that the fault is near but not at the base of the thick
Chattanooga Shale of Late Devonian and Early Mississippian age. In the next lower
position, the fault is within a thick predominantly shale sequence consisting of the
Rockwood Formation of Early and Middle Silurian age and the Sequatchie Formation
of Late Ordovician age. The third position is at or near the contact of the relatively
competent Maynardville Limestone of Late Cambrian age and the underlying rela-
tively incompetent Conasauga Shale. The oldest stratigraphic position for the fault
is near the base of the Rome Formation of Early Cambrian age.

In three of these four stratigraphic positions, the fault has not formed at the
interface of competent and incompetent units. The geologic evidence thus refutes
the theory that competent units have been sheared off the top of incompetent ones
as the result of lateral pressure. The principle that abnormally high fluid pressures
in thick relatively impervious sequences support most of the overburden seems to
apply to the Pine Mountain and other major overthrust faults. Thus, zones of almost
no resistance to lateral movement were established within the shale units, and the
formation of overthrust faults of large displacement by gravity sliding was facilitated.

INTRODUCTION

Major overthrust fault planes in the western part of the Valley and
Ridge province and the eastern part of the Cumberland Plateau in
Virginia, Kentucky, and Tennessee are consistently at four stratigraphic
positions. Only where they ramp upward from one stratigraphic position
to a higher one do the faults intersect other formations. This localiza-
tion of the fault planes at only four horizons exists in spite of the fact
that more than 4900 m (16,000 ft) of highly variable sedimentary rocks
has been involved. Within this thick sequence are many competent and
incompetent units, both thick and thin, which might be considered
favorable for controlling the location of major faults, but which have
not been utilized.

The purpose of this paper is to describe briefly the stratigraphic
location of the Pine Mountain and other major overthrusts in the Valley
and Ridge province and Cumberland Plateau of southwest Virginia,
southeast Kentucky, and northeast Tennessee, to examine various solu-
tions that might explain the localization of the fault planes, and to pro-
spose a hypothesis that seems to account for the observed phenomena.

CUMBERLAND OVERTHRUST BLOCK AND PINE MOUNTAIN FAULT

The Cumberland overthrust block, in Virginia, Kentucky, and Ten-
nessee has been the subject of many reports (Wentworth, 1921; Rich,
1934; Miller and Fuller, 1954; Miller and Brosge, 1954; Harris, 1970;
and others), and its major geologic features are so well known to students

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Fig. 1. The Cumberland overthrust block and generalized structure section showing the stratigraphic positions of the Pine Mountain overthrust fault beneath the block. The heavy line marks the boundary between the Cumberland Plateau and the Valley and Ridge province.
and readers of Appalachian geology that it seems unnecessary to re-describe them here. Figure 1 shows the location of the block and its bounding faults and major folds. The accompanying generalized structure section shows the subsurface location and the nature of the movement along the Pine Mountain fault. It also shows a sole fault which is thought to be present near the basement (Miller, unpub. data) and from which the Pine Mountain fault has ramped upward.

The Pine Mountain fault is a bedding-plane fault throughout most of its areal extent of more than 7700 sq km (3000 sq miles). It has been shown, either by exposure along Pine Mountain in Kentucky and Tennessee and in fensters along the Powell Valley anticline or by drilling, to be in the following positions: near the base of the Rome Formation of Early Cambrian age, at or near the base of the Maynardville Limestone of Late Cambrian age, within the Sequatchie-Rockwood Formations of Late Ordovician and Early and Middle Silurian age, and near the base of the Chattanooga Shale (or equivalents) of Late Devonian and Early Mississippian age.

The approximate areas within the Cumberland block where the fault is a bedding-plane thrust at each of the four stratigraphic horizons are shown in figure 1. We will examine each of these in turn to see the lithology of rocks of the fault zone and the lithologies of the rocks overlying and underlying the fault zone.

CHATTANOOGA SHALE

The name Chattanooga Shale is used here for the sequence of shale and siltstone in the Tristate area that is of Late Devonian and Early Mississippian age. Formation names other than Chattanooga have been used for these beds in parts of Virginia and Kentucky, but inasmuch as the complex stratigraphic nomenclature of these rocks is not relevant to the theme of this paper, the catchall name Chattanooga will be applied even in those areas where it is not in current usage.

The Pine Mountain fault is a bedding-plane fault within the Chattanooga Shale beneath almost all the Middlesboro syncline except in the extreme southwest part of the block in Tennessee. The formation is composed largely of shale but contains thin-bedded siltstone in the middle part of the formation in Virginia. Dark-gray to grayish-black shale in thick zones composes most of the lower part of the formation in Virginia and practically all of it in Tennessee. The upper part of the formation in Virginia is predominantly gray shale but contains zones of black shale. The formation is at least 260 m (850 ft) thick in the northeast part of the Cumberland block but thins to 75 m (250 ft) at the Virginia-Tennessee State line and to 23 m (75 ft) near the southwest end of the block. Thus, in Virginia and in northernmost Tennessee, it is a thick “incompetent” unit.

The location of the Pine Mountain fault within the Chattanooga has been abundantly documented by drilling in and near the northeastern part of the block (Young, 1957). The penetration of the fault
zone was clearly evident to the driller because, when the fault zone was penetrated, a gas blowout invariably occurred, hurling the tools back up the hole, and in many wells necessitating a fishing job. Surprisingly, the fault is not at or very close to the base of the Chattanooga, where relatively competent sandstones of the Wildcat Valley Sandstone (Lower Devonian) or Hancock Dolomite (Upper Silurian) are next beneath. Rather it generally is 15 to 75 m (50 to 250 ft) above the base of the formation and averages 29 m (95 ft) above the base. Figure 2 shows the locations of 32 wells that penetrated the fault and the interval (based on table 1 in Young's paper (1957)) between the base of the formation and the fault zone (blowout zone). One well, shown in the south-central part of figure 2 is anomalous. According to Young, the gas blowout in this well occurred 230 m (754 ft) above the base of the Chattanooga. I have logged the cuttings from this well, lent to me through the courtesy of the Wise Coal and Coke Company, and found slickensides in many of the samples from the blowout depth down to within 7.6 m (25 ft) of the base of the Chattanooga. This indicates crumpling and probably faulting of the shale through a zone about 220 m (725 ft) thick. This disturbed zone is much thicker than in any of the other wells. The blowout zone is, however, 245 m (800 ft) below the top of the Chattanooga, which is its approximate position in the other wells shown in figure 2. It seems,
therefore, that in this anomalous well, the fault is about where it is in
the other wells with respect to the top of the Chattanooga, but the lower
part of the formation is greatly overthickened by folding and faulting
associated with the Pine Mountain overthrust.

It should be emphasized that in these 32 wells that penetrated the
Pine Mountain overthrust, the fault invariably is within the Chattanooga
Shale, and undeformed beds are invariably present between the fault
zone and the base of the formation. In no well was the fault at the top
of the Chattanooga where more competent beds of the medium-bedded
Price Shale overlie the shale, nor was it at the base of the formation
where the Wildcat Valley Sandstone or the next older Hancock Dolomite
directly underlie the Chattanooga. Section D on figure 3 shows the strati-
graphic position of the fault in these wells.

SEQUATCHIE-ROCKWOOD FORMATIONS

The Sequatchie is the oldest formation exposed above several fault
planes that make up the Pine Mountain fault zone, where it comes to
the surface along the northwest flank of Pine Mountain and adjacent
Elk Valley in Tennessee (Englund, 1968). However, a well drilled within
the Middlesboro syncline 8 km (5 miles) southeast of Pine Mountain
encountered the fault within the Rockwood Formation (Englund, 1968,
p. 56-57). The well was extended only 27 m (90 ft) deeper after passing
through the fault and was still in the Rockwood. It seems likely that
another bedding-plane fault would have been found in the Sequatchie
had this well been drilled deeper. I thus conclude that the Pine Moun-
tain fault is within the Sequatchie-Rockwood Formations of Late Ordo-
vician and Early and Middle Silurian age, respectively, in a small area
beneath part of the Middlesboro syncline near the southwest end of the
Cumberland block (figs. 1 and 3C).

The Rockwood Formation consists of medium-gray and dark-greenish-gray shale (Englund, 1968) and is about 75 m (250 ft) thick (fig. 3C).
It is underlain by the Sequatchie Formation which consists of 60 to 75
m (200-250 ft) grayish-red and greenish-gray calcareous siltstone. The
ridge-forming Clinch Sandstone, which overlies the Sequatchie in south-
west Virginia, has either changed facies to Rockwood lithology or tongues
out just south of the Virginia-Tennessee State line.

The Rockwood is overlain by the Chattanooga Shale which has
thinned from some 75 m (250 ft) near the Virginia-Tennessee State line
to only 23 m (75 ft) in the well southeast of Pine Mountain previously
referred to. Thus, there is a continuous vertical sequence of some 170 m
(575 ft) of fine-grained clastic rocks in the Sequatchie, Rockwood, and
Chattanooga, with one fault plane in the Rockwood at about 85 m (275
ft) below the top of the sequence, but none in the Chattanooga. Another
fault plane may be in the Sequatchie Formation beneath the Middles-
boro syncline from 110 to 175 m (365 (275 + 90) -575 ft) below the top
of the sequence. This is suggested because previous experience provides
no examples where the Pine Mountain fault plane has cut downward
Fig. 3. Generalized stratigraphic sections showing location of the Pine Mountain overthrust. These generalized sections are for some of the areas shown in figure 1.
in a forward (northwest) direction from one stratigraphic horizon to a lower one, as would be required to explain the Sequatchie slices that are present in the Pine Mountain fault zone at the outcrop. Considering the characteristics of the Pine Mountain thrust zone in southwest Virginia, if there is a lower fault plane in the Sequatchie below the fault found in the well, it would probably be closer to 175 m (575 ft) than 110 m (365 ft) below the top of the sequence.

The Chattanooga Shale southeast of Pine Mountain is lithologically practically identical with the lower part of the Chattanooga, where the Pine Mountain fault plane is located, in southwest Virginia and northernmost Tennessee. The fault occurs at lower horizons in the Rockwood and Sequatchie farther south in Tennessee, apparently because the Chattanooga is there too thin to provide the requisite conditions for overthrust fault development.

**MAYNARDVILLE LIMESTONE**

The third stratigraphic position favorable for the formation of the Pine Mountain fault is in the lowermost part of the Maynardville Limestone of Late Cambrian age (figs. 1 and 3B). Detailed mapping in and near the fensters shown on figure 1 (Miller and Fuller, 1954; Miller and Brosge, 1954; Englund and others, 1961; Harris, Stevens, and Miller, 1962) and many wells in and near the Rose Hill and Ben Hur oil fields, in Lee County, Va., the westernmost county of the state, have accurately located the Pine Mountain fault plane 54 km (21 miles) along the crest of the Powell Valley anticline. Throughout this distance, the fault is quite consistently at or very close to the base of the Maynardville, although, locally, slices and slivers of the Maynardville have been broken off the base of the moving block, so that a branch of the fault cuts upward into the Maynardville in great scallops. Within this well-documented area, the formations exposed within the fensters or drilled nearby, which are directly below the Maynardville and below the fault, range in age from Middle Ordovician through Silurian. Thus, the fault that has formed at the base of the Maynardville crosscuts younger formations in the stationary block. This is not an analogous structural situation to the bedding-plane thrusts previously described, where the fault is entirely within one formation or sequence. Many structure sections showing the relation of the Maynardville and the fault plane to the formations beneath the fault have been published by Miller and Fuller (1954) and Miller and Brosge (1954). Because the structure of this area differs from the structures previously described, the favorability of the Maynardville as a locus for breaking and sliding also requires examination.

The Maynardville Limestone consists of about equal parts of ribbed and mottled argillaceous, very fine crystalline limestone below and fine crystalline, even-bedded, argillaceous to silty dolomite above. The formation is nearly 90 m (300 ft) thick. It gives way upward by interbedding into a sequence of even-bedded quite massive dolomite more
than 600 m (2000 ft) thick. This sequence constitutes the Knox Group of Late Cambrian and Early Ordovician age.

The Maynardville Limestone is underlain by the Conasauga Shale, which consists predominantly of greenish-gray sericitic shale but includes subordinate amounts of thin-bedded glauconitic limestone and thin-bedded nonresistant sandstone. The Conasauga is about 175 m (575 ft) thick.

Here then is a clear-cut case where the Pine Mountain fault plane has formed at or very close to the contact of a thick competent carbonate sequence and a thick incompetent shale sequence. This contrasts sharply with the two previously described positions of the fault.

The fault is also near the base of the Maynardville in the Shoun well (fig. 1) near Jacksboro, Tenn. This well is, however, on the northwest flank of the Powell Valley anticline, where the Pine Mountain may be ramping upward from an assumed position near the base of the Rome to a known position in the Sequatchie-Rockwood sequence below the Middlesboro syncline.

**ROME FORMATION**

Within the Cumberland overthrust block, the Pine Mountain fault is known to be near the base of the Rome Formation in only one location—the Brooks well, in Lee County, Va., on the crest of the Powell Valley anticline, 2.4 km (1½ miles) west of the westernmost fenster and the Rose Hill oil field (fig. 1). Wells intermediate in position between the fenster and the Brooks well provide evidence that the fault plane plunges downward from the base of the Maynardville in the fenster to a position near the base of the Rome Formation, some 670 m (2000 ft) stratigraphically lower. The direction of this plunge is parallel to the Powell Valley anticline and normal to the forward movement of the Cumberland overthrust block. The Pine Mountain fault is probably near the base of the Rome beneath the Powell Valley anticline from the Brooks well southwest to the Jacksboro fault at the southwest edge of the block (fig. 1), because Conasauga Shale is exposed along the crest of the anticline in the valley of the Clinch River in Tennessee in normal position below the Maynardville Limestone. Inasmuch as the fault thus is not at the Conasauga-Maynardville contact in this area, it is probably located at its next deeper favored position. In addition, both the Wallen Valley and Hunter Valley faults are near the base of the Rome Formation just southeast of the Powell Valley anticline, so the Pine Mountain fault must be stratigraphically that deep on the south flank of the Powell Valley anticline. It probably ramps upward beneath the north flank rather than beneath the broad nearly flat crest of the anticline in this region.

The Rome Formation is a heterogeneous assemblage of several lithologies. Greenish-gray and grayish-red shale and siltstone predominate, but zones of sandstone and carbonate are present in every section (fig. 3A). The sandstone is fine and medium grained, light gray, medium gray,
and brownish gray. Carbonate units consist of both limestone and dolomite. Most of these units are lenticular, but a zone of carbonate, about 18 m (60 ft) thick, which is dolomite in the Brooks well but limestone at the outcrop to the southeast, seems to be widespread.

In the central and northwest parts of the Valley and Ridge province, the lowest part of the Rome is everywhere cut out by faults, the Pine Mountain fault in the Brooks well, and the Wallen Valley and Hunter Valley and other faults to the southeast (fig. 6). The maximum preserved thickness of the Rome above these faults is consistently about 500 m (1600 ft) of beds, suggesting that conditions favored the formation of major glide planes at about this location in the unit. The fault is thought not to be at the base of the Rome, because slices and slivers of the underlying formation would surely have been brought to the surface in some places along one of the major faults if the break had taken place exactly at the contact with underlying beds, whatever these beds might have been. Because no pre-Rome beds have been reported in the northwestern part of the Valley and Ridge, I conclude that the Pine Mountain and other faults found a favorable position for breaking and sliding near but not at the base of the Rome Formation.

PRELIMINARY SUMMARY

Three of the four stratigraphic positions for major bedding-plane faults (décollements) in the northwest part of the Valley and Ridge province are within thick, predominantly fine-grained clastic sequences. These three positions are (1) near the base of the Chattanooga Shale, (2) within the Sequatchie Formation-Rockwood Formation sequence, and (3) near the base of the Rome Formation. The fourth position, at the base of the Maynardville Limestone, does not seem to fit the pattern of the other three. Except for local loss of slices and slivers of Maynardville from the base of the sliding block during forward movement, the Pine Mountain and other faults do seem to favor breaking at the base of the Maynardville. True, the underlying beds are thick sequences of shale of the Conasauga (or partly equivalent Nolichucky) Shale, and the Maynardville itself is essentially a fine-grained calcareous and dolomitic sedimentary rock, but even so, the resemblance of this position for the fault at the base of the Maynardville to the other three situations is not striking.

INCOMPETENCE OF STRATA AS A CONTROLLING FACTOR

It has long been a tenet of structural geology that major faults of the overthrust type form in incompetent strata. Wentworth (1921b, p. 63) stated that “rocks of the Cumberland block were subjected to strong lateral compression from the southeast”. Butts (1927, p. 9) proved the validity of Wentworth’s interpretation of the Pine Mountain fault as underlying the entire Cumberland block by finding fensters along the crest of the Powell Valley anticline where erosion had breached the overthrust sheet and exposed the fault plane. He attributed the movement of the block to “a push acting northwestward”. It follows that the
whole region southeast of the Cumberland block has also been pushed northwestward. Rich (1934), in a classic and oft-cited paper, described a mechanism for explaining the formation of the Pine Mountain and similar low-angle overthrusts, which did not involve faults rooted in the basement. He may be considered the father of the "thin-skinned" concept for explaining low-angle Appalachian faults. He concluded (Rich, 1934, p. 1596) that "the thrusting . . . is entirely confined to the sediments, which have been sheared off from the underlying crystalline basement, pushed forward, and piled up in a shingle-fashion by a great plunger moving from the southeast—presumably the pre-Cambrian mass of the crystalline Appalachians". Miller and Fuller (1954) modified Rich's interpretation but accepted the general principles. They stated (p. 256-258) "The Cumberland block has been able to move forward as a unit along a nearly flat fault plane because it is in the main composed of competent formations capable of transmitting lateral pressures long distances without buckling. . . . Interbedded with the competent formations are, however, two relatively thin very incompetent units, the Conasauga shale and the . . . Chattanooga. . . . It is curious and unexplained that in the Rose Hill area most of the incompetent Conasauga shale has been left behind in the stationary block while the competent Maynardville Limestone and dolomites of the Knox Group overrode it, whereas at Pine Mountain in Kentucky most of the incompetent Chattanooga shale lies above the fault plane and has moved forward with the overriding rocks".

Inherent in the above quotations and in many other contributions to the understanding of southern Appalachian structure is the concept of thick competent units transmitting lateral stresses from the southeast, which finally caused shearing in interlayered incompetent units, resulting in miles of movement along the glide plane. Miller and Fuller seem to have had some doubts, however, because of their inability to comprehend how in one case the competent units have been sheared off the top of the incompetent ones, whereas in the other case the incompetent units have been sheared off the top of the competent ones. The second of the two is indeed hard to understand under the concept of transmitted lateral stresses.

Let us consider which are the most competent and which the least competent sequences in the rock column of this region.

**COMPETENT STRATIGRAPHIC SEQUENCES**

The most competent of all the formations in the sedimentary column in the region of the Cumberland overthrust block is probably the Lee Formation of Late Mississippian and Early Pennsylvanian age (fig. 4C). Although it varies considerably from place to place, throughout most of the region it contains thick, massive, crossbedded sandstone and conglomerate units, as much as 125 m (400 ft) thick, and its basal unit is a conglomeratic sandstone more than 30 m (100 ft) thick (Englund and DeLaney, 1966). It is underlain by the Bluestone Formation of the
Fig. 4. Sections showing juxtaposition of competent and incompetent formations. The Pine Mountain overthrust and other major bedding-plane faults did not form at the queried horizons.
Pennington Group or by the uppermost part of the Pennington Formation, which consists largely of shale and siltstone (figs. 3 and 4C). Surely the contact between these formations would be a highly favorable place for an overthrust fault to form if the competent units were transmitting lateral stresses, but I know of no place where a bedding-plane fault has formed at the base of the Lee Formation.

A second highly competent formation is the Clinch Sandstone of Early Silurian age (fig. 4B). In most of the Cumberland block region, the Clinch consists of very resistant quartzitic sandstone and conglomerate, which ranges from 30 to 60 m (100-200 ft) in thickness. It is underlain by red and green calcareous mudstone of the Sequatchie Formation (Upper Ordovician). This also appears to be a very favorable position for shearing of competent (Clinch) over incompetent (Sequatchie) beds, but it is equally barren of overthrust faults.

The third very competent unit in the area is the thick carbonate sequence of the previously described Maynardville Limestone and Knox Group (Upper Cambrian and Lower Ordovician), which is underlain by Conasauga Shale (fig. 3B). Overthrust and thrust faults have formed at this locus, involving a part of the Cumberland block (fig. 1) and also parts of the slices that have ridden forward along the Wallen Valley and Hunter Valley faults.

Here again is a puzzling anomaly. What seems to fit the translated lateral compression theory in the case of the Maynardville-Knox competent unit doesn't work at all for the two most competent units in the section.

INCOMPETENT UNITS

Many incompetent to very incompetent units are included in the known section of more than 4900 m (16,000 ft) of Paleozoic sedimentary rocks. Probably the most incompetent of all is the Eggleston Limestone of Middle Ordovician age which is predominantly a calcareous mudstone and is about 46 m (150 ft) thick. The lower part of the Eggleston is so subject to flowage that bedding is extremely obscure. In the middle and upper parts of the Eggleston are two bentonite beds ranging from a half to 1 m (1½-3 ft) in thickness. These are so incompetent that when drilled, they sluff off for many meters down the hole. In only two places have I seen any faulting or crumpling in the Eggleston in which slippage within the Eggleston was the cause of the deformation. Both of these were very local. No major faults have formed within this formation in the regions with which I am familiar.

Other incompetent units are the Conasauga Shale, Sequatchie Formation, Rockwood Formation, and Chattanooga Shale, which have been discussed previously. All these consist of fine-grained clastic rocks, and all are thick sequences in most of the Cumberland block. In different parts of the block, these have been the locus for the formation of the Pine Mountain fault. The Chattanooga Shale contains the fault beneath more than half the block, but this is only in the area where the formation
is thick. In Tennessee, where it thins to less than 30 m (100 ft), the fault plane has deserted this formation and has found a more favorable location in the Sequatchie-Rockwood sequence.

From the above, it appears that in only one case out of three has the Pine Mountain fault been localized by very competent units overlying incompetent ones. The presence of incompetent units has exerted a control, but only where the incompetent units are thick.

CONTROLLING MECHANISM FOR THE PINE MOUNTAIN OVERTHRUST

The key to the mechanism that has controlled the formation of the Pine Mountain overthrust is found in two publications. Young's paper (1957) proved that in a large area the fault (his blowout zone) was near but not at the base of the Chattanooga Shale. My studies of well cuttings in this area show that undeformed beds of Chattanooga Shale everywhere lie below the fault zone and separate the fault from the underlying formation. Hence, it can not be said that the incompetent Chattanooga Shale has been stripped off the surface of the underlying competent formation, be it the Wildcat Valley Sandstone of Early Devonian age or the Hancock Limestone (or Dolomite) of Late Silurian age. Similarly, the fault in the southwestern part of the block is within the incompetent Sequatchie-Rockwood sequence beneath the Middlesboro syncline, and for reasons already adduced, the fault is thought to be near but not at the base of the heterogeneous but relatively incompetent Rome Formation beneath the Powell Valley anticline.

The second publication, which provides the answer to this consistent behavior of the Pine Mountain fault, is the classic paper by Hubbert and Rubey (1959). They demonstrated (1) that abnormal pressures can and do develop in water-saturated porous but relatively impermeable sediments that are subjected to loading by accumulation of thick overburden or to tectonic compression; (2) that these pressures are eventually relieved by leakage, but because leakage from clays is very slow, the abnormal pressures remain for long periods of geologic time; and (3) that the "pressure in the water contained in large parts of these sediments must have been raised to, or approaching the limit of flotation of the overburden" (Hubbert and Rubey, 1959, p. 162). Under these circumstances the movement of great slices of crust along low-angle overthrust fault planes becomes not only possible but probable.

The Hubbert-Rubey concept of overthrusting provides the answer to the location of the Pine Mountain fault. The fine-grained water-saturated sediments were compressed by loading so that abnormally high fluid pressures developed. Over the course of time, leakage away from the pressurized saturated sediments would reduce these pressures to the normal hydrostatic levels. In thin sequences, the leakage progressed outward toward upper and lower more pervious enclosing sediments, and the flotation factor was completely lost. In thick sequences, however, time was not adequate for the leakage across the pervious-relatively impervious interface to penetrate more than a few meters into the hyperpressurized
mass, and the flotation factor was retained. Hence, when uplift during the Appalachian orogeny took place, the gravitational stresses, perhaps accompanied also by a "push" from the rising crystalline masses to the southeast, caused great slices of the crust to slide long distances on very gentle, perhaps nearly flat surfaces. These surfaces were within the thick sequences of fine-grained rocks, the Rome, the Sequatchie-Rockwood, and the Chattanooga. They were not at or near the interfaces of physically competent and incompetent sequences such as the Bluestone-Lee or the Sequatchie-Clinch, because the pervious sandstones and conglomerates of the Lee and Clinch drained off the fluids and relieved the excess pressure, thus eliminating the flotation factor.

Terzaghi and Peck (1967, p. 174, fig. 25.1) have shown how the principle of excess fluid pressures operates in a relatively impervious consolidating sediment between two pervious sediments. Their demonstration involves inserting manometers in an impervious (clay) layer between two pervious (sand) layers at top, intermediate, and bottom levels of the clay (fig. 5). Weight of the overburden inducing consolidation produces excess fluid pressures. Initially the level of water rises to the same level (de) above the water table in all the manometers as the result of the pressure increase. As time passes, however, drainage (leakage) at top and bottom from the consolidating clay into the porous sand reduces the excess pressure, so that the water levels on the higher and lower manometers fall to the levels shown by curve $C_1$, whereas the level in the

![Fig. 5. Diagram illustrating generation and release of excess fluid pressures in a consolidating layer of clay between two sand layers. Slightly modified from Terzaghi and Peck (1967, fig. 25.1).](image-url)
middle manometer is still unchanged. At a later stage, shown by the curve C2, the water level in the outer manometers has fallen to normal hydrostatic pressure, and leakage has reached the middle of the clay layer but has not drained off all excess pressure. If leakage is faster at top than bottom, the zone of greatest remaining excess pressure migrates downward. If the reverse is true, the zone migrates upward. Eventually all excess pressures leak away, and the water level in all manometers falls to the same level (ac), representing equilibrium.

This experiment, demonstrating how the excess pressures can build up and be relieved in a relatively impervious sediment near the surface, is equally applicable in a rock column on a much grander scale over geologic time. It also permits us to answer why the Pine Mountain fault is near but not at the base of the Chattanooga Shale. In the actual case of the Chattanooga Shale, leakage upward from the Chattanooga Shale into the overlying more pervious Price Slitstone was easier and faster than leakage downward into the Wildcat Valley Sandstone, which is carbonate cemented, or into the Hancock Dolomite (or Limestone) which is a fine-grained carbonate. The zone of greatest excess pressure thus lay near but not at the base of the impervious clay rock column with the result that breaking and gravitational sliding took place in this flotation zone near but not at the base of the sequence. It is amazing how consistently this is true in the Chattanooga. Although fewer good measurements are available, it appears fairly consistent also in the Rome in the Tristate region, because the maximum thickness of that formation above a major fault, whatever fault it may be, is known in several places to be in the 460- to 500-m (1500 to 1600 ft) range, and this may be true in many other places.

The above explanation of the overthrusting requires only gravity sliding as a mechanism to account for formation of the fault in three of the four situations that have been discussed in this paper. Where the Pine Mountain fault is at the base of the Maynardville-Knox carbonate sequence, the development of and movement along the overthrust fault plane by gravity sliding alone seems inadequate. It is true that the Maynardville was a fine-grained carbonate mud before lithification and must have been water saturated and quite impervious to fast leakage. The underlying Conasauga Shale was also a water-saturated, argillaceous mud. These two formations thus formed a thick clastic sequence within which abnormal fluid pressures probably did develop. Nonetheless, the fact that the fault quite consistently formed almost exactly at the contact between the two seems to require that, although abnormal fluid pressures within the Conasauga-Maynardville sequence facilitated faulting, compressive stresses in the form of a push from the mass of sliding rocks to the southeast controlled the formation of the fault at the exact contact between competent and less competent rocks. The Maynardville and all overlying rocks were sheared off the top of the underlying incompetent shale.
OTHER OVERTHURSTS AND THRUSTS SOUTHEAST OF THE VALLEY AND RIDGE PROVINCE

I believe that a master sole fault underlies the Cumberland block and all of the Valley and Ridge province to the southeast in southwest Virginia and east Tennessee, where other overthrust and thrust faults are common. I think that the Pine Mountain fault joins this sole fault at depth, as do the other faults. The underground structure is, however, undoubtedly complex, and there is too little information on behavior of the faults at the surface and on the structure, and the formations present at intermediate and greater depths to attempt a reconstruction of a cross section across the Valley and Ridge province at this time. However, this sole fault apparently is near the base of the Rome Formation beneath the northwestern part of the Valley and Ridge, because the Rome is brought to the surface repeatedly by faults, and it is the oldest rock exposed anywhere in this belt (fig. 6). Beneath the southeastern part of the Valley, and the Blue Ridge, however, the Shady Dolomite (Lower Cambrian) and a very thick wedge of still Lower Cambrian clastic rocks (Chilhowie Group) and Upper Precambrian clastic rocks (Ocoee Supergroup), which are not present beneath the Cumberland block, appear at the surface beneath the Rome. In this region, the sole fault has dropped to a greater depth and to lower stratigraphic horizons in this thick sequence. The Rome is present in many of the slices, but in most places it is not in contact with the faults (fig. 6) and is conformably underlain by these older formations. It seems logical to assume that the positions of the major bedding-plane (not ramping) faults in this region have likewise been controlled by the flotation principle here described for the Pine Mountain fault. The details of where and how this all fits together into a well-coordinated framework are beyond the scope of this paper. It is interesting to note, however, that Hatcher (1972, fig. 3) has recently postulated a sole fault beneath the Blue Ridge and extending southeastward some 115 km (70 miles) to the Brevard fault in North and South Carolina. Possibly the sole fault I am proposing beneath the Valley and Ridge extends southeastward at great depth beneath the Blue Ridge and thus is a northwest extension of Hatcher’s sole fault. If so, all faults that come to the surface between the Brevard fault in the Carolinas and Pine Mountain in Kentucky and Tennessee are imbricate faults rising from this master sole fault.

CONCLUSION

The stratigraphic placement of the Pine Mountain fault beneath the Cumberland overthrust block in Virginia-Kentucky-Tennessee has been described, and a mechanism of excess fluid pressures that promote gravity sliding has been presented to account for the placement. This same mechanism should be operative on the low-angle large-displacement bedding-plane faults beneath the remainder of the Valley and Ridge province and may continue as the controlling factor in the great faults of the Blue Ridge-Great Smoky Mountain complex. More detailed map-
ping in selected strategic areas is needed, however, and more nonconfidential geophysical work, particularly seismic work, is also needed before we can hope to construct reasonably accurate sections to basement across the Valley and Ridge province. Deep drilling at carefully selected sites would also help to provide the necessary data to understand and depict the subsurface behavior of the great overthrust faults that dominate this fascinating region.

Fig. 6. Map showing the major faults of southwest Virginia, east Tennessee, and northwestern North Carolina. The map also shows the belts of Rome Formation that have been brought to the surface by faulting. Compiled principally from the state geologic maps.

References


