VALLEY STRESS RELEASE IN THE ALLEGHENY PLATEAU

H. F. Ferguson
U.S. Army, Corps of Engineers, Pittsburgh, Pa.

ABSTRACT

Recent foundations exposed during the construction of Flood Control and Navigation Dams in the flat lying rocks of the Allegheny Plateau Region has disclosed release of stress in the valley walls and bottom. These valleys, cut into sedimentary rocks of variable hardness, show compression faults in the valley bottoms and tension fractures in the valley walls. Generally, the tension fractures in the valley walls are vertical or near vertical and parallel the strike of the valley or they may strike at an angle reflecting a tangential release of stress from tributary valleys as they intersect the main valley. The distance between these fractures is a function of the competency and thickness of the particular stratigraphic bed with the weaker rocks having closer spacing.

The valley bottoms have been subject to compression forces produced by that zone of the valley walls that has fractured and expanded horizontally. This horizontal movement together with load of this mass, produces forces that cause a wedge failure of the valley walls and bottom in the form of arching, thrust faulting or shear breaks in the rocks. These areas of release of stress have been in the center of the valley with valleys of uniform topography. The depth of the compressional breaks in the

valley vary with the competency of the rock with the more massive rocks such as limestone or sandstone having deeper areas of disturbance than weaker non-compentent rocks such as clay shales or indurated clays. Any fractures in the rock of the valley floor generally re

flect vertical shear forces. Mylonite or gouge in the valley walls and valley bottom indicate the end of the zones of stress release.

INTRODUCTION

In 1959 at the annual Geological Society of America meeting I coauthored a paper with Dr. S.S. Philbrick on Thrust Faulting in Engineering Structures in the Pittsburgh District. The paper came about because of a history of foundation faults in our flood control and navigation structures. We concluded that the cause and age of these faults were unknown. Since that time we have examined

and explored many more foundations and have continued to find faulting in the foundations of the major river valleys.

GENERAL GEOLOGY

The rocks that crop out within the area investigated range from Middle Devonian to Permian in age and are located in the Allegheny Plateau area and they are the typical cyclic deposited generally flat lying to gently dipping sedimentary rock -- that ranges from the highly variable coal measures through the uniform Devonian shales. Most of the rocks are cemented and relatively hard with the weakest rock being a compaction, nonbedded shale called indurated clay. Since most of the area was in the influence of the glaciers and a part of it was glacier covered, many of the stream valleys were downcut to their greatest extent by melt-water runoff during glacial times. Now most of the major streams are flowing in alluvium-filled valleys. These valley bottoms range from 5,000 feet wide in the major rivers to less than 700 feet in width in tributary streams.

The distinctive features of some of these faults caused a new look at the whole valley section. The first feature outside of the faulting was the well-developed fracture or joint system that was evident on valley side outcrops. These outcrops usually comprise only about 1 to 2 percent of the area. This fracture system consisted almost entirely of vertical fractures with the most prominent set paralleling the valley walls. This fracture system according to students of the Appalachian area represents a systematic regional pattern that reflects Tectonic or deep-seated stresses.

However, it became evident in continuing subsurface investigations that included a joint or fracture orientation survey by means of angle test borings drilled into the valley walls, that there was a definite bottom or diminishing frequency to this vertical fracturing system. This same type of investigations that included angle holes drilled into the valley bottom showed this systematic pattern of closely spaced fractures to be practically nonexistent and the valley bottom edge to mark the end of the systematic vertical joints. On inspection of large areas of valley bottom foundation rock after cleanup, this lack of systematic jointing or fracturing was startling.

The investigations of the valley bottoms showed that next to the faulted areas the chief defect is along bedding planes.

It seemed logical that there had to be a reason for similarity of foundation defects in the valleys of widely differing rocks and varying dimensions. It was noted that the phenomena of thrust faulting or compression break always occurred in the center of symmetrical valleys and are skewed in non-symmetrical valleys. When these faults were dug out, there was a bottom of thrust or broken area and the gouge zones developed into horizontal trending or bedding plane defects that sloped away from the broken area toward the abutments.

These bedding plane breaks in the valley bottoms were sometimes open or filled with gouge or mylonite depending

on the rock and amount of movement. It was also noted that the base of vertical fracturing or jointing in the abutment or valley wall areas usually ended at a horizontal gouge or mylonite zone. Studies of numerous geologic sections with good stratigraphic control showed almost always an upwarping or arching of the key beds toward the center of the valleys. If the beds were dipping across the valley, a slight flattening of the dip showed up.

In analyzing the types, depth and character of the valley bottom failures, it appeared that the rock across the valley bottom acted as a strut and the competency of this rock controlled the type and extent of bottom failure. A thick massive sandstone may have the competency to resist the tendency to break and only deform by arching, whereas a plastic yielding rock such as clay shale or indurated clay may break in a series of circular arc failures.

STRESS RELEASE CONCEPT

The concept of stress release in the valleys is as follows. The valley wall section because of its height usually contains rocks with differing strengths and competency, and when the valley is down cutting the stress inherent in the rock seeks to be released. This release takes place with the more elastic and plastic rocks yielding by stretching. The yielding continues until the rocks break, with the plastic rock failing in circular arcs and the elastic rock by vertical tension breaks. Next, as the more competent rocks are dragged along, they yield when their tensile strength is exceeded. Most of these breaks are vertical tension fractures with the major fracture face normal to the release of stress. If the valley wall is uniform, the fracture pattern is usually parallel with the valley. When side valleys intersect the main valley, the fracture pattern near the intersection will have a tangential direction. The spacing of these fractures is a function of the competency and thickness of the beds with shales having a fracture spacing as close as a few inches or less apart and sandstones or limestone spacing of up to 5 to 10 feet. The valley wall continues to yield under this process, until the mass of stressed relieved rock is large enough to confine the underlying rock.

As the mass of rocks moves out from the valley wall, the mass puts a compressive thrust on the rock that is strutting the valley bottom. When this compressive force exceeds the shearing strength of the rock, deformation takes place in the form of thrust faulting, or folding, and always by bedding plane breaks.

It was found that the depth of this deformation is the deepest in brittle rocks such as limestone and the shallowest in elastic or plastic rocks as clay shales or indurated clays.

In a foundation where the main valley is intersected by side valleys immediately upstream, the resultant stress was a function of the release of stress in two directions, with the broken or fractured area extending over much of of the valley bottom and some rotational movement apparent.

This release of stress has help in the normal geologic processes such as chemical and mechanical weathering, water loading and uplift pressure on the bottom rock with high water during time of flooding.

SUMMARY AND GEOLOGIC IMPLICATIONS

Erosional valley areas are now zones of weakness, with zones of unstressed rock. The question as to which, came first -- the zone of weakness or the valley or whether it is geologically, stratigraphically or structurally controlled is still a good question. It is apparent, however, that one of the chief forces in valley erosion and the rapid down cutting of valley is the degradation of the rock by stress release in both the valley walls and valley bottoms. This phenomenon of release of stress in the center of the valley gives a new dimension to the theory of valley development. There is also reason to believe that this release of stress in actuality is much deeper than the tens to hundreds of feet we have found. I feel that this stress may manifest itself to several thousand feet in depth or to at least several times the valley height and width.

It may be that areas of valley tend to propogate similar zones of weaknesses during geologic time particularly if the valleys are refilled with granular sediments. It is possible that this type of area would be self-perpetuating. I don't believe that the theory of stress release should be restricted to sedimentary flat lying rock and can be used in areas that have geologic deformation superimposed in the stratigraphy. With careful study, these areas of stress release can be determined. Preliminary work in other terrain indicates this phenomenon does occur.

Finally, when geologic studies of engineering sites are conducted under concept of stress release, they become more economical and simpler.

FIGURE 1. DIAGRAMMATIC SECTION SHOWING RELEASE OF STRESS AND TYPICAL BREAKING OF BRITTLE ROCK.

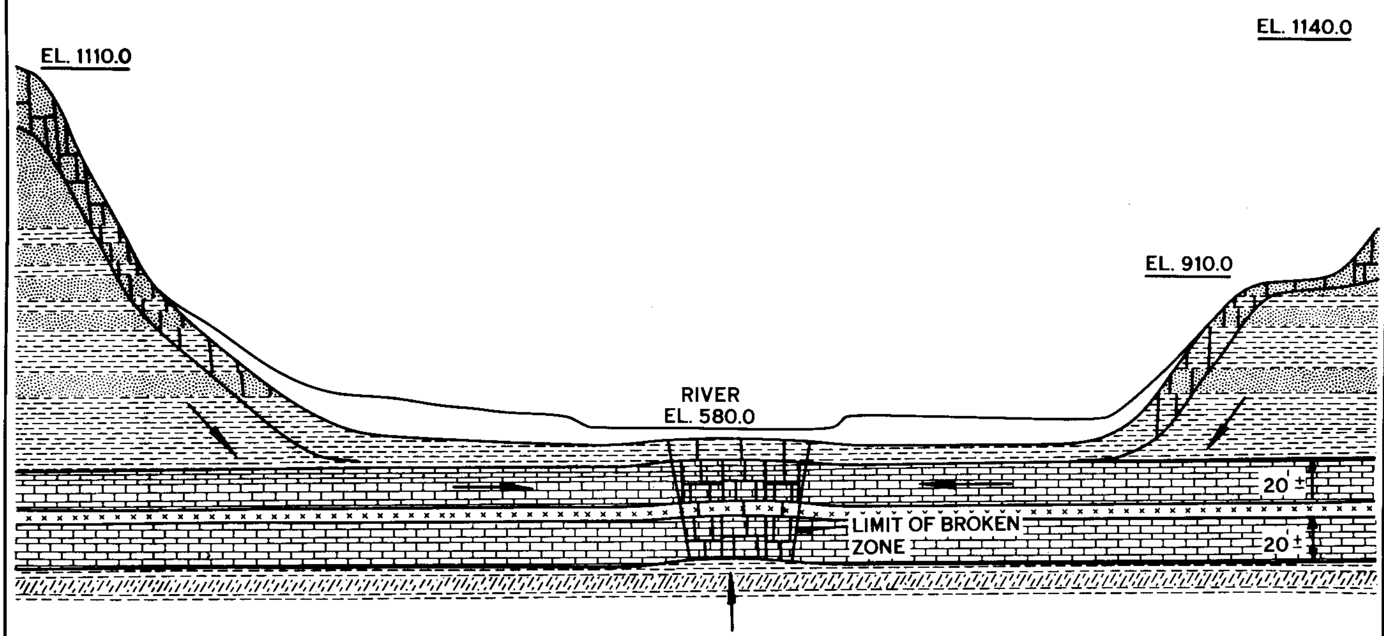


FIGURE 2. DIAGRAMMATIC SECTION SHOWING STRUTTING OF VALLEY BY COMPETENT ROCK AND TYPICAL FAILURE ARCHING.

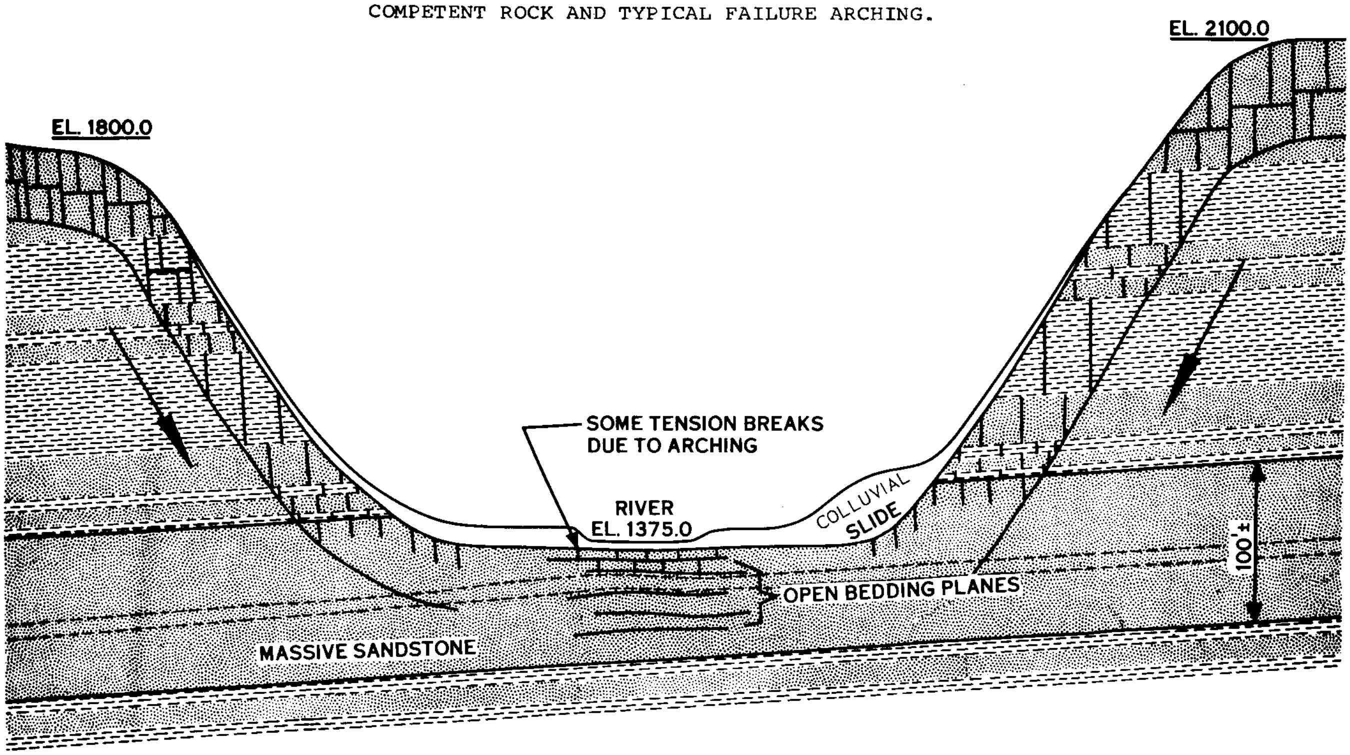
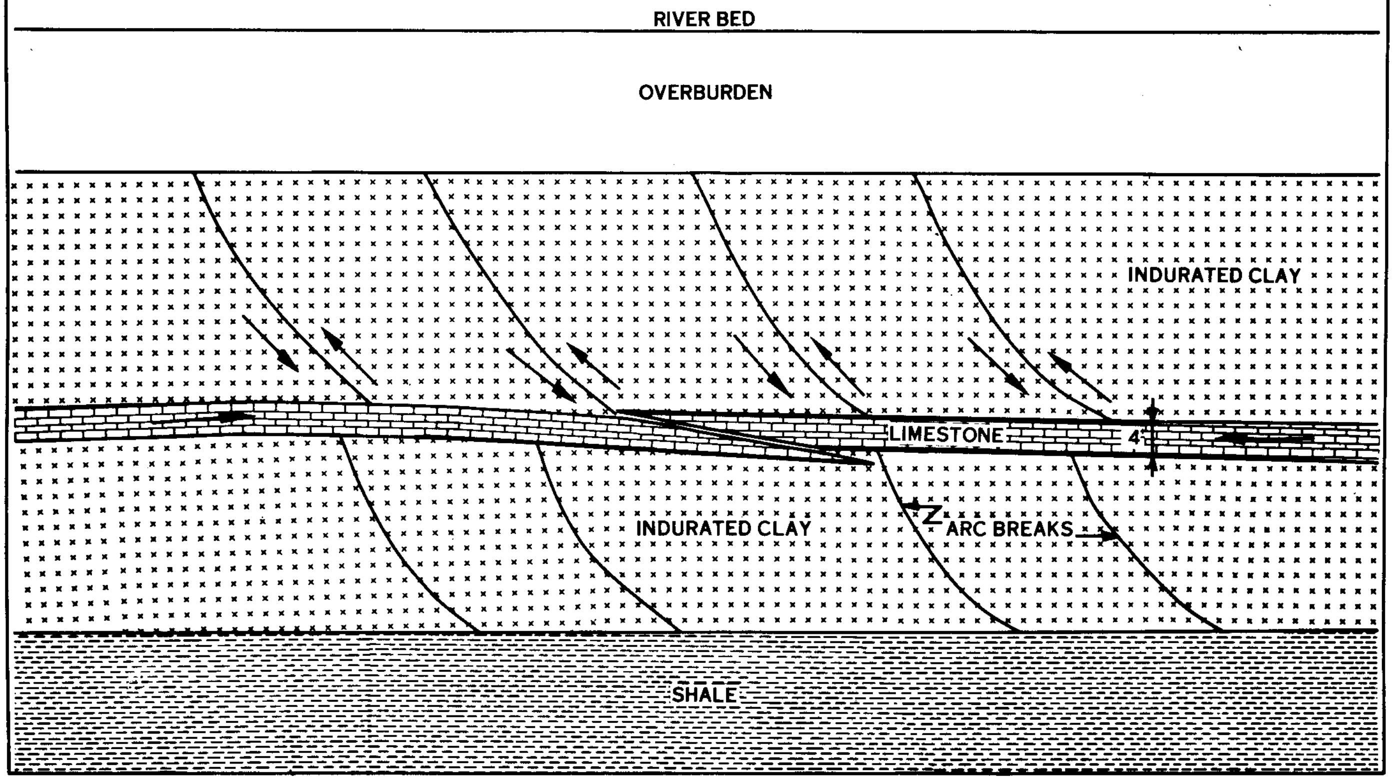


FIGURE 3. DIAGRAMMATIC SECTION SHOWING RELEASE OF STRESS AND BEHAVIOR OF A RIGID BED OF LIMESTONE BETWEEN TWO PLASTIC LAYERS IN THE CENTER OF A VALLEY.



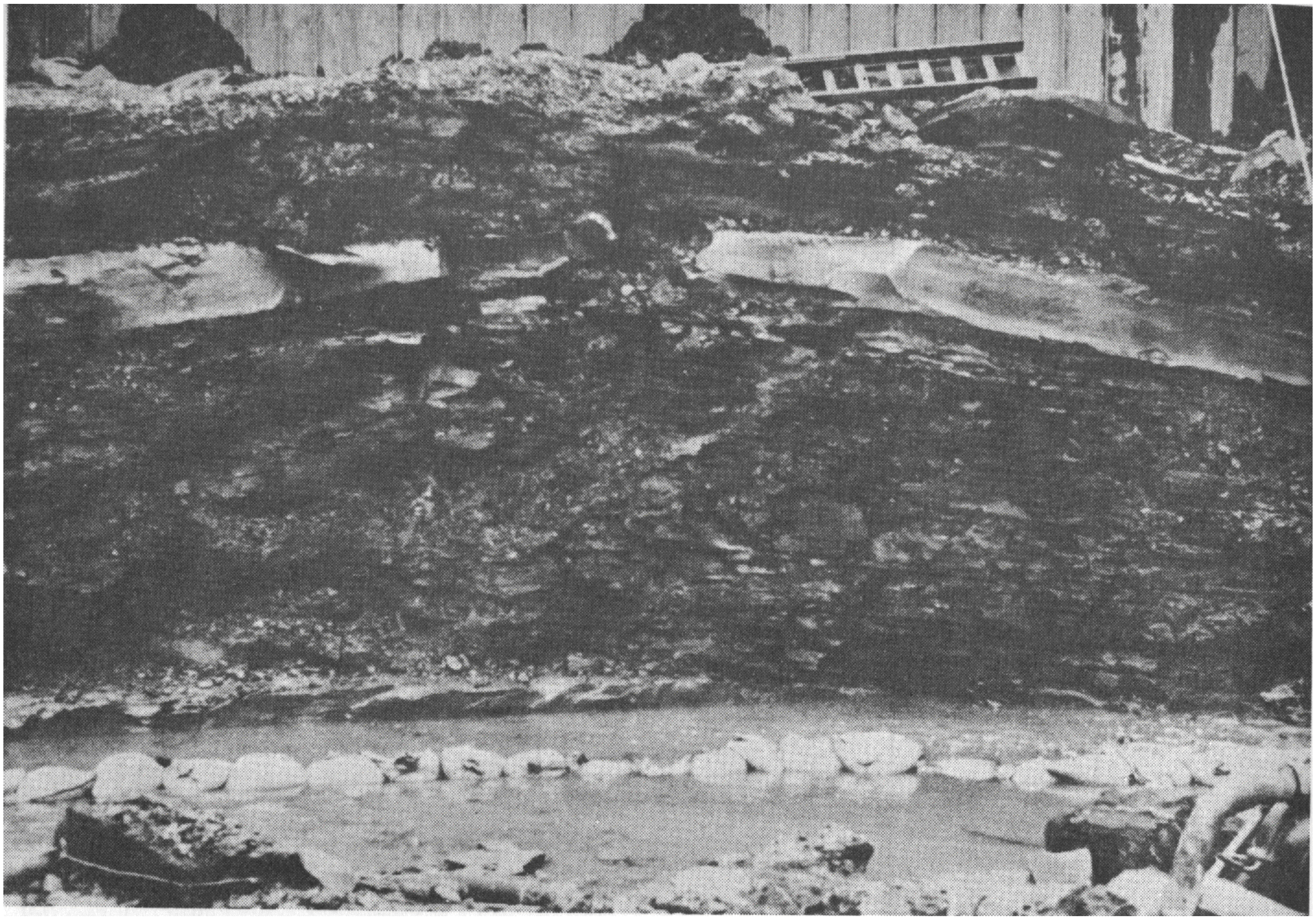


Figure 4. Arching and breaking of Devonian silty shale interbedded with thin sandstone beds in center of valley bottom.

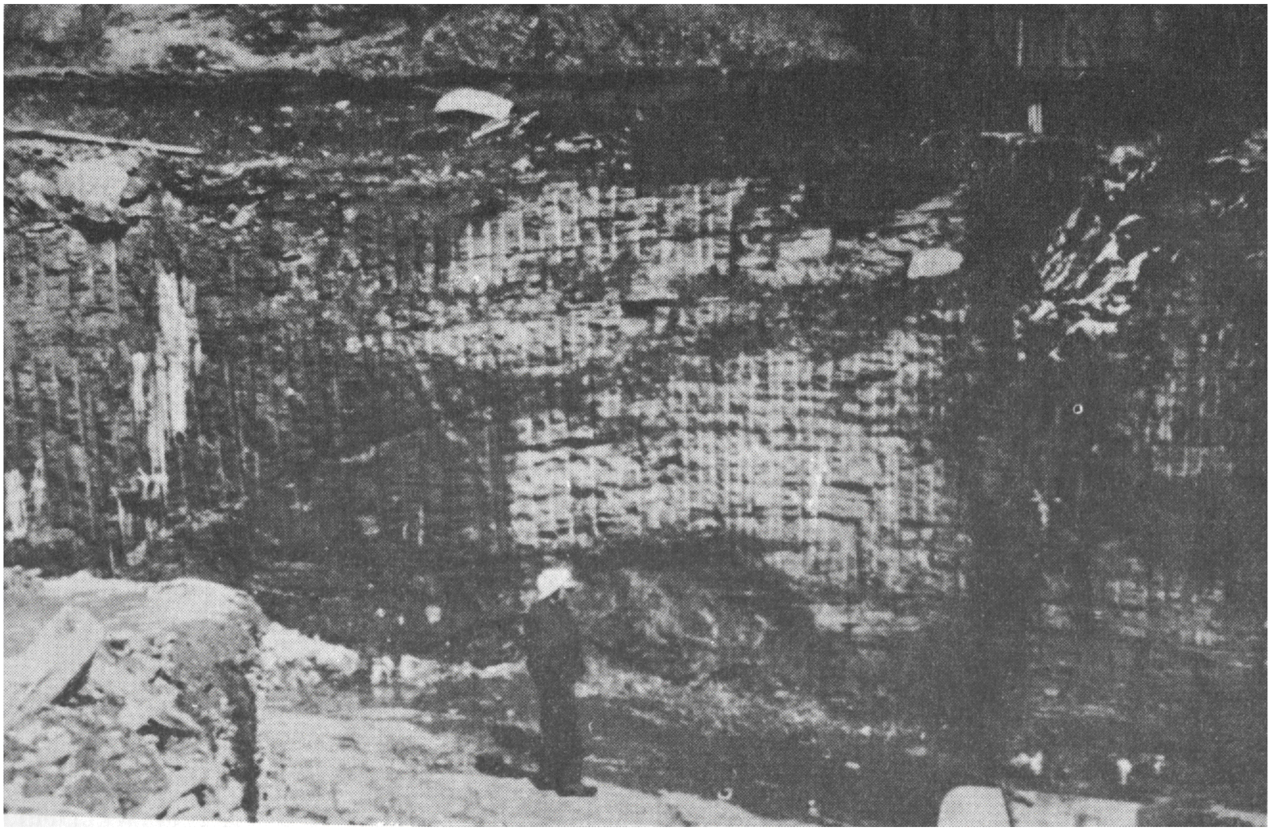


Figure 5. Arching and compression break in sandy silty shale located in center of valley bottom about 17001 from valley walls. Notice mylonite dipping away from center and continuity of beds over the broken zone.

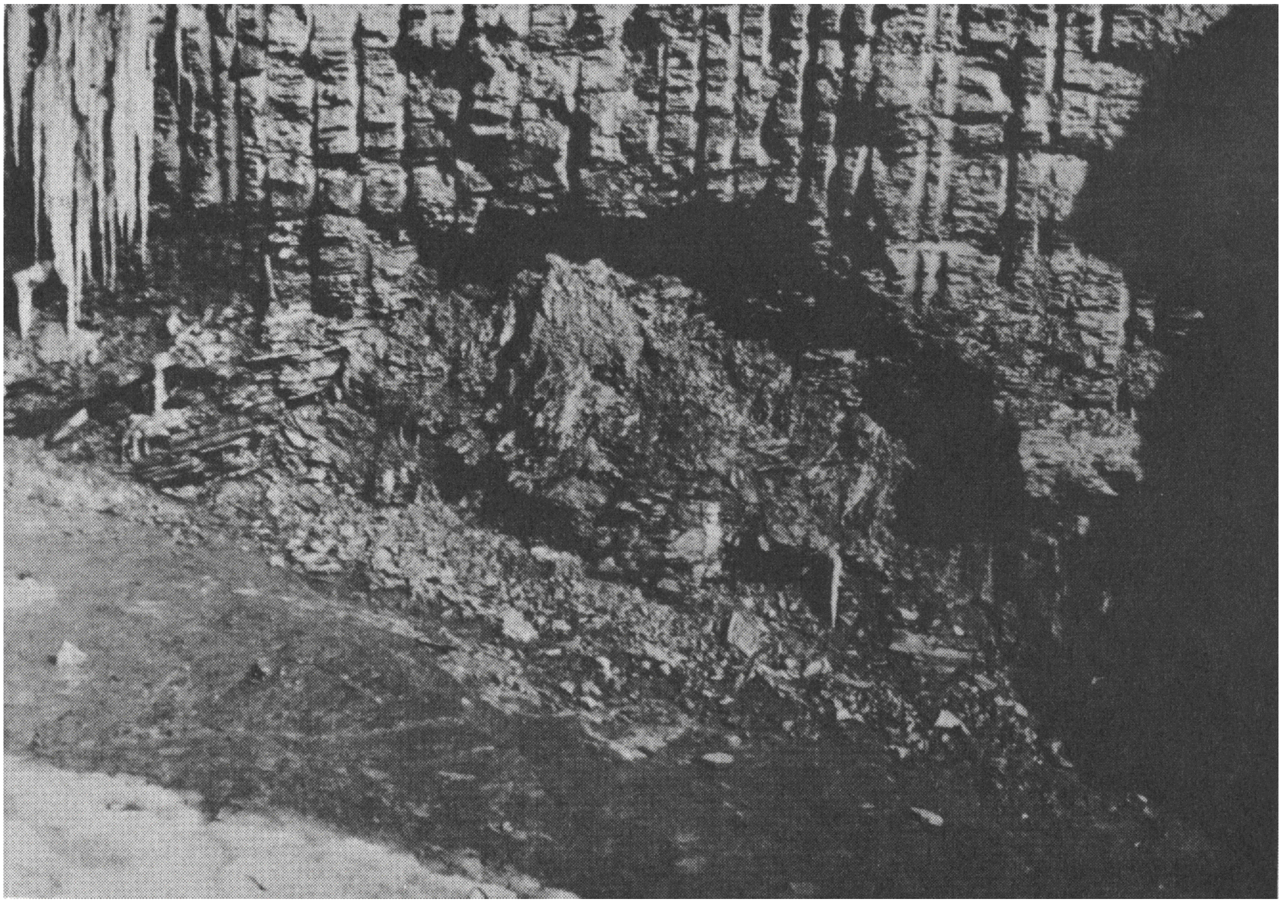


Figure 6. Close-up of broken area in center of figure 5.

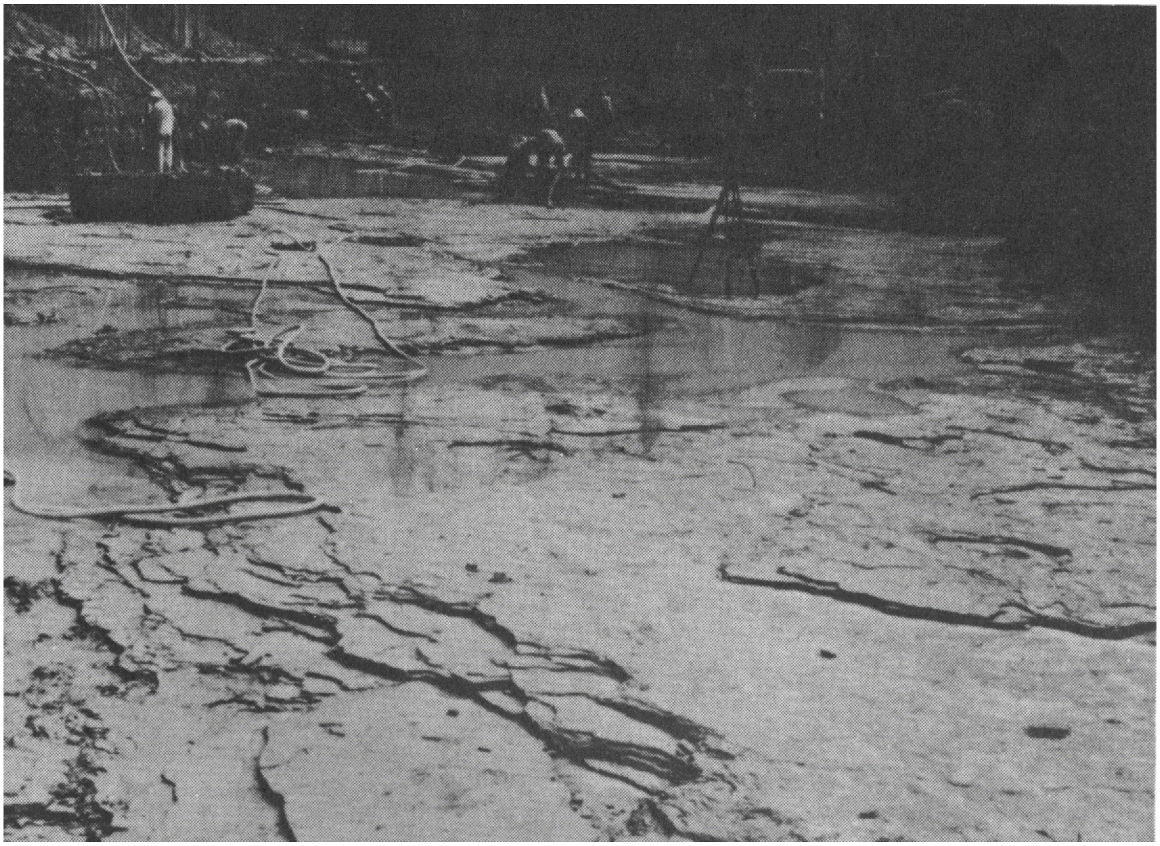


Figure 7. Area landward of broken area in figures 5 and 6.Systematic fracture pattern is absent.