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HYDROTECTONICS:

PRINCIPLES AND RELEVANCE

By

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ABSTRACT[1]

Hydrotectonics combines the principles of hydraulics and rock mechanics. The hypothesis assumes that: (1) no faults are truly planar, (2) opposing noncongruent wavy wallrock surfaces form chambers and bottlenecks along the fault, and (3) most thrusting occurs beneath the water table. These physical constraints permit the following dynamics.

Shear displacement accompanying faulting must constantly change the volume of each chamber. Addition of ground water liquefies dry fault breccia to a heavy incompressible viscous muddy breccia I call <u>fault slurry</u>. When the volume of a chamber along a thrust fault decreases faster than its fault slurry can escape laterally, overpressurized slurry is hydraulically injected into the base of near-vertical fractures in the otherwise impervious overriding plate. Breccia pipes commonly form where such fissures intersect.

Alternating decrease and increase in volume of the chamber subjects this <u>injection slurry</u> to reversible surges that not only raft and abrade huge clasts sporadically spalled from the walls of the conduit but also act as a forceful hydraulic ram which periodically widens the conduit and extends its top. If the pipe perforates a petroleum reservoir, leaking hydrocarbons float to its top.

Sudden faulting may generate a powerful water hammer that can be amplified at some distal narrow ends of the anastomosing plumbing system, where the shock may produce shatter cones. If vented on the Earth's surface, the muddy breccia, now called <u>extrusion slurry</u>, forms a mud volcano.

This hypothesis suggests that many highly disturbed features presently attributed to such catastrophic processes as subsurface explosions or meteorite impacts are due to the rheology of <u>tectonic slurry</u> in an intermittently reactivated pressure-relief tube rooted in a powerful reciprocating hydrotectonic pump activated by a long-lived deep-seated thrust fault.

[1]Reproduced from Eos (American Geophysical Union Transactions), v. 62, no. 45, p. 1047, Nov. 10, 1981.

The following paper, amplifying the subject presented in the above abstract, was read at the Fall Meeting of the American Geophysical Union, Holiday Inn, San Francisco, 15:30, Dec. 10, 1981. Additions are indicated in brackets:

HYDROTECTONICS: PRINCIPLES AND RELEVANCE

Welcome to my wonderful world of hydrotectonics!

The hydrotectonic hypothesis combines the principles of fluid and rock mechanics. It is based on several assumptions. Perhaps the most important is that, contrary to the shape implied by the popular term "fault plane," no faults are <u>truly</u> planar.

SLIDE 1

How undulatory can thrust faults be?

This fenster in the Amargosa Chaos in Death Valley exposes crests of the highly wavy Amargosa thrust fault. My 6-foot tall son stands on the nearest crest. The surface is underlain by homoclinally dipping volcanic rocks that dip gently to the right.

If these bumps were the crests of later anticlines, as has been suggested, the immediately underlying strata would also be folded, <u>not</u> homoclinal. Therefore, this fault surface represents the exhumed part of a thrust fault that <u>must</u> have been this highly undulatory <u>during</u> thrusting [Kopf, 1970].

SLIDE 2

What is the effect of shear displacement on a fault having opposing wavy surfaces such as these?

SLIDE 3

This laboratory model represents the cross section of two hypothetical deep-seated impervious thrust plates separated by a wavy thrust fault. Both plates are in a narrow tank. The upper plate is weighted with lead implants to simulate the lithostatic load of overlying rocks. A 14-cm-long hollow glass tube penetrates the upper plate. A clear viscous fluid occupies the fault. This fluid also occupies the tube but is dyed red for contrast.

The upper plate will be slowly pulled to the right. Note the fluid level in the tube before thrusting.

SLIDE 4

With 2 cm horizontal displacement, the fluid level falls <u>6</u> cm!

SLIDE 5

With 1 cm renewed displacement, fluid level returns half-way up the tube!

SLIDE 6

With 3 cm renewed displacement, the tube is completely evacuated, and air is being sucked into the underlying chamber!

SLIDE 7

At the end of the experiment, the fluid level is 2 cm higher than when we began!

This experiment suggests that:

SLIDE 8

Opposing undulatory walls of any fault produce chambers and bottlenecks. Shear displacement along wavy surfaces causes the volume of these chambers alternately to expand and contract. In other words, faulting can create a powerful subsurface reciprocating pump! In order to equalize the lithostatic pressure between thrust plates, incompetent rocks in a fault breccia are normally squeezed, like toothpaste, from a contracting chamber (upper left) into the nearest expanding chamber (upper right).

However, when a chamber expands faster than breccia can flow into it (lower right), pressure within the chamber must decrease. Since most thin-skinned thrust faulting occurs beneath the water table, water in adjacent plates presumably flows through pores and fractures in the wallrocks and into this chamber to restore the normal hydrostatic head. Addition of water to the chamber liquifies the dry fault breccia and gouge and increases its volume. I call this muddy fault breccia fault slurry to emphasize its fluid behavior.

So shouldn't this water be squeezed out when the same chamber contracts?

When a partly sealed chamber contracts (lower left), the fluid pressure of the slurry must increase. Since rocks cannot pass through a hole of smaller size, the various-size rock particles suspended in the pressurized slurry act as a filter cake that immediately plugs up leaks in the walls of the chamber. Therefore, slurry acts as a one-way valve. I repeat, slurry acts as a one-way valve: it allows pressurized water readily to enter the fault but, once converted to slurry and pressurized, hampers escape of both water and slurry. Slurry converts the reciprocating hydraulic pump to a powerful bellows that pumps water into the fault. Excess slurry is squeezed along the fault till the upper plate essentially floats on an incompressible layer of slurry, a sort of tectonic banana peel that lubricates the fault [Kopf, 1979a].

However, if the edges of a chamber that has acted as a bellows are completely plugged, its fluid pressure may rise so high that the pressure finally may greatly exceed the weight of the overlying rocks. Therefore, to relieve this anomalously high fluid pressure, part of the overpressurized slurry may locally be hydraulically injected upward into the base of steep fractures in the otherwise impervious upper plate to form breccia dikes. Breccia pipes form where near-vertical fractures intersect. The fluid pressure may be so great as to squeeze apart the confining walls. I call this fluidized breccia injection slurry [Kopf, 1979b].

SLIDE 9

Upward injection continues until the anomalously high fluid pressure in the underlying chamber returns to normal. Later, when the fluid pressure in the chamber is reduced, the injection slurry becomes partly withdrawn.

As you saw just a moment ago, alternating decrease and increase in volume of the underlying chamber acts as a powerful reciprocating hydraulic pump that now converts the pipe to a pressure-relief tube. The pump subjects the injection slurry to reversible surges that cause the top of the pipe to grow upward. As the pipe lengthens, the long column of heavy incompressible block-bearing mud in the pipe begins to act as a powerful hydraulic ram [Kopf, 1980; 1981]. Since the great inertia of the upper plate acts as an anvil, we now have a classic example of an irresistible force penetrating an immovable object. The resulting shock at the top of the pressure-relief tube shatters adjacent brittle rocks into shatter cones, expands its diameter, and forms the focus of an earthquake. Excess inertia will cause the top of the pipe to be extended upward. Renewed reversible surges cause the hydraulic ram to behave like an upside-down pile driver that squeezes apart the inner walls of the pipe and again converts the new top of the pipe to a shock tube where new shatter cones may form [Kopf, 1981].

SLIDE 10

If injection slurry perforates the entire upper plate, this muddy breccia is vented on the Earth's surface as a mud volcano, which I call extrusion slurry. This mud volcano, on the Island of Trinidad, is one of a cluster of mud volcanoes [Higgins and Saunders, 1974], all of which I consider to be of hydrotectonic origin. In New Zealand, Ridd (1970) recorded the eruption of a similar mud volcano on North Island on February 3, 1931, the same time as the nearby disastrous Hawke Bay earthquake. That mud volcano lies on the trace of a steep fault which, I suggest, is bottomed in an active thrust fault.

SLIDE 11

This is Pierce's (1979, fig. 9) illustration of a typical breccia dike rooted in fault breccia along the Heart Mountain fault, Wyoming.

SLIDE 12

A polished specimen of such a dike (Pierce, 1979, fig. 18) reveals a good example of laminar flow, a flow characteristic of such viscous fluids as injection slurry.

SLIDE 13

This is Sage's (1979, fig. 6) illustration of size gradation of clasts within and parallel to the walls of a clastic dike on the Slate Islands, Lake Superior. This is another example of emplacement by a viscous fluid that underwent laminar flow.

SLIDE 14

These shatter cones are associated with Sage's breccia dikes. Shatter cones have been considered by some workers to be diagnostic of meteorite impact. However, there is no evidence of a meteorite impact on the island, but ample evidence of fluid injection.

The stronger and heavier the walls of the pump, the more powerful the surges that can be generated. The thick supposedly stable cratonic parts of continental plates are ideal candidates for certain types of hydrotectonic pressure-relief tubes. For example:

SLIDE 15

Upheaval Dome is about 35 km SW of Moab in southeastern Utah. It is a breached dome in otherwise flat-lying strata that reveals an essentially circular disturbed area about 3 miles (5 km) in diameter. The core consists of highly disturbed Permian strata that have been displaced upward more than 1,200 feet. Surrounding the core is a ring-shaped syncline composed of less disturbed Triassic and Jurassic strata.

This and similar features presently recognized in every continent have been explained in such diverse ways as the roof over a salt plug, a cryptoexplosion structure over a deeply buried igneous plug, and the scar of a meteorite. Obviously not all breccia-filled pipes are a result of any single geologic process. However, I interpret injection slurry, and its disturbed wallrocks such as these, as evidence of an underlying regional thrust fault or decollement. [See companion paper by Reidel (1981) on probable hydrotectonic origin of a similar structural feature, the Serpent Mound disturbance, Ohio]

Strangely enough, the Wingate Sandstone, one of the most tectonically competent rocks in this disturbance, is only about 100 feet thick, less than one third its normal thickness in the immediately surrounding area [Mattox, 1975, p. 226, 231]! Similar anomalous stratigraphy is recorded in the wallrocks of Sierra Madera, Texas, Jeptha Knob, Kentucky, and many other disturbances. What causes certain strata locally to become anomalously thicker or thinner millions of years before it is penetrated by the disturbance?

The anomalous stratigraphy seen in the wallrocks of these and other disturbances appear to constitute preserved parts of a geologically long-lived seismogram that has recorded the times, type, rate, and intensity of the deformation of the Earth's surface in response to sporadic reactivation of the directly underlying pressure-relief tube long before the tube finally penetrated that record. The stratigraphic seismogram appears to reflect periods of unusually high activity of the directly underlying pressure-relief tube and, therefore, of the sole in which it is rooted.

But what driving mechanism can create a decollement that can remain active for such long periods of geologic time? The only mechanism I know is plate tectonics. Do the records of these stratigraphic seismograms in nearby hydrotectonic pressure-relief tubes correlate temporally? I don't know. But if they do, they constitute evidence not only that the entire plate is underlain by a near-horizontal long-lived decollement in which sedimentation on its upper surface throughout the Phanerozoic has recorded its repeated deformations but also that, millions of years from now, continuing movement of the continental plates will most assuredly reactivate some of these pressure-relief tubes!

These tubes constitute evidence not only that the entire continental plate is underlain by a near-horizontal thrust fault but also that the record of many former surges within the tube have deformed the surface topography above the tube, as revealed by anomalously thicker or thinner strata before burial under additional strata, after which the strata were penetrated by the rising top of the pipe.

SLIDE 16

The following table, which presents criteria considered evidence for the hydrotectonic origin of so-called "cryptoexplosion structures" and tectonically related features, can be used as a checklist:

Table 1. Evidence for hydrotectonic origin of so-called "cryptoexplosion structures"

Part I. Geologic features that are commonly present (Hydrotectonic explanation given in parentheses)

A. Regional	1. Commonly miogeoclinal deposits (Record times in which surface of laterally moving continental plate sank below sea level)
B. Local	1. Strata deformed into concentric ring-shaped anticlines and synclines (Represent repeated failure of walls of pipe when the fluid pressure of its contents repeatedly exceeded the strength of its conduit) 2. Commonly occur at intersection of fissures, faults, and (or) fold axes (Represent structural flaws in upper plate) 3. Laminar flow (A flow characteristic of slurry) 4. Deformation increases toward center and upward (Direction of maximum hydraulic pressure during injection) 5. Presence of breccia or pebble dikes (The now-solidified former injection slurry; "pebbles" result from repeated exfoliation of outer surfaces of brittle angular clasts during sudden decompression, such as by a sharp drop in fluid pressure of injection slurry) 6. Presence of shatter cones (Failure of rocks when subjected to rapidly expanding compression and rarefaction waves accompanying shock triggered by a hydrotectonic ram) 7. Reactivation of injection and (or) extrusion slurry (Renewal of reversible surges) 8. Anomalous thickness of some strata forming wallrocks (Stratigraphic seismogram) 9. Ductile and brittle deformation (Each reflects varying rates of deformation and amount of confining pressure) 10. Absence of thermal metamorphism (No igneous activity; however, great compression may conceivably cause shock melting deep beneath the Earth's surface) 11. May contain clasts of great upward and (or) downward stratigraphic displacement (Sudden drop in confining pressure on deep-seated walls of pipe, such as by sharp reduction in fluid pressure of its contents, may cause huge parts of the conduit to spall into the injection slurry; these clasts are then effortlessly rafted vertically in response to the reversible surges that the injection slurry then undergoes)
C. Petrology	1. Tectonic melange (Blocks, derived from tectonically more competent rocks, are embedded in matrix derived from tectonically less competent rocks; both constitute "ghosts" of preexisting imbricate thrust plates of varying lithic composition and structural competence that had been displaced between wavy walls of a deep-seated thrust fault (Kopf and Bailey, 1976) and may have been injected into the overriding plate; such rocks are

lithotectonic units and their origin should not be confused with that of any of their tectonic protoliths)

2. Fine-grained clastic rocks (Muddy matrix of the slurry; may have been called pseudotachylite)

D. Mineralogy	1. May form site for mineral deposits, including hydrocarbons, sulfides, fluorite, and high-pressure minerals (Tectonism acts as a mill; it fractures, rotates, and crushes rocks, increases their surface area, then leaches their outer surface by aqueous fluids in which the clasts are immersed -- fluids whose pressure may fluctuate greatly and rapidly. Finally, the mineralized fluid is pumped into a new chemical environment where some of its minerals are now precipitated. Other minerals, such as diamond, stishuvite, and coesite, are presumably formed under anomalously high hydrotectonic compression)
E. Vertical zoning of minerals and mixtures in pipes	1. Crosscutting relations (Caused when part of a column of partly solidified injection slurry is fluidized and replaced by a vertical surge of injection slurry containing different mixtures of rocks and minerals. This results in a clastic pipe forming within a clastic pipe. As many as 15 crosscutting relations (termed "eruptions" by Moulle, in Wagner, 1914, p. 37) have been recognized in the Kimberley diamond pipe. Elsewhere, the vertical pipe may also act as a fractionation tower, in which heavier minerals will sink and lighter compounds, such as hydrocarbons (Parson, 1974; Parson and others, 1980), will collect at its top)

Part II. Geologic features that are not found

Meteorites
Objective evidence of one or more explosions

To sum up; the hydrotectonic pump converts horizontal motion to vertical motion. Since slurry is virtually incompressible, excess fault slurry is converted to injection slurry. If it penetrates the entire plate, it forms extrusion slurry. I suggest to you that the process appears to have left revealing clues that will help date the tectonism that produced these disturbances.

I will make myself available for nonviolent discussions in the vestibule after the next paper.

Thank you.

DISCUSSION

Q: If I understand you correctly, you are proposing the existance of a low angle fault under Upheaval Dome, which is in the Colorado Plateau. Do you consider this fault to be above or below the Permian evaporites?
A: I consider the entire Colorado Plateau to be underlain by a fault. Based on exposures in the Grand Canyon and elsewhere, I suspect that the fault must well underlie the top of the Precambrian.
Q: You might be interested in Prodehl's (1979) interpretation of geophysical data as indicating the presence of a flat velocity zone boundary under the Colorado Plateau at about 40 km below sea level.
A: Thank you. I wasn't aware of that paper. I also hope the surface isn't absolutely flat.
Q: Your hypothetical mechanism suggests a method for triggering earthquakes. Do you know of any way that such earthquakes can be predicted?
A: I'm afraid I can't answer that question.

The next paper, entitled "The Serpent Mound disturbance, south-central Ohio: An example of hydrotectonics?", was read by Stephen P. Reidel (see Reidel, 1981).

GLOSSARY OF HYDROTECTONIC NOMENCLATURE

antimorph -- a smoothly curved arch-shaped surface of part of an undeformed thrust fault. Commonly misinterpreted as part of a once-planar thrust fault that had been folded, that is, "warped" or "deformed," into an anticline. Usually exposed in fensters. Turtlebacks in Death Valley, Calif., are interpreted as exhumed antimorphs (Kopf, 1970; Kopf and Bailey, 1976). Typical examples of antimorphs include a cluster of about 12 small turtlebacks, some of which are seen in slide 1, and which are exposed in NW1/4SE1/4 sec. 8, T. 21 N., R. 3 E., about 1½ km NNE. of the former site of the Ashford Mill, Confidence Hills 15-minute quadrangle. See also synmorph.

extrusion slurry -- a tectonic slurry that has been extruded onto the Earth's surface as a mud volcano or mudflow. Constitutes one of three types of tectonic slurry in the hydrotectonic hypothesis (Kopf, 1979b, 1981).

fault slurry -- a more or less muddy fault breccia that has undergone liquefaction during faulting. Believed to constitute an effective lubricant that overcomes friction between opposing walls of a fault. Considered to be one of three types of tectonic slurry in the hydrotectonic hypothesis (Kopf, 1979a, b, 1981).

hydrotectonic bellows -- a powerful subsurface tectonically activated bellows that pumps Newtonian fluids, such as water or oil, into the sole of an active fault; its origin is attributed to the ability of tectonic slurry to behave as highly efficient one-way valves that, while closed, convert a hydrotectonic pump whose walls are highly permeable to Newtonian fluids to a bellows whose walls are highly impermeable to both Newtonian and non-Newtonian fluids. See hydrotectonic pump.

hydrotectonic filter cake -- part of a tectonic slurry, consisting of densely packed but nonindurated rock particles of unsorted size and shape, that contains more than a few percent by volume of rock flour, and whose interstices are filled with mud. It clogs pores and narrow fractures which act as a filter. It forms whenever the fluid pressure of tectonic slurry is greater than that of fluid in adjacent pores and fractures. Increase in fluid pressure of the slurry only increases the pressure gradient across the cake; this increase in gradient, in turn, increases the degree of packing between the grains and sharply decreases the permeability of channelways clogged by such a cake to all fluids, Newtonian and non-Newtonian. The cake disintegrates whenever the fluid pressure gradient in the cake is reversed, that is, when the fluid pressure of slurry is considerably less than that of the fluid occupying the channelways; this ability of tectonic slurry to alternately form and disintegrate a hydrotectonic cake when the slurry undergoes great fluctuations in fluid pressure causes it to act as temporary but highly efficient one-way valves that can repeatedly convert a hydrotectonic pump into a hydrotectonic bellows and back again.

hydrotectonic hypothesis -- a hypothesis that applies the principles of fluid and rock mechanics to tectonism. It assumes that; (1) no faults are truly planar, (2) noncongruent undulatory wallrock surfaces form chambers and bottlenecks along the fault, and (3) most thrust faults occur beneath the water table. The hypothesis states that, during shear displacement between opposing undulatory wallrocks, each chamber alternately expands and contracts. During expansion, addition of ground water into the chamber liquefies dry fault breccia and converts it to fault slurry. This viscous fluid is then pumped along the fault so as to more nearly equalize the fluid pressure between the plates. If a chamber along a thrust fault contracts faster than its fault slurry can escape laterally, the fluid pressure of the slurry may increase to such a degree that excess slurry is injected into the base of fractures in the overriding plate, where it is called injection slurry. Breccia pipes commonly form where these near-vertical fracturs intersect. Continued faulting may cause the injection slurry to undergo reversible surges. This converts the pipe to a pressure-relief tube. If the injection slurry perforates the entire upper plate, excess slurry is vented on the Earth's surface as extrusion slurry in the form of mudflows and so-called mud "volcanoes" (Kopf, 1981). Indurated hydrotectonic units commonly form lithotectonic units (which see).

hydrotectonic pressure-relief tube -- a near-vertical more or less cylindrical conduit or pipe cutting the upper plate of an active thrust fault and containing injection slurry. Believed to have formed by injection of pressurized tectonic slurry from an underlying thrust fault into leaks in the overriding plate so as to reduce that anomalously high fluid pressure. Changes in volume of a slurry-filled chamber in which the conduit is rooted may subject the injection slurry to reversals of flow direction in the conduit, causing the pipe to act as a pressure-relief tube (Kopf, 1979b, 1981). Forms clastic pipes. See hydrotectonic hypothesis.

hydrotectonic pump -- according to the hydrotectonic hypothesis, chambers produced by opposing walls of a nonplanar deep-seated fault alternately increase and decrease in volume during shear displacement of its undulatory wallrocks. The mechanism mimics the chambers of a rotary engine except that the chambers, instead of being arranged cylindrically, are arranged along an imaginary more or less planar surface (Kopf, 1979b, 1980, 1981).

hydrotectonic ram -- the sudden change from kinetic to potential energy when a long rising column of heavy relatively incompressible injection slurry undergoing reversible surges strikes the closed top of its near-vertical conduit (Kopf, 1980, 1981).

stratigraphic seismogram -- strata forming the walls of a hydrotectonic pressure-relief tube whose thickness, presence, or absence is markedly different from the same part of the stratigraphic section in the same locality but more distant from that conduit; interpreted as evidence that a hydrotectonic pressure-relief tube, whose top at one time underlay an ancient land surface at shallow depth, had been reactivated so as to deform that land surface and that, after modification of that surface and burial under younger strata, that surface and its underlying and overlying strata were finally perforated by the rising top of the tube during yet another reactivation. This evidence appears useful in determining: (1) whether the deformation of the land surface was in the form of uplift or subsidence, (2) the amount of deformation, (3) the geologic age of the deformation of that surface, and (4) whether or not additional periods of deformation can be recognized and, if so, the period(s) of geologic time during which younger strata remained undisturbed. The term is chosen to signify the apparent record left in stratified rocks of repeated hydrotectonic disturbances. Example: the anomalous thickness of the Wingate Sandstone in Upheaval Dome, Utah.

hydrotectonic shock tube -- conversion of the top of a hydrotectonic pressure-relief tube to a shock tube; believed to occur when a rising column of injection slurry fills a temporary void at the top of a hydrotectonic pressure-relief tube so as to develop water hammer in the slurry.

injection slurry -- one of three types of tectonic slurry that, during faulting, is injected into near-vertical fractures. Slurry-filled pipes are believed to commonly form where these fractures intersect. Continued faulting may cause the injection slurry to undergo reversible surges (Kopf, 1979b, 1981). See hydrotectonic hypothesis.

lithotectonic unit -- a three-dimensional mappable body of rock that has been mechanically fragmented, mixed, and transported at or beneath the Earth's surface. Class of rocks (sedimentary, metamorphic, or igneous) commonly misidentified on basis of correct identification of class, origin, and age of one or more of its tectonic protoliths. Example: melange, chaos, kimberlite.

slurry hammer -- shock believed to result when a long rising column of heavy incompressible injection slurry strikes the closed top of a deep-seated near-vertical pipe, thereby converting the top of the tube into a shock tube. Shatter cones may have formed by this mechanism (Kopf, 1980).

synmorph -- a smooth trough-shaped part of an undeformed undulatory thrust fault. Commonly misinterpreted as part of a once-planar thrust fault that had been deformed into a syncline. Typically covered by erosional remnants of the upper plate (Kopf and Bailey, 1976). See also antimorph.

tectonic slurry -- a tectonic breccia that has undergone liquefaction owing to viscous flow of its matrix, commonly more or less muddy breccia, and in which faulting or landsliding causes it to undergo differential changes in fluid pressure so as to flow. A prime material component of the hydrotectonic hypothesis. Divisible into three types: fault slurry, injection slurry, and extrusion slurry (Kopf, 1981, 1982).

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I am grateful to the following persons who expressed interest in the application of the hypothesis to their field of interest: to Kim Kastens, of Columbia University, in the origin of a mud cone on the floor of the eastern Mediterranean Sea; to P. A. Lilly, in deficiencies of previous interpretations concerning the origin of the Vredefort structure, South Africa; to S. M. Zand, in assessing previous interpretations concerning the origin of clastic pipes in part of the Delaware Basin, New Mexico; and to Stephen P. Reidel, in the probable application of the hypothesis to the Serpent Mound disturbance, Ohio.

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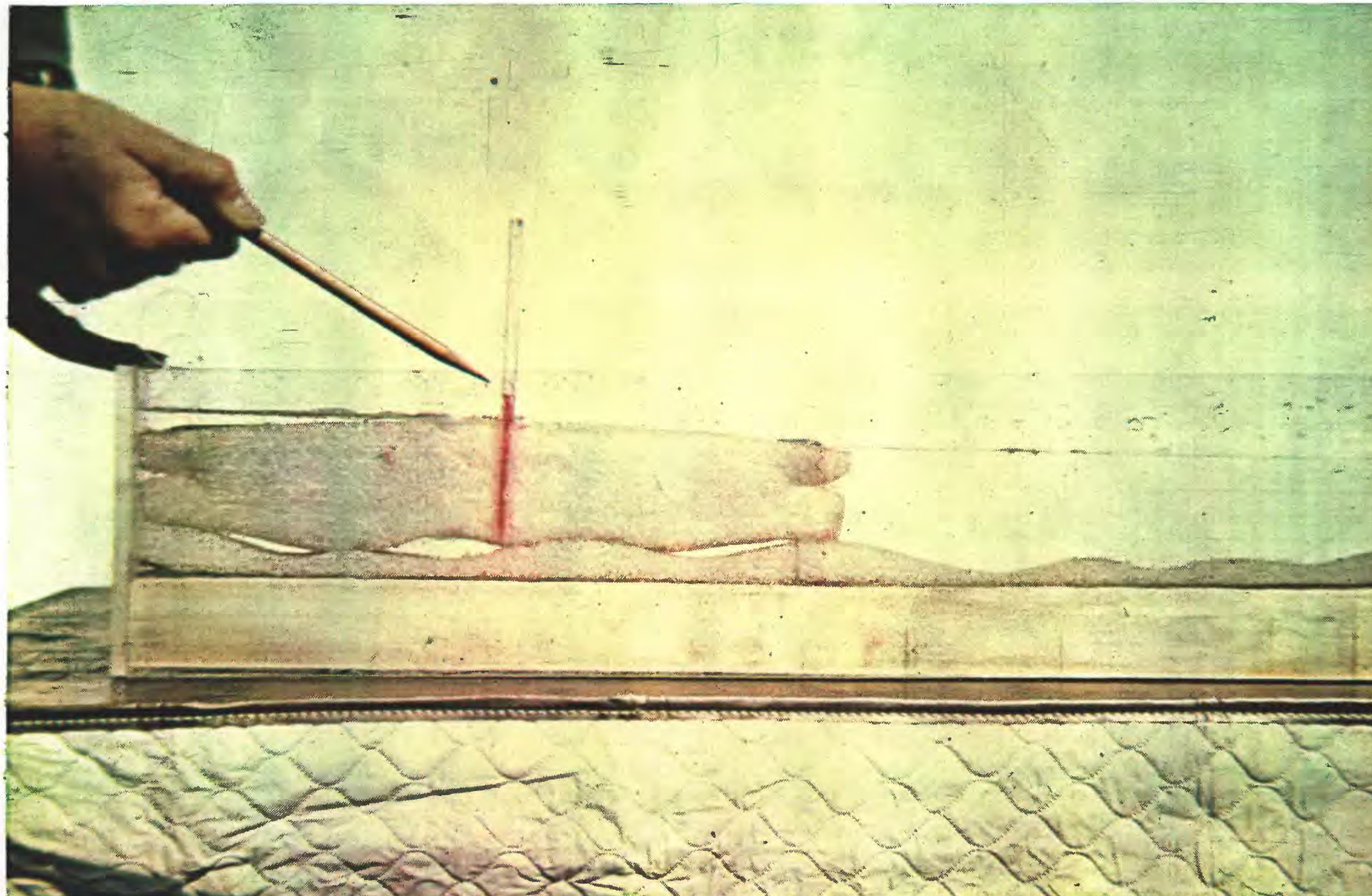
Slide 1

Slide 2



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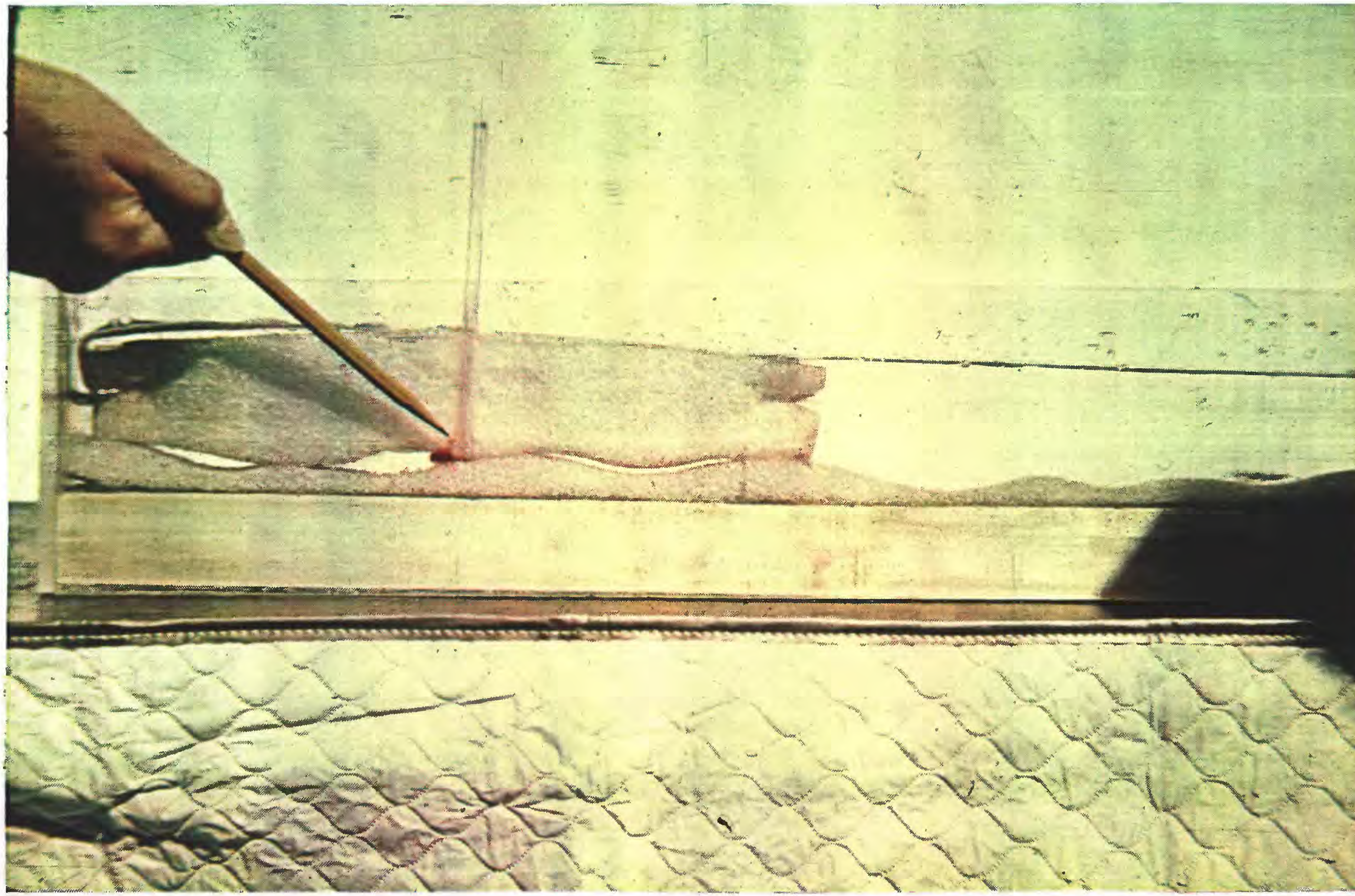

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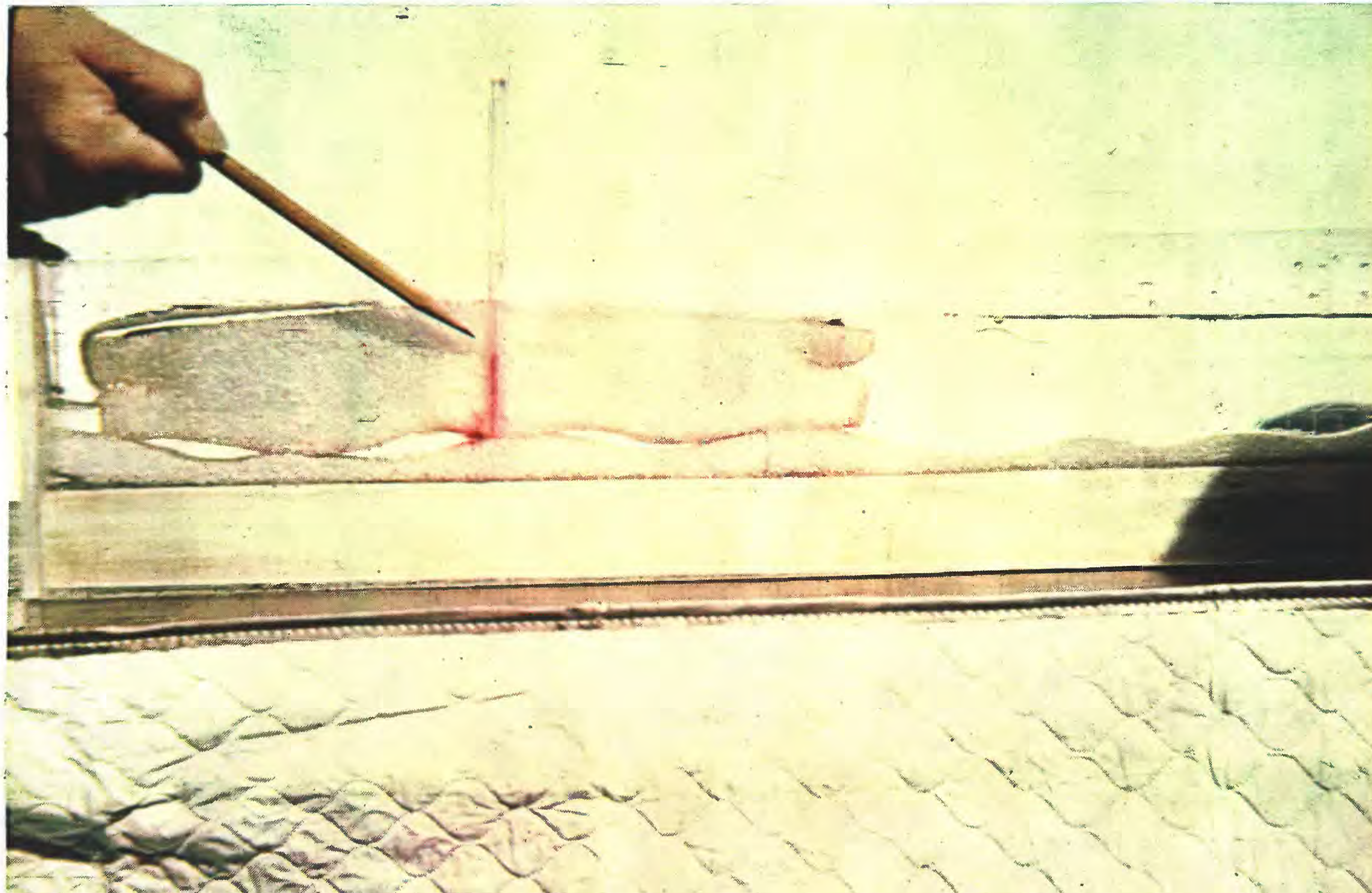

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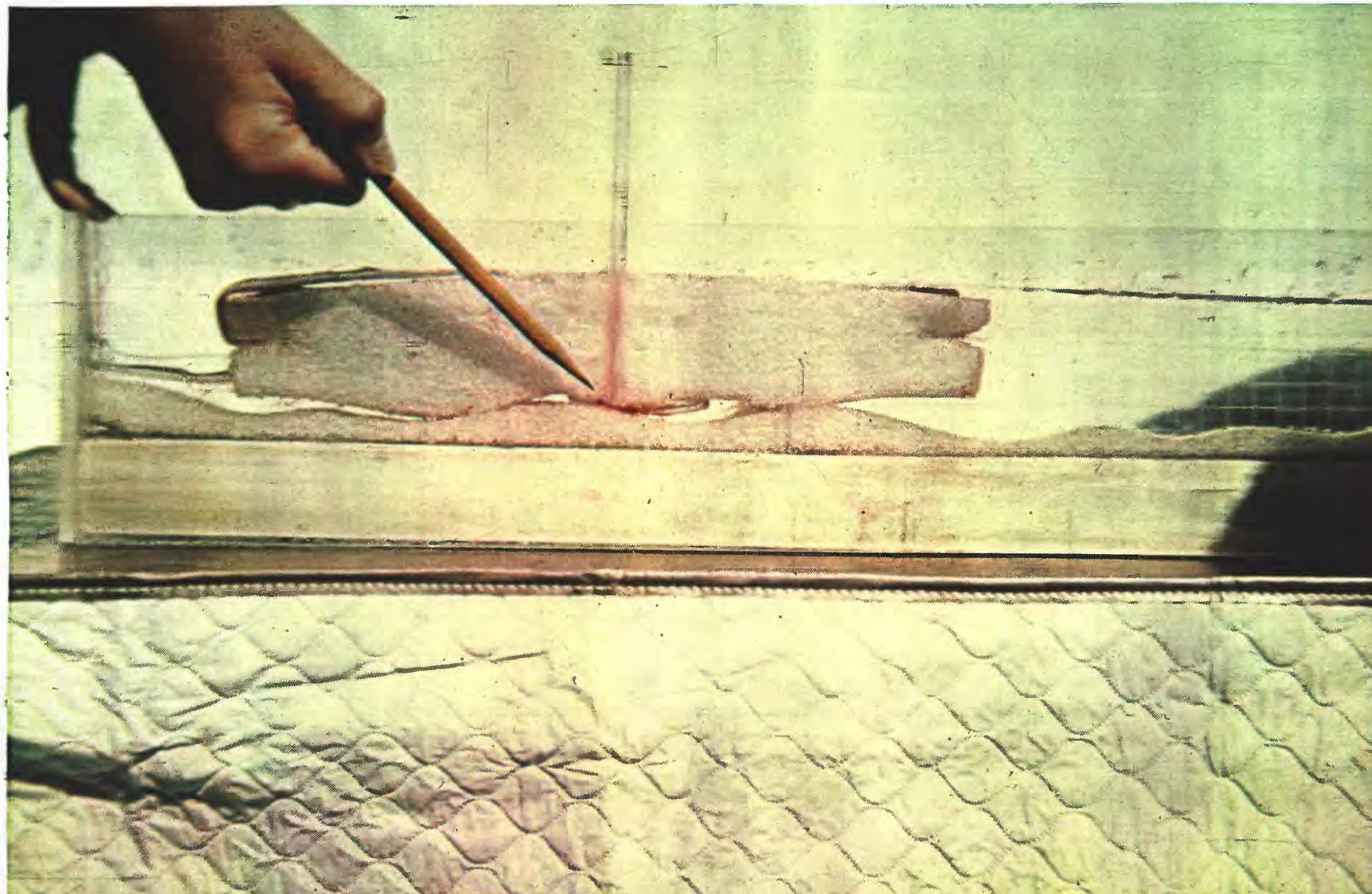
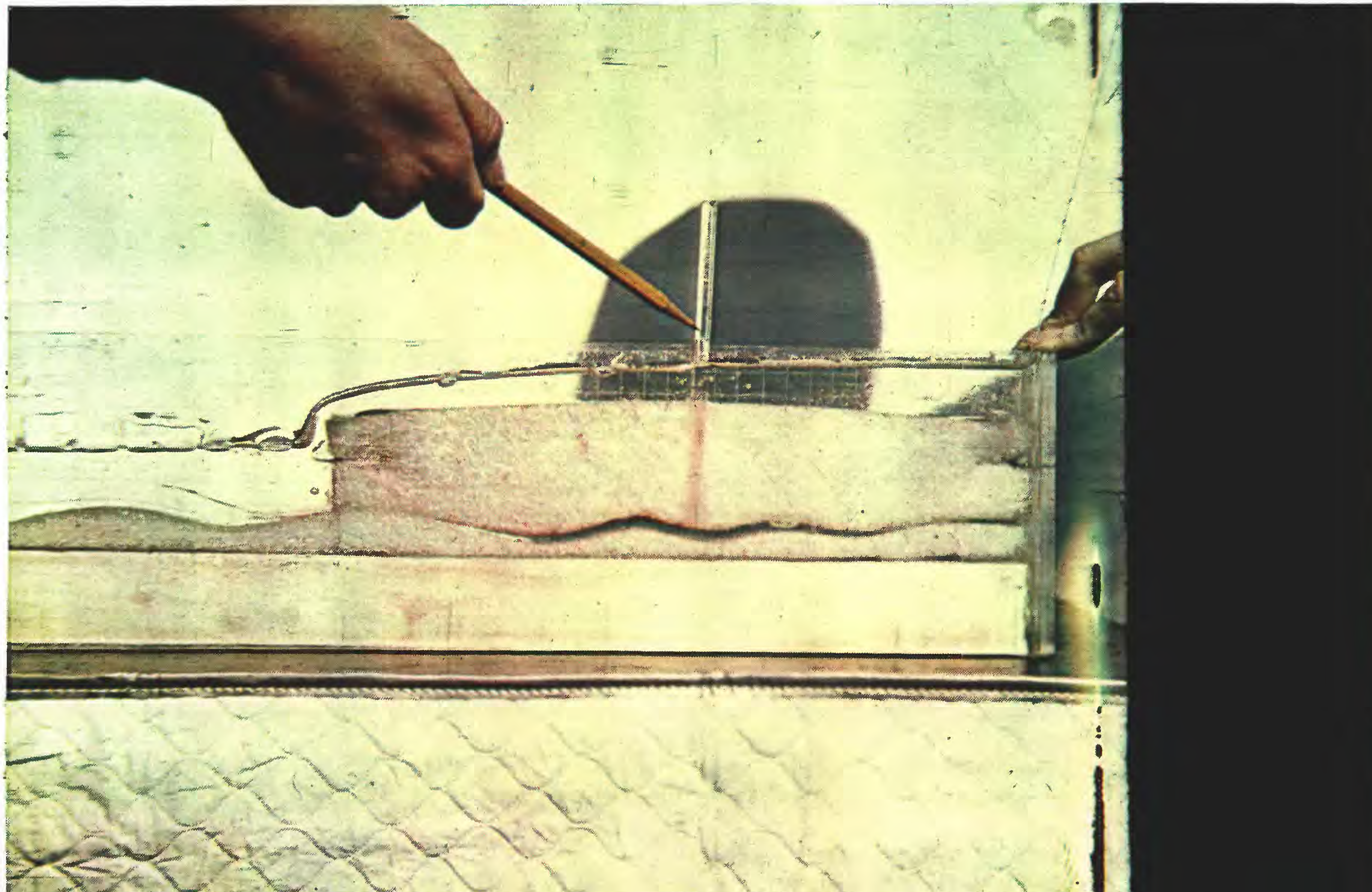


Slide 6



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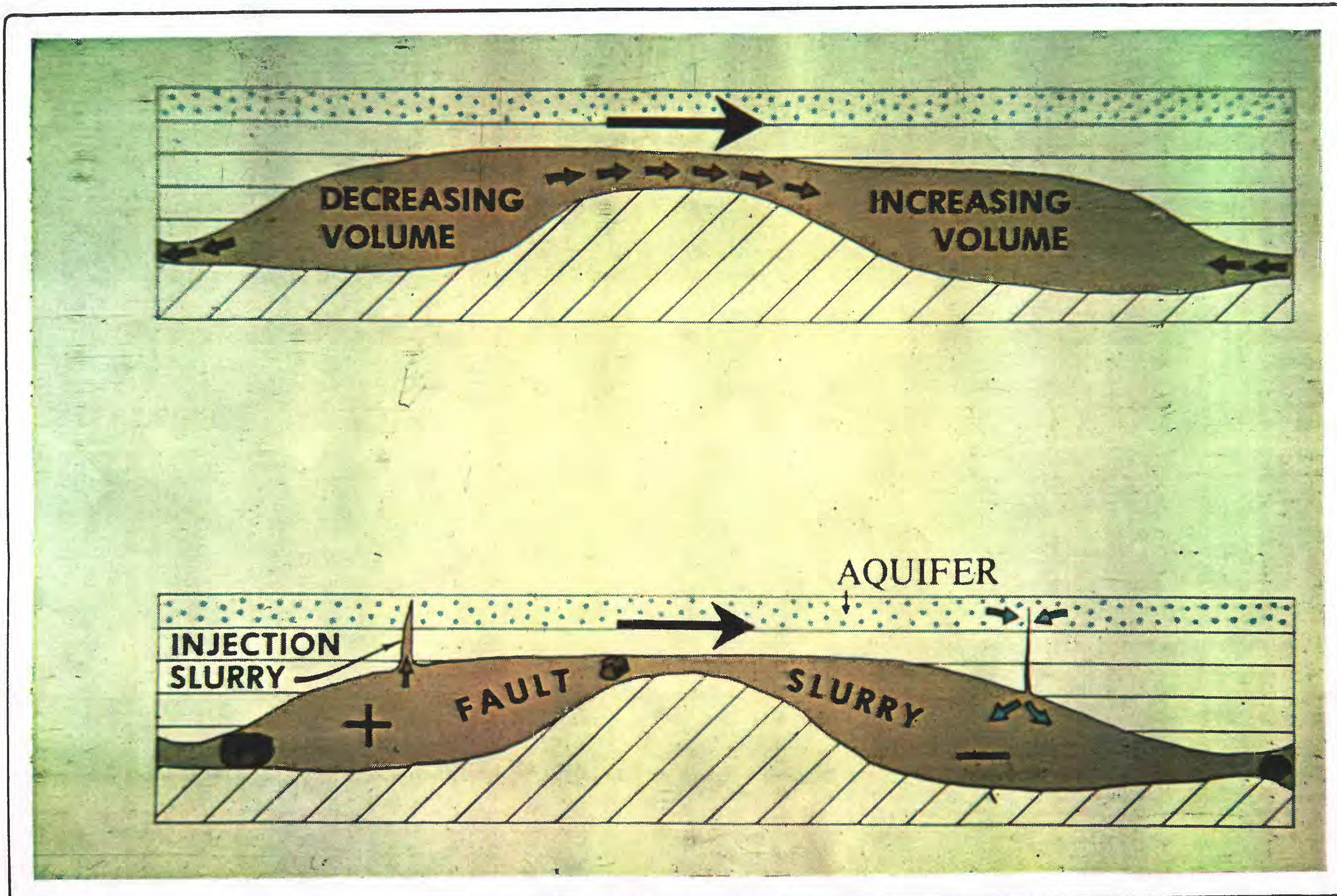
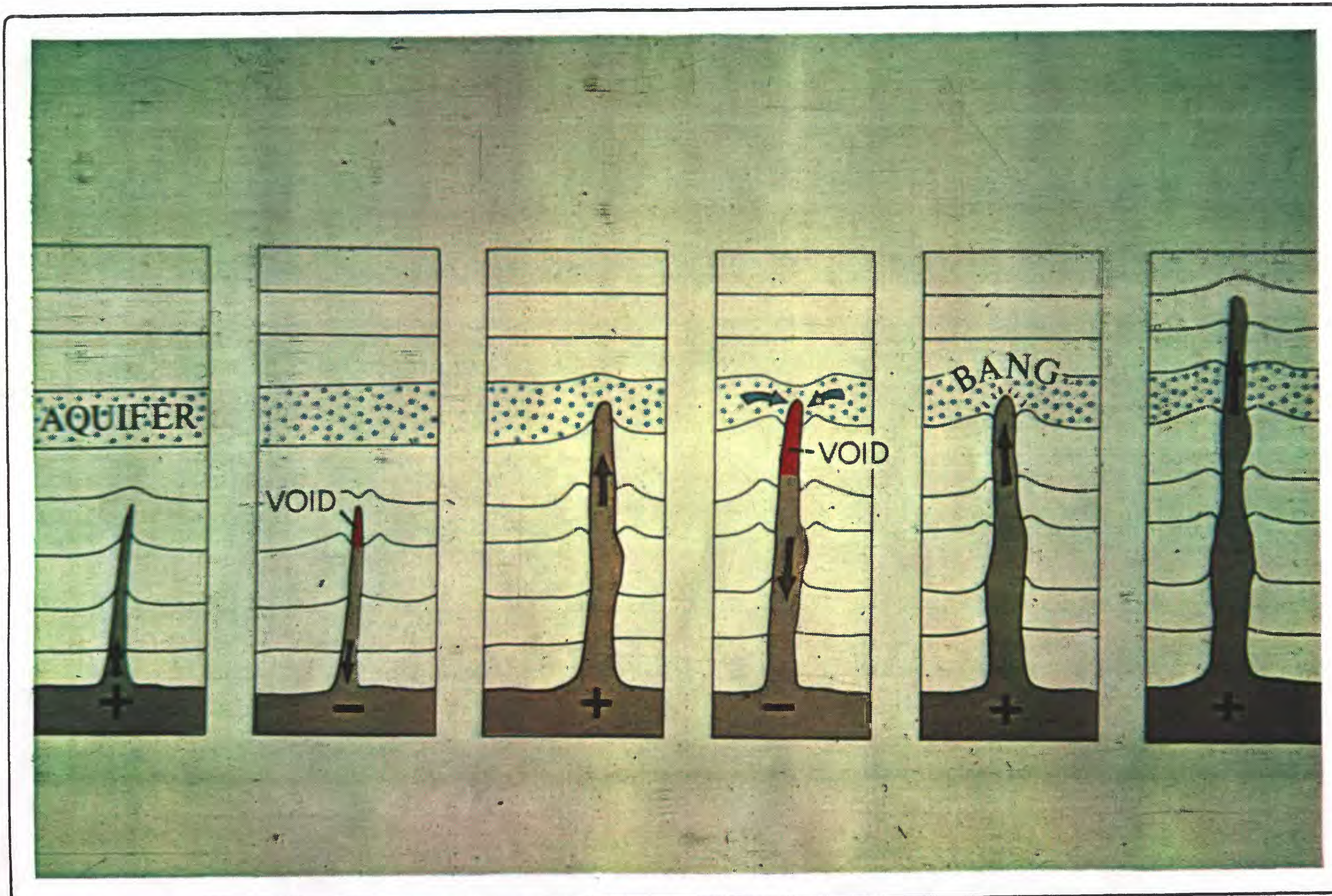
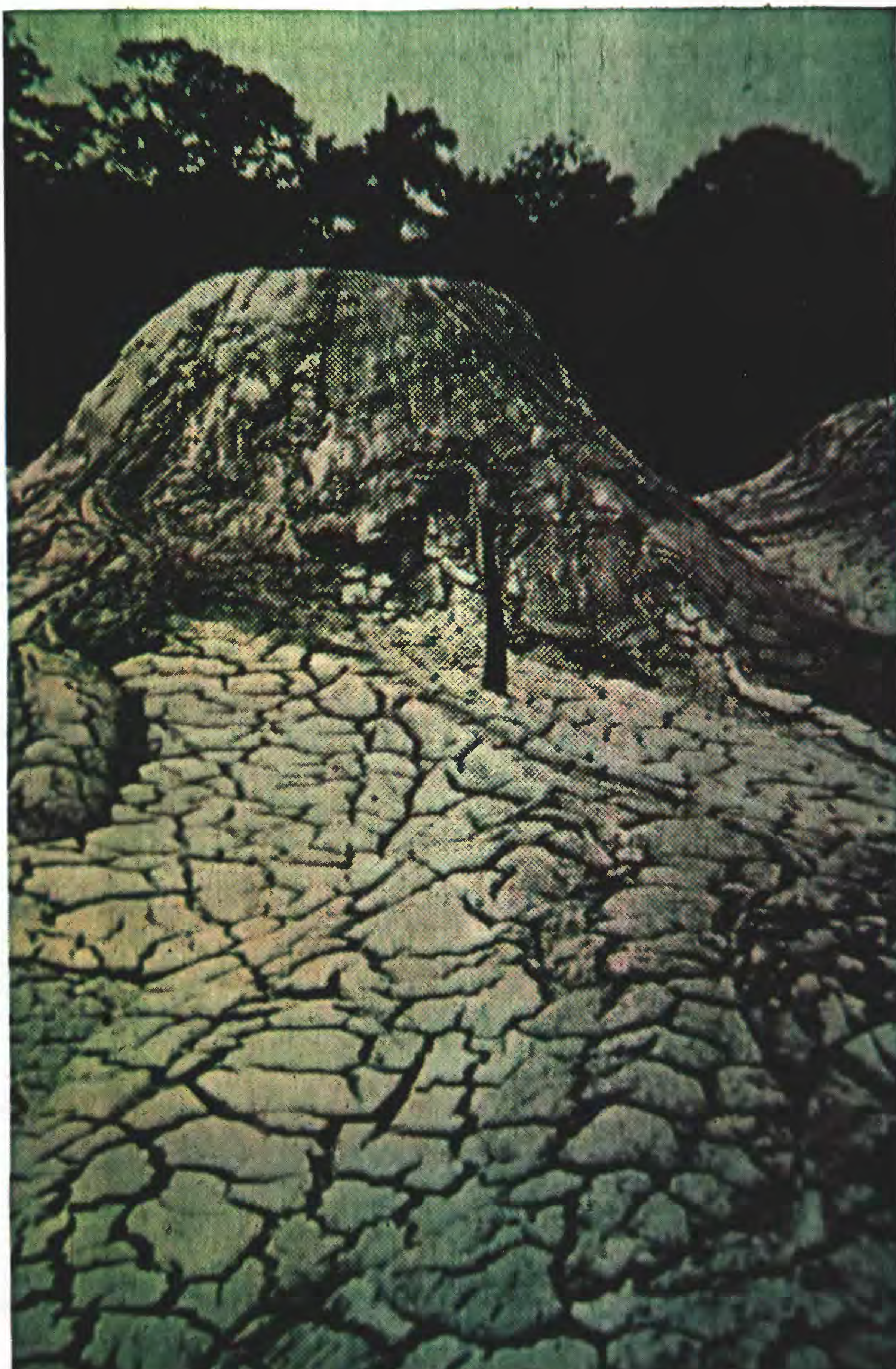

DECREASING
VOLUME
INCREASING
VOLUME
AQUIFER
INJECTION
SLURRY
FAULT
SLURRY
+
—

Slide 8



Slide 9



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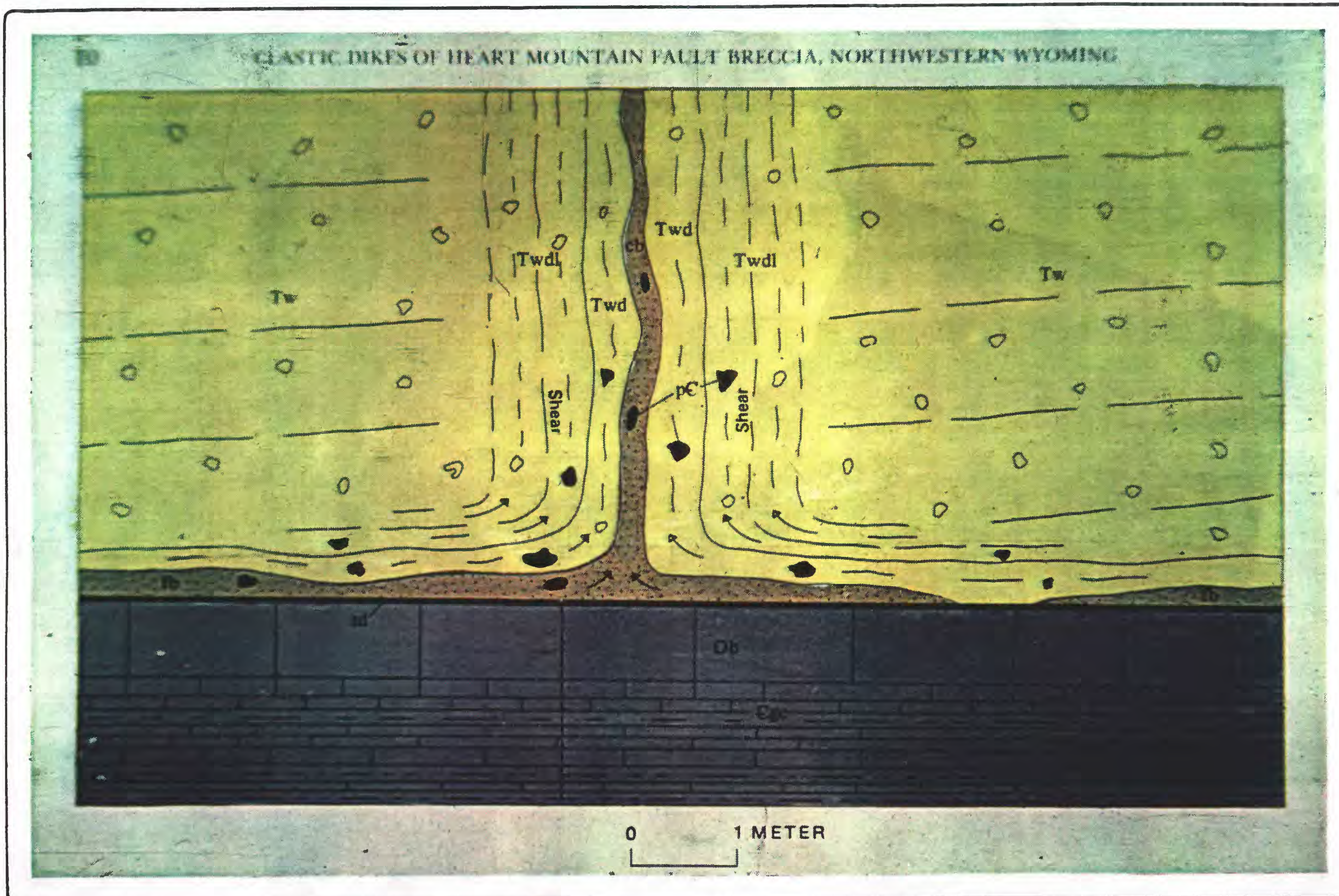
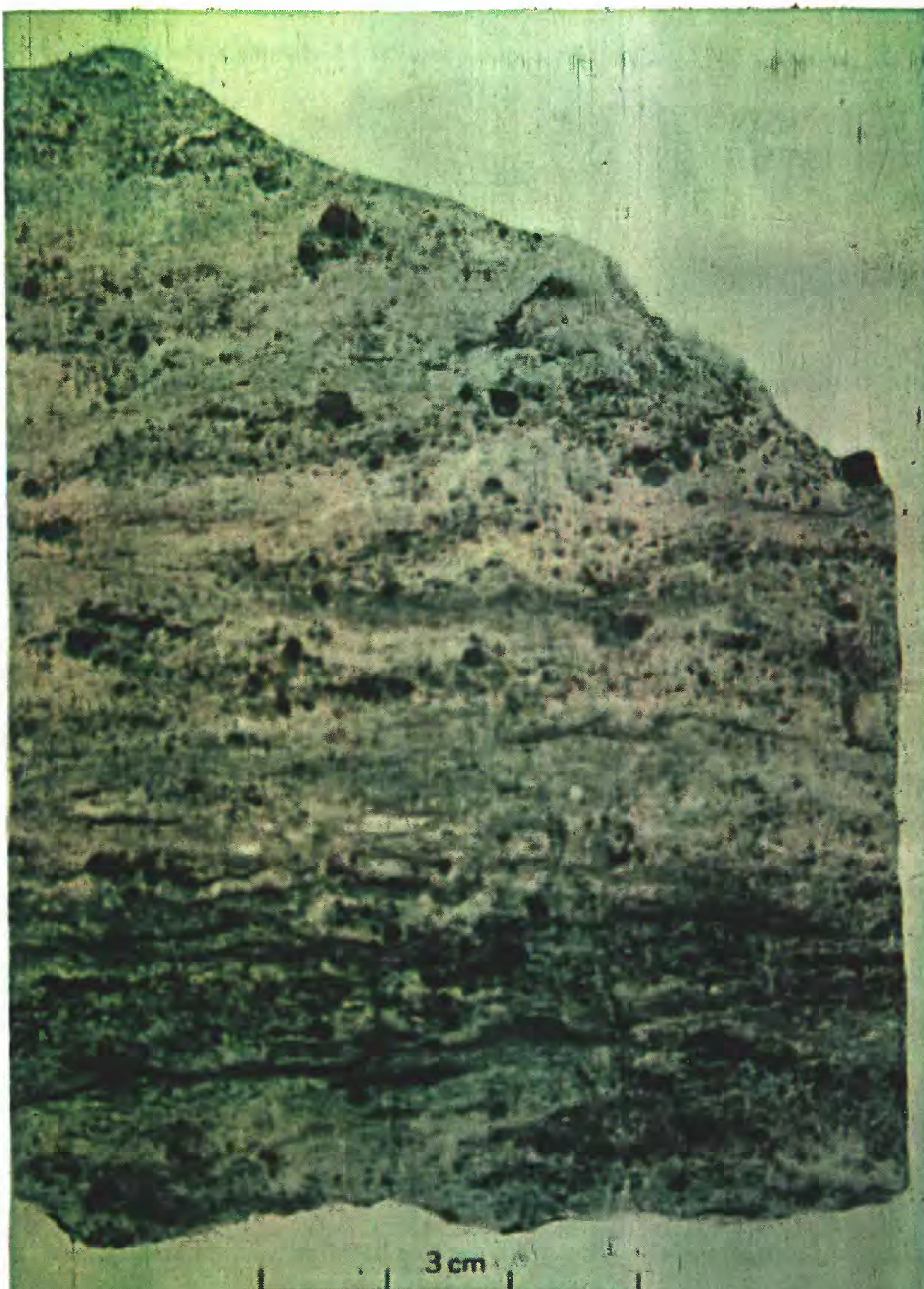


CLASTIC DIKES OF HEART MOUNTAIN FAULT BRECCIA, NORTHWESTERN WYOMING
Tw
Twdl
Twd
cb
Twd
Twdl
Tw
Shear
pC
Shear
Ob
0
1 METER

Slide 11



IGURE 18.—Polished specimen of calcibreccia from near top of 2-m-high mound in figure 17. Note unusual crinkled, wavy layering. Photograph by Lowell Kohnitz.

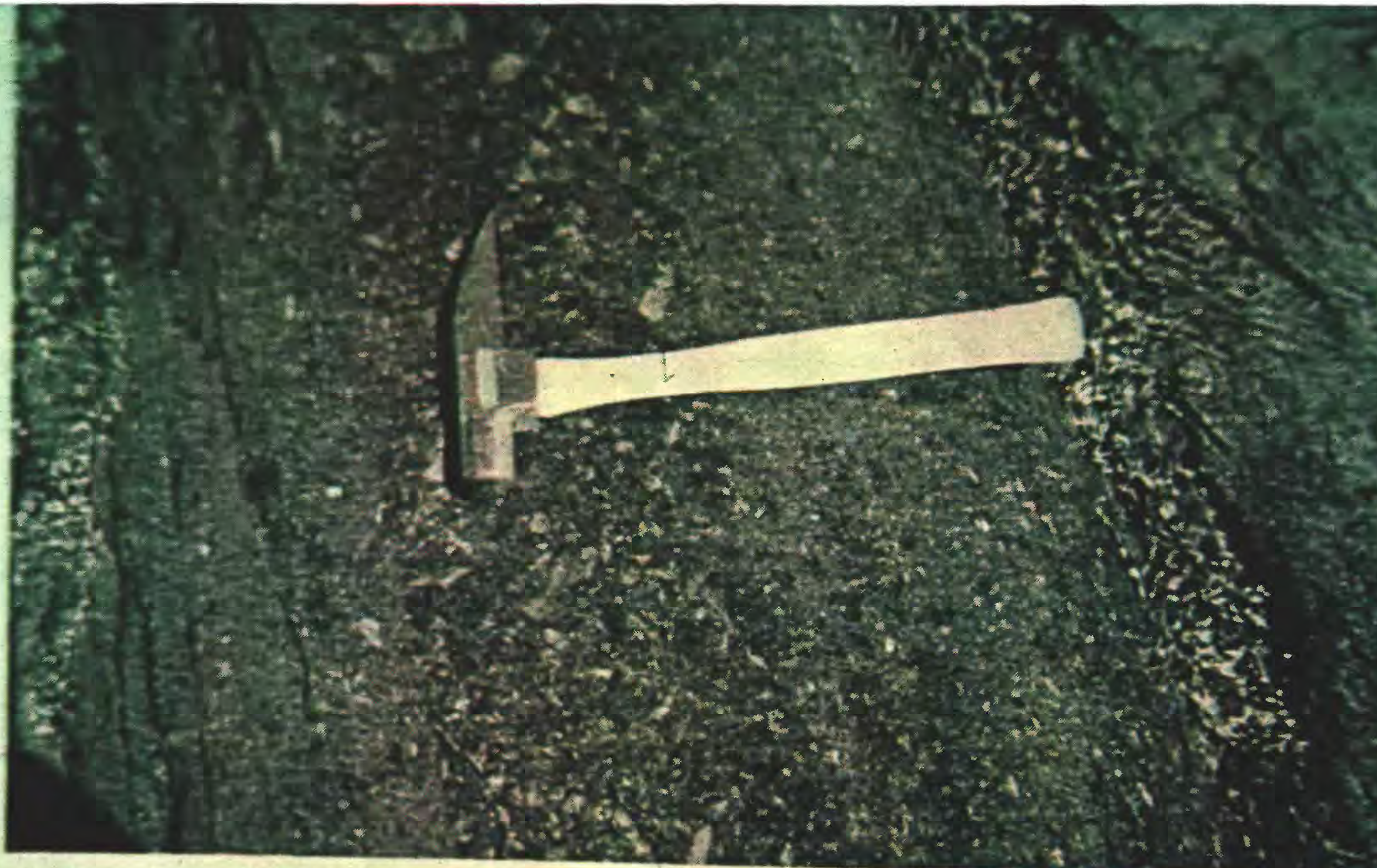
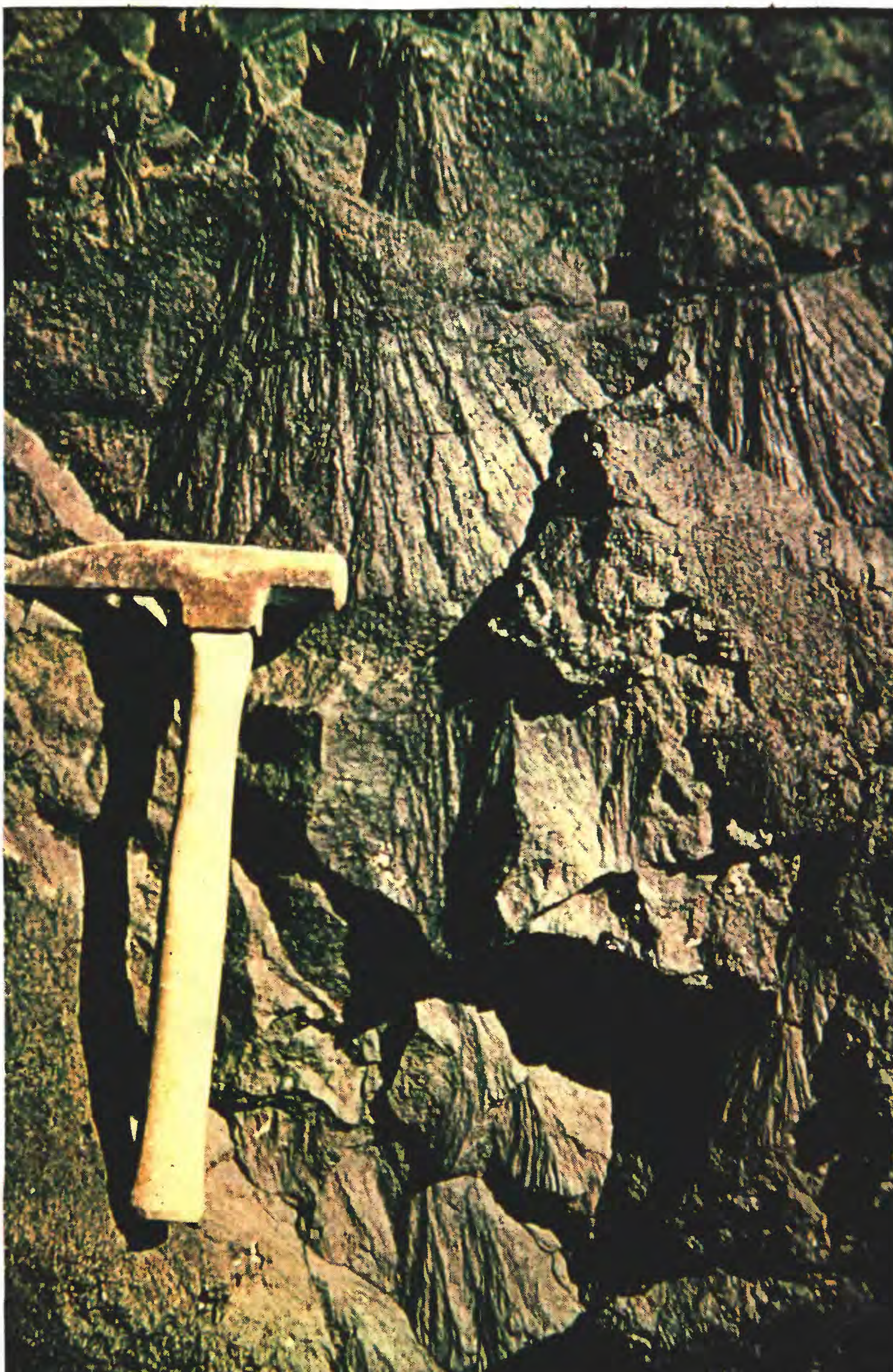


Figure 6. Unusually well-developed clast size gradation in diatreme dike on north side of Spar Island. Photograph taken at lake level.

Slide 13



Slide 14

Slide 15

EVIDENCE FOR HYDROTECTONIC ORIGIN OF SO-CALLED 'CRYPTOEXPLOSION STRUCTURES'

GEOLOGIC SETTING	
REGIONAL	USUALLY MIOGEOSYNCLINAL DEPOSITS
LOCAL	STRATA DEFORMED INTO CONCENTRIC RING-SHAPED ANTICLINES AND SYNCLINES COMMONLY OCCURS AT INTERSECTION OF FISSURES, FAULTS, AND (OR) FOLD AXES LAMINAR FLOW DEFORMATION INCREASES TOWARD CENTER AND UPWARD PRESENCE OF BRECCIA OR PEBBLE DIKES PRESENCE OF SHATTER CONES REACTIVATION OF INJECTION AND (OR) EXTRUSION SLURRY ANOMALOUS THICKNESS OF SOME STRATA FORMING WALLROCKS DUCTILE AND BRITTLE DEFORMATION LACK OF THERMAL METAMORPHISM MAY CONTAIN CLASTS OF GREAT UPWARD AND (OR) DOWNWARD STRATIGRAPHIC DISPLACEMENT
PETROLOGY	TECTONIC MELANGE FINE-GRAINED CLASTIC ROCKS
MINERALOGY	MAY FORM SITE FOR MINERAL DEPOSITS INCLUDING HYDROCARBONS, SULFIDES, FLUORITE, HIGH-PRESSURE MINERALS
ABSENT	METEORITES EXPLOSIONS

Slide 16