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HYDRAULIC MODEL STUDIES FOR BACKFILLING MINE CAVITIES (Second Series of Tests)

Engineering and Research Center
Bureau of Reclamation

March 1975

Prepared for
U.S. BUREAU OF MINES
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16. ABSTRACT

The study is a continuation of the investigation reported in Report REC-ERC-73-19, "Hydraulic Model Studies for Backfilling Mine Cavities." Eighteen additional tests were conducted in the hydraulic model that simulated injection of backfill material into an idealized coal mine. Mine pillars were constructed in the model to a horizontal scale of $1^m:48^p$ (model to prototype) to represent horizontal dimensions 40 feet long and 10 feet wide, with a cavity spacing of 10 feet between ends of pillars. The cavity volume was 60 percent of the total mine volume. Vertical scale for the model was $1^m:48^p$ for tests 6-18. For tests 1-5, a vertical scale of $1^m:14.908^p$ was used to maintain equal velocities in model and prototype, and establish deposit patterns for equal velocity conditions. Tests simulated the conditions of: (1) sloping floor with cavity submerged, (2) level floor with cavity submerged, (3) level floor with cavity dry, (4) simulated mine with and without blind entries, and (5) corridors and rooms in which there were roof falls and cavities in the roof over roof falls. The 8-foot-square mine area in the model represented a 384-foot square or 3.39 acres in the prototype. Backfill material was fine, uniform sand with mean diameter of 0.14 mm. Test results are given in a summary table and 34 figures showing photographs and contour maps of deposit patterns of backfill material are included. (7 ref)

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Division of General Research
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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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The studies described in this report were conducted by the author. Danny L. King is Chief of the Hydraulics Branch and J. C. Schuster is Head of the Hydraulics Research Section. Russell A. Dodge assisted in operating the model, taking data, and drafting the figures. The photographs were taken by Photographer W. M. Batts. Representatives from the Bureau of Mines, Denver, Colo., visited the Engineering and Research Center during the study to observe the hydraulic model tests and give guidance. A Memorandum of Understanding between the Bureau of Mines and the Bureau of Reclamation, Modification No. 1 to Agreement No. H0230011, was the contractural arrangement for the study.

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PURPOSE

This study is a continuation of the investigation reported in Report REC-ERC-73-19, "Hydraulic Model Studies for Backfilling Mine Cavities." The Bureau of Mines asked the Bureau of Reclamation to conduct additional hydraulic model tests to study different aspects of backfilling mine cavities with sand and waste material to reduce subsidence of land at the surface above the mine cavities.

SUMMARY AND CONCLUSIONS

Additional tests were made in the model of an idealized coal mine that was operated to determine the results of various conditions where mine cavities are backfilled by pumping a fine sand slurry. Fine, uniform blow sand having a median size of 0.14 millimeter obtained from the Rock Springs, Wyoming area was used to produce the sand slurry.

Eighteen tests were conducted in this second phase of hydraulic model tests. The following mine conditions with slurry injection were simulated:

1. Sloping floor with cavity submerged
2. Level floor with cavity submerged
3. Level floor with cavity dry
4. Simulated mine with and without blind entries
5. Corridors and rooms in which there were roof falls and cavities in the roof over the roof falls

Conditions under which the tests were made are summarized in table 1.

Conclusions from the first series of tests were reported in Report REC-ERC-73-19. Data from the second series consisting of 18 tests lead to the following conclusions which are in addition to conclusions made for the first series of tests. The results from the 18 tests reported here support the conclusions derived from the first series.

1. As deposited backfill material reaches the quantity and pattern to build up back pressure in the injection system, one final breakout may occur. A channel is formed down an unobstructed corridor between rows of pillars. The entire discharge from the injection pipe goes down this one channel with high enough velocity to keep the fine sand moving without causing a high back pressure in the pipeline. This final breakout channel can transport slurry material for a long time over a comparatively long distance away from the injection pipe. Deposit would occur at each cross channel junction between the pillars.

2. Fine sand backfill material injected into a submerged mine is transported over roof falls that block corridors when there is an open cavity over the top of the roof fall. In the model study, backfill material almost filled the cavities above the roof falls at the end of the tests.

3. The extent to which backfill material will be transported into and deposited in slack water areas (blind entries) will depend on the position and geometry of the entry with respect to slurry flow past the entry. Fill material will deposit in slack water areas (blind entries) if circulation of sediment-laden water occurs in and out of the slack water areas.

THE MODEL

Model Box—Pump and Slurry Sump

A watertight box made from 3/4-inch waterproof plywood, 15 feet square and 2-1/2 feet deep, was used to contain the model, figure 1. This box was used for previous tests of backfilling mine cavities as described in Report REC-ERC-73-19 prepared for the Bureau of Mines. The same slurry sump and 2-1/2-inch Kimball-Krogh sand pump as described in that report was used to pump the slurry from the sump to the model mine. A recirculating system was used in which fine sand was mixed with water in a sump that was 8 feet long by 2 feet wide by 3.5 feet deep mounted below the floor. Slurry material was pumped into the center of the model, in every case, through the injection pipe mounted in the removable mine roof. Sand material was deposited in the mine and water would flow to the simulated water table. The water level was held above the mine cavity for submerged cavity tests. For dry cavity tests, the water level control gate on the model box was lowered completely; water would leave the elevated mine floor, flow into the model box surrounding the section of simulated mine, out the 4-foot-long by 2.5-foot-wide sluice channel, and back to the slurry sump. Water level in the model box and slurry sump was maintained at the desired level by adding water as necessary. With the propeller mixer running at constant speed, concentration of fill material in the slurry sump would be varied according to the level of energy imparted to the fluid slurry by the mixer and according to the depth of fill material deposited in the slurry sump.

Piping and Measuring System

Previous tests showed that the general pattern of deposit was not dependent upon slurry concentration nor on injection pipe velocity, providing velocities were high enough to transport sediment without deposition in the injection pipe. The concentration and pipe velocities in the tests described here, therefore, were not intended to duplicate those conditions of the Rock Springs injection operations. The deposits should predict the pattern that would occur in a typical mine with a symmetrical uniform pattern of mine pillars and cavities.

For tests 1 through 3 the vertical intake to the sand pump used in previous tests was left in place. However, the pipe entrance was about 3 feet away from the vertical mixer propeller. To obtain a more uniform slurry concentration, the 2-inch nominal intake pipe was lengthened and set on a 45° angle to the vertical so the intake would be closer to the propeller mixer. The propeller mixer was used to keep the fine slurry sand in suspension. A 1/2-inch feed pipe was used for tests 1 through 6 and replaced by a 3/4-inch pipe for the remainder of the tests described in this report. The Venturi meters used for measuring discharge in previous tests were removed. A 3/4-inch Annubar flowmeter with 0.824-inch inside diameter was installed in the horizontal section of the pipe for measuring discharge in all tests, figure 1. To minimize possible plugging of the impact and low-pressure ports in the flowmeter, two purge water lines were attached to the ports, each line having a rotameter to measure the purge water.

The Annubar flowmeter was calibrated for clear water without the purge inflow at the pressure ports. Flows through the rotameters were then set to give the same discharge rating as without the purge water connections. To continuously determine the slurry discharge without getting fine sand in the meter ports and plugging them, a small amount of purge water was used.

Pressure piezometers were located about one pipe diameter from the end of the injection pipe and in the mine cavity as shown on figure 2. The pressures were read on the water manometer board and recorded at short time intervals to determine changes in the pressure as the backfill material deposited in the cavity during each test. For tests 1 through 5, seven piezometers were used including a piezometer showing the water table elevation surrounding the mine cavities. For tests 6 through 17, pressures were measured at 11 points. At points where fill material deposited up to the mine roof, the pressure taps became plugged with the fine sand.

All figures in the report showing drawings and contour maps of the mine model are oriented with north at the top of the figure for easy comparison of the deposit patterns. Contour intervals are designated in feet above the mine floor on all contour maps.

Model Scales—Mine Pillars

The model mine was constructed to represent a mine with the cavity volume equal to 60 percent and the pillar volume equal to 40 percent of the total volume. The horizontal scale for all model tests was $1^m:48^p$ (1 in the model is equal to 48 in the prototype.) The vertical scale for most tests were also $1^m:48^p$. Some early tests (1 through 5) were made with a vertical scale of $1^m:14.908^p$, a vertical distortion of 3.22, to establish deposit patterns with velocities in the model mine cavity equal to the velocities in the typical prototype cavity. Deposit patterns for undistorted and distorted scales were similar; therefore, tests 6 through 18 were performed with the model constructed to an undistorted scale of $1^m:48^p$, vertical and horizontal.

Mine pillars were constructed in the model to represent horizontal dimensions 40 feet long and 10 feet wide, with a cavity spacing of 10 feet between sides of pillars and also 10 feet between ends of pillars. This gave a mine arrangement as described above with 40-percent solid and 60-percent cavity both for the distorted and undistorted model scales. The 8-foot-square mine area in the model represented a 384-foot square or 3.39 acres in the prototype.

Backfill Material

Fine sand obtained from the Rock Springs injection project was used in the model studies. A size analysis and relative density determination for the backfill material used in the model and prototype mine is shown in figure 3. The median diameter of the fine sand was 0.14 millimeter. Standard properties and bearing capacity tests on the backfill material were made in the Soils Laboratory of the Earth Sciences Branch of the Bureau of Reclamation. These studies are reported in Report REC-ERC-73-19.

THE INVESTIGATION

Sloping Mine Floor

Distorted model tests.—Tests 1 through 5 were made to evaluate the changed piping system, the Annubar flowmeter, the seal of the roof against the mine pillars, and general operation of the pump-piping system and slurry sump. Tests 1 to 3 were conducted with the vertical intake pipe on the pump. At the end of test 3, an inspection showed a hard crust of fine sand in the slurry sump just below the vertical pipe intake located 3 feet horizontally from the mixer propeller. The crust which apparently formed over a period of operation, was similar to hard surface crusts that form in open channels having bed material made from fine sand.

In test 1 sand was fed to the slurry sump at a rate of 1.1 pounds per minute. For test 2 the rate of sand was increased to 12 pounds per minute. On both tests 1 and 2, pressure built up in the mine cavity after fill material was deposited up to the roof level. In test 2, the pressure increased so much that the roof lifted from the pillars, and fill material was transported between the roof and the tops of the pillars, figures 4 and 5. After test 2 was completed, four bolts were installed through the pillars from the mine floor to the roof. An additional 1/4-inch layer of sponge rubber was fastened with adhesive to the roof to form a seal on the pillars as the bolts were tightened. After conducting test 2 for about 35 minutes in the model, the mine cavities were filled to cause back pressure in the injection pipe. Shortly after this pressure built up, breakouts occurred upslope first, then downslope and to the slides. The mine was set on the 5° dip.

Test 3 was operated for about half an hour. Water discharge was started at 0.030 ft^3/s. When sand was added to the slurry, the discharge dropped to 0.020 ft^3/s. The average discharge during the test was 0.025 ft^3/s. Pressures measured at the piezometer on the end of the injection pipe varied from 1.02 to 1.74 feet compared to 1.56 to 1.74 feet measured at the piezometers in the cavity. Figure 6 shows the deposit pattern at the end of test 3.

After completing test 3, the 2-inch intake pipe was lengthened 1 foot 3 inches and was reconnected to the pump intake at a 45° angle. With this arrangement, the end of the intake pipe was 0.9 foot above the floor of the slurry sump and closer to the mixer propeller. Test 4 showed that moving the intake pipe closer to the mixer propeller caused extra deposit in a cone shape around the mixer in the slurry sump. Consequently, much of the sand added at 14 pounds per minute deposited in the slurry sump and was not pumped to the model mine. The amount of fill material that was pumped and deposited in the mine was comparatively small, figures 7 and 8. Test 5 was therefore made as a continuation of test 4.

Tests 4 and 5 were made with the mine submerged and dipping 5°. The model had a horizontal scale of $1^m:48^p$ with a vertical distortion of 3.22. The breakout through the initial deposit caused clouds of slurry to come through the corridors to the edge of the mine area. Pressures on the end of the discharge pipe in test 4 remained approximately the same throughout the test, indicating that there was no back pressure; consequently, the solid fill material did not fill the cavity near the ceiling. In test 5, pressure at the end of the discharge pipe increased with continued injection. Figures 9 and 10 show the deposit pattern in the mine cavity at the end of the test.

Undistorted model tests.—For tests 6 through 18 the pillars were changed to give an undistorted geometric scale of $1^m:48^p$ in both horizontal and vertical directions. An observation test was conducted with the mine submerged and dipping at an angle of 5°. Velocity in the 1/2-inch pipe was about 9.9 ft/s. Deposits occurred and silty water that could be observed at the edge of the mine section was moving upstream in corridors 3 through 9, counting from the left side looking downslope. Additional piezometers in the mine roof were added to give a wide pattern of pressure distribution away from the injection pipe. As the backfill material deposited, pressures with the additional deposit ring were slightly higher than pressures outside the central cavity (piezometers 7 through 11). The additional piezometers 7 through 11 were added in the mine roof after test 6 was started. The test was stopped, the mine drained, the roof was raised, and the piezometers installed. No photographs were taken nor was a contour map of backfill deposit prepared for test 6 because of the changes during testing.

Test 7 was performed with the same conditions as for test 6 except the injection pipe with an inside diameter of 1/2 inch was replaced by an injection pipe with an inside diameter of 3/4 inch to get higher discharge capacity through the pump-piping system. The 1/2-inch pipe was restrictive, which caused debris to collect in the pipeline. A valve was installed on the high point to the bowl of the centrifugal pump which made it possible to bleed air and later to extract sediment samples from the pump. The valve also made it easier to prime the pump at the startup for a test. At the end of test 7, material was flowing between the pillars and the mine roof in a few places, figures 11 and 12. After test 7 was completed, two additional toggle bolts, making a total of 6, were installed to hold the roof tight against the pillars.

A water purge system for the Annubar flowmeter was installed at the end of test 7. Previous test discharges were set with only water in the piping system before the mixer was turned on. Without the purge system, when fill material was pumped in slurry form, the ports to the flowmeter would tend to plug. By using the purge system, pressure was positive at each of the two ports of the Annubar flowmeter, which caused a small flow into the pipeline, preventing fine sand from entering and plugging the pressure tubes to the flowmeter.

Test 8 was made with a velocity of approximately 7.5 ft/s in the 3/4-inch injection pipe. The mine was dipping 5° and submerged. The deposit pattern was observed at the end of the test after the roof was raised, figures 13 and 14. No deposit on the top of the pillars indicated the roof held tight against the back pressure that occurred in the mine cavity. After the initial deposit ring was established around the injection pipe, back pressure built up and a breakout occurred downslope in corridors 8 and 9, counting from the left looking downslope. The fine sand was carried in suspension along the bed and deposited in a large mound off the edge of the mine platform. With increased pressure, a breakout occurred and high velocity flow started upslope in corridor 9, counting from the left looking downstream.

The characteristics of test 8 were typical of an injection into a submerged cavity with open corridors. After the initial deposit ring has occurred and back pressure builds up in the cavity and in the injection pipe, a breakout occurs in one or two corridors. Fill material is carried along this channel in suspension or as bedload according to basic sediment transport principles. With the full flow of the injection pipe discharging along a channel, an equilibrium condition develops for sediment transport. Fill material deposits at intersections to essentially block side corridors and confine the flow along the one channel. Deposit builds in the channel until the cross-sectional area reduces and the velocity increases to cause critical transport conditions.

Reports from field operations at Rock Springs, Wyoming, indicate flow occurs in a single channel over long distances after fill material is deposited up to roof level around the injection hole. Model tests showed that flow in a single breakout channel started when deposit sealed or nearly sealed the space adjacent to the roof around the injection hole. Pressure would build up in the cavity prior to the breakout and would lower as flow started in a single channel. Extensive deposit and lowered pressure prevented other breakout channels from forming. For test 8, after material had deposited up to the roof, slurry flowed down one corridor until the test was stopped.

Blind entries—submerged mine.—Tests 9, 10, and 11 were made as a series with the mine dipping 5° and submerged. After each test was stopped, the roof was raised and the deposit pattern observed. The mine roof was then lowered, fastened in place, and the next test in the series continued. A contour map and photographs were made of the deposit pattern for tests 9 and 11. Blind entries were simulated in the model by installing blocks at various places in corridors in the mine. Some blocks were installed to block corridors at ends of pillars and also near the middle area of pillars. Some blocks were installed to prevent communication within corridors and over considerable distances in some cases, figures 15 through 19. During test 9, initial fill material deposited up to the roof around the injection pipe, and back pressure caused a reduction in discharge. Piezometers attached to the roof showed the increase in back pressure and then the sudden decrease in back pressure when a breakout occurred. The pictures and contour map prepared at the end of test 9 are shown in figures 15 and 16.

Test 10 was a continuation of test 9, using a smaller discharge. The smaller discharge resulted in a lower intake velocity and, consequently, a lower sand concentration. A small additional amount of fill material was deposited in the mine during test 10. The pressure in the area around the injection hole was comparatively high. No photographs were taken nor was a contour map prepared at the end of test 10. Before test 11 was started, the sand deposit was carved back to the deposit pattern left at the end of test 9.

Test 11 was made with a slightly lower average discharge throughout the test. When the discharge tended to decrease because of back pressure, the control valve was opened to maintain a constant discharge. For test series 9, 10, and 11, the fill material seemed to deposit downslope first, then upslope, and then on the level out from the injection hole toward the sides. At the end of test 11, the last breakout established a comparatively high velocity flow upslope in corridor 8, counting from the left side looking downslope. The flow being confined to a single corridor caused the velocity to be comparatively high and, thus, the transport capacity continued at a comparatively high value. The flow at the end of test 8 for a mine without blind entries was similarly confined to a single corridor. At the end of the series of tests 9, 10, and 11, flow was confined to a single corridor and the slurry traveled upslope with a comparatively high velocity. Figures 17, 18, and 19 show a photograph and contour maps of deposited slurry material at the end of test 11. Figure 19 indicates that fill material will not enter and deposit where blind entries prevent flow circulation.

Level Mine Floor

Roof falls and cavities over roof falls—submerged *mine.*—Tests 17 and 18 were conducted to show how fill material would be transported over simulated roof falls and through cavities above the roof falls, a condition occurring in coal mines after being abandoned for some time. Roof falls were simulated by truncated wood pyramids sloped 60° from the floor, figures 20 and 21. The top of the roof falls were 6 feet above the mine floor, the same height as the normal roof. Above the roof fall a cavity was formed by cutting the roof and constructing a box over the hole cut in the roof, figure 20. A piezometer was placed in each simulated cavity to measure pressures developed in the cavities during the backfilling operation. Two roof falls were placed at intersections of corridors; one roof fall was placed between ends of pillars and one was placed between sides of pillars, figure 21.

For tests 17 and 18, the mine was level and submerged. Before beginning test 17, sand was added to the slurry tank so that the backfill supply was sufficient to complete the test. During the 50-minute test, samples of slurry taken from the pump discharge pipe varied in concentration from 1.2 to 5.1 percent, by weight, with an average of 1.8. These samples were taken using a 1/8-inch tube with its entrance pointing upstream in the vertical pipe where flow lines were parallel. A photograph showing backfill deposit at the end of test 17 and contour maps at the end of tests 17 and 18 are shown on figures 22, 23, and 24. Test 18 duplicated test 17, except test 18 had a higher injection velocity and higher slurry concentration, table 1. At the end of both tests 17 and 18, high velocity flow moved along one corridor directly away from the injection pipe. The velocity along the breakout corridors was high enough to transport fill material without depositing.

At the end of test 17, slurry was flowing up over the roof fall, through the cavity above, and down the corridor, figure 23. The mine was submerged and the resistance offered by the roof fall was not great enough to cause slurry flow to move to another corridor. The slurry takes the flow path of least resistance.

At the end of test 18, the last breakout channel was along a corridor adjacent to a corridor having a roof fall at a corridor intersection, figure 24. This breakout channel was in the opposite direction from the last breakout channel for test 17. It is apparent that for a level mine that is submerged, there is very little difference in the resistance to flow in one direction than to the flow in the opposite direction. In tests 17 and 18, the last breakout channels were along the length of the pillars. Apparently, the abrupt expansion and contraction losses caused by the intersections of lateral channels in the short direction of the pillars may be greater than the losses in the corridors along the length of the pillars. For dry mine cavities, the flow conditions and, consequently, the patterns of resistance to flow are different from those in submerged cavities.

Dry mine cavities.—Tests 12 through 15 were conducted with the mine cavity in an unsubmerged (dry) condition. The water table is lower than the floor of the mine cavity. To provide for this condition in the model, the injection water was allowed to drain out of the model box by having the water level control gate completely lowered. The mine roof was in place for all four tests. Fill material is deposited and slurry water returns to the water table. The backfill material in a dry mine cavity develops a deposit with a surface slope that is dependent on the critical tractive force ($T_D = \gamma DS$) for the material, where T_D = tractive force, γ = specific weight of water, D = depth of water flowing over the deposit, and S = slope of the flowing water surface. A critical tractive force (tractive force that causes a given size of fill material on the bed to start moving) is related to the depth and the slope so that the product (DXS) is constant for the given size bed material.

Tests 12 through 15 were conducted as a series in which fill material was not removed at the end of each test, table 1. A photograph and contour map were made at the end of each test to compare the progress of fill deposit, figures 25 through 32. The progress of the deposit with each successive test can best be observed on the contour maps, figures 25, 27, 29, and 31. The 1-, 3-, and 5-foot contours show the deposit buildup and how the sloping face of deposited backfill material moves with time. Backfill material builds up close to the roof near the injection pipe. A breakout occurs when deposit around the injection pipe is high enough to force most of the flow in one concentrated channel, figures 27, 29, and 31. The direction of the breakout channel varies for different tests when the mine floor is level, indicating initial deposits are uniform and symmetrical for a symmetrical pillar pattern on a level floor. The difference in resistance to breaking out in one direction compared to another direction is very small.

Discharge and, consequently, injection pipe velocity for the series of four tests conducted in a dry cavity were very nearly identical, 0.013 or 0.012 ft^3/s and 3.5 or 3.2 ft^3/s, respectively. Solids concentration in the injection pipe varied from 1.0 (test 15) to 4.5 percent (test 12) by weight, table 1.

Submerged mine cavities.—Test 16 was conducted in two parts over a period of 2 days on a level submerged mine cavity. The first part had a discharge of 0.013

ft^3/s with a slurry concentration of 0.74 percent by weight, and the second part had a discharge of 0.021 ft^3/s and a slurry concentration of 6.7 percent. Photographs, figure 34, and a contour map, figure 33, were made at the end of the test on the second day. The deposit pattern, particularly the mine area that had deposited material up to and very near the roof, was extensive. This was caused by the high concentration and higher discharge and, consequently, higher injection velocity. The higher velocity caused the high concentration of backfill material to deposit at a greater depth farther from the injection pipe than could be obtained with a lower injection velocity.

The breakout channel develops whether or not there is a high injection velocity or lower injection velocity. For a higher injection velocity, pressure buildup in the mine cavity caused by pumping and deposit of backfill material takes longer than for a lower injection velocity. The deposit depth up to the roof or near the roof extends over a greater area for higher injection velocities.

In test 16, some cavities were left in corridors between pillars. Slurry material was transported past opposite ends of pillars depositing material at the same time from opposite ends of corridors. The deposit blocked the corridors, leaving a small unfilled cavity. In a prototype mine, the extent of unfilled cavities between pillars depends on the pattern of the pillars and corridors. Cavities could be left between pillars when the flow pattern was symmetrical.

A final breakout channel on test 16 formed at the end of the test in which most of the injected slurry was flowing down one corridor. This type of flow would continue if the test were not stopped. The slope of the bottom of the deposit in this last breakout channel was very flat, similar to the final breakout channels in previous tests in a submerged mine.

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Table 1

SUMMARY DATA OF MODEL TESTS FOR BACKFILLING MINE CAVITIES

Test No.	Injection pipe diameter, in.	Q, ft^3/s	V in pipe, ft/s	Sed. con. % by wt by imhoff cone	Mine dry or sub-merged	Time with sed. transport, min.	Fill deposited in mine, ft^3	Dip of mine floor, degrees	Center cavity: Radius to mid. contour model, ft	Center cavity: Diameter prototype ft	Comments
Model scale: $H = 1^m:48^P$; $V = 1^m:14.908^P$ distorted											
1	0.5	0.033			Sub	59		5			
2	0.5	0.032			Sub	70	7.74	5			
3	0.5	0.025	11.8		Sub	31	1.57	5	0.76	73.0	
4	0.5	0.032	15.1		Sub	52	0.89	5	0.61	58.6	Sand deposit not removed at end of test.
5	0.5	0.035	16.5		Sub	37	2.10	5	0.16	15.4	Continuation of test 4.
Model scale $1^m:48^P$ undistorted											
6	0.5	0.021	9.9		Sub	39		5	-	-	
1/2-inch-diameter injection pipe changed to 3/4-inch diameter											
7	0.75	0.034	9.2	3.1	Sub	35	0.44	5	0.39	37.4)	V in last break-out single channel = 3.6 ft/s. (tests 7 and 8)
8	0.75	0.029	7.8	11.4	Sub	46	2.34	5	0.65	62.4)	
9	0.75	0.017	4.6	5.6	Sub	15	0.60	5	0.33	31.7	Blind entries.
10	0.75	0.014	3.8	4.8	Sub	24	-	5	-	-	Blind entries.
11	0.75	0.13	3.5	4.5	Sub	17	0.33	5	0.39	37.4	Blind entries; V in last break-out channel = 3.7 ft/s

Table 1 - continued

Test No.	Injection pipe diameter, in.	Q ft³/s	V in pipe, ft/s	Sed. con. % by wt by imhoff cone	Mine dry or sub-merged	Time with sed. transport, min.	Fill deposited in mine, ft³	Dip of mine floor, degrees	Center cavity: Radius to mid. contour model, ft	Center cavity: Diameter prototype ft	Comments
1/2-inch-diameter injection pipe changed to 3/4-inch diameter - continued											
12	0.75	0.013	3.5	4.5	Dry	17	0.30	0	0.38	36.5)	Accumulated time: 17 minutes
13	0.75	0.012	3.2	3.0	Dry	27	0.29	0	0.37	35.5)	44 minutes
14	0.75	0.012	3.2	1.6	Dry	51	0.16	0	0.40	38.4)	95 minutes
15	0.75	0.012	3.2	1.0	Dry	71	0.15	0	0.43	41.3)	166 minutes
16	0.75	(0.013 (0.021	3.3 5.6	0.74 6.7	Sub	17) 28)	0.87	0	0.38	36.5	
17	0.75	0.013	3.5	1.8	Sub	52	0.65	0	0.41	39.4	Roof falls and cavities.
18	0.75	0.019	5.1	3.4	Sub	50	-	0	0.48	46.1	Roof falls and cavities.

Average diameter 36.9 feet - tests 7-18. Avg 36.9

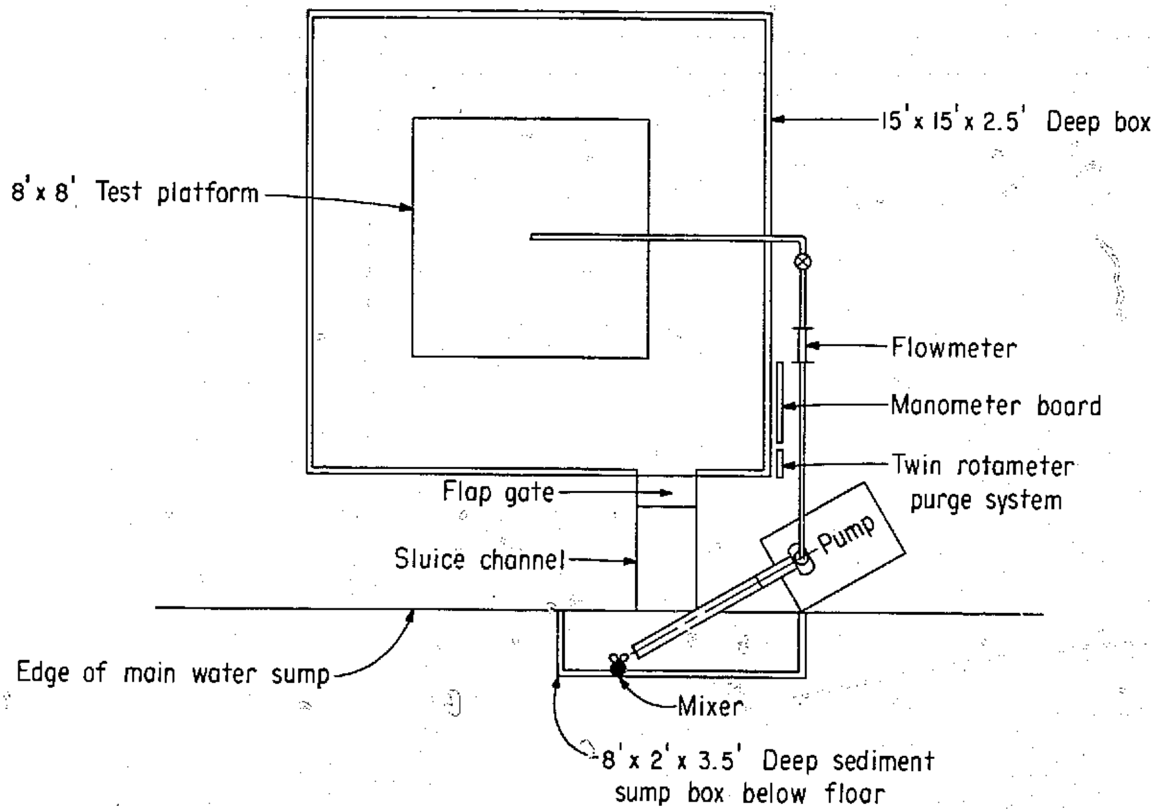


Figure 1. Model test facility.

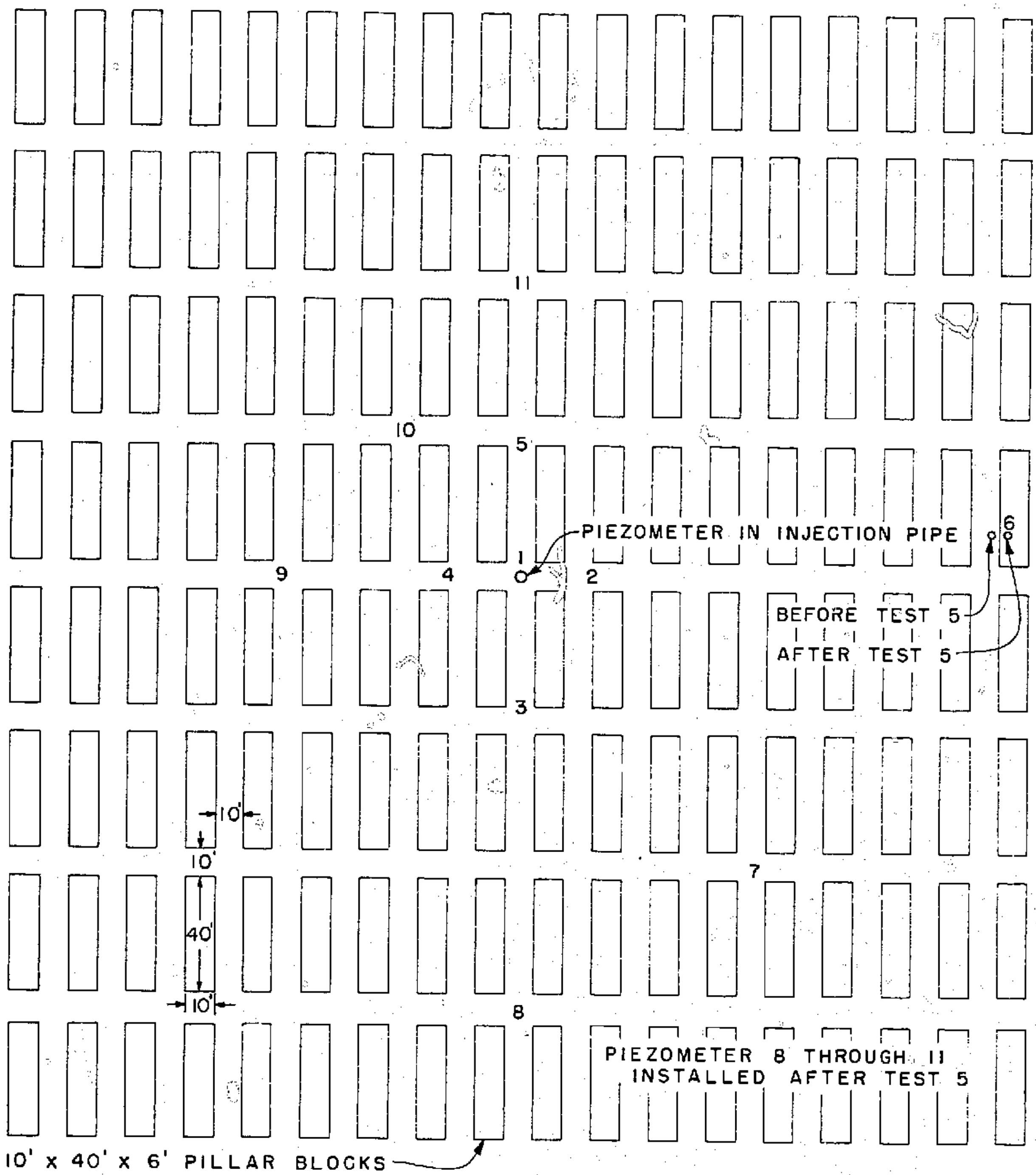
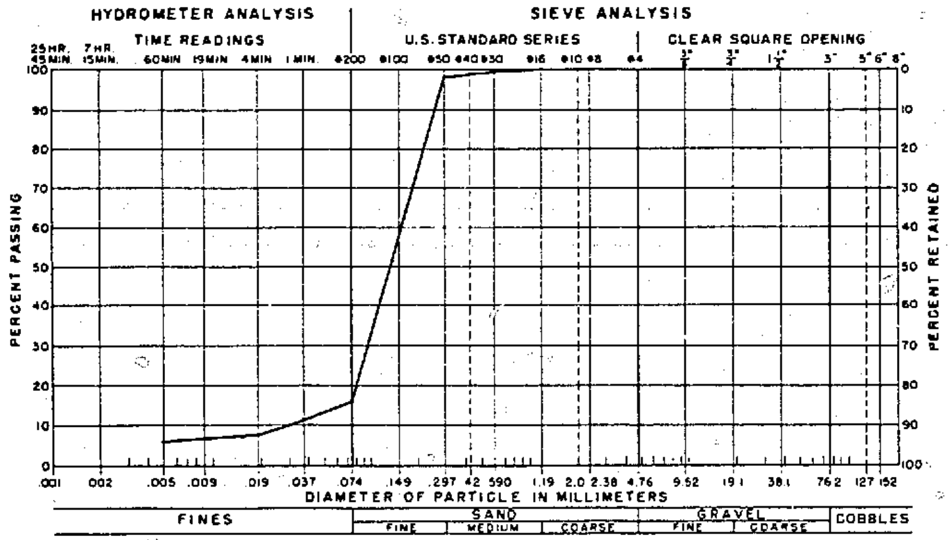
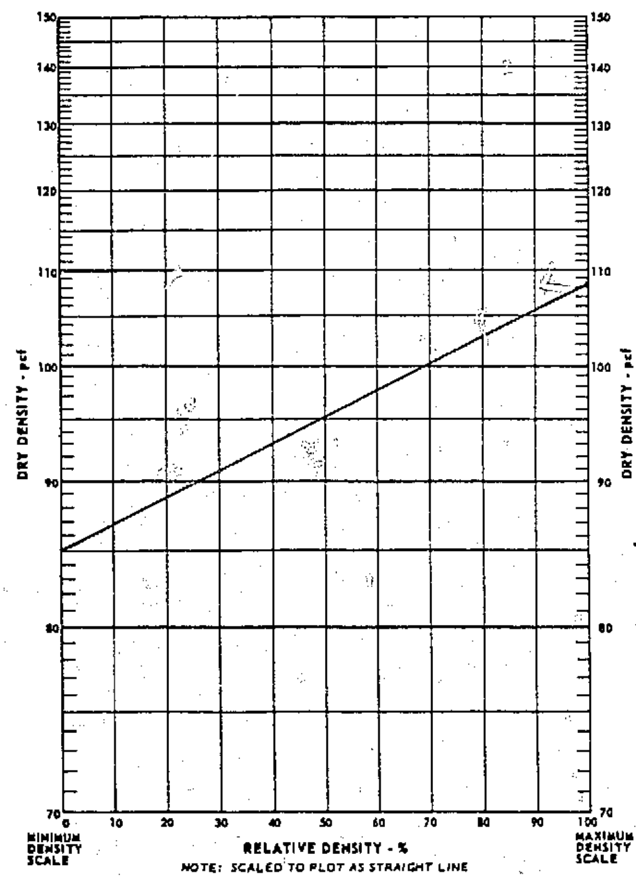


Figure 2. Location of piezometers installed in mine roof and injection pipe.

7-1742 (8-70)
Bureau of Reclamation

PHYSICAL PROPERTIES SUMMARY PLOT (Relative Density)





Classification Symbol SM

Gradation Summary
- Gravel 0 %
- Sand 84 %
- Fines 16 %

Atterberg Limits
- Liquid Limit ____ %
- Plasticity Index NP %
- Shrinkage Limit ____ %

Specific Gravity
- Minus No. 4 2.68
- Plus No. 4
- Bulk ____
- Apparent ____
- Absorption ____ %

Relative Density
- Minimum Density 85.0 PCF (1.36 gm/cm³)
- Maximum Density 108.4 PCF (1.74 gm/cm³)
- 1/ In-place Density 93.8 PCF (1.50 gm/cm³)
- Percent Relative Density 43.5

Permeability Settlement
- Placement Condition ____
- Coef of Permeability ____ ft/yr (____ cm/sec)
- Settlement Under ____ psi Load ____ % (____ kg/cm²)

Notes: 1/ as determined in laboratory model study

Sample No. 545-1 Hole No. ____ Depth ____ ft (____ m)

Figure 3. Size analysis and relative density of fine sand backfill material.

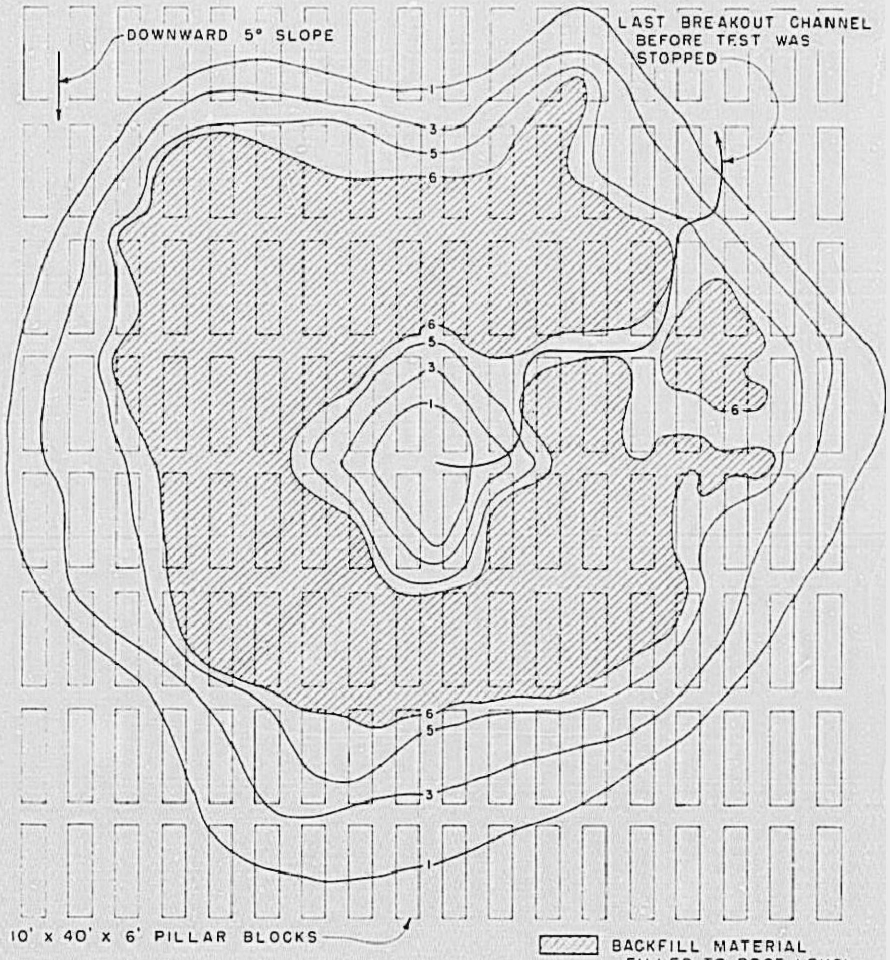


Figure 4. Test 2. Contours of deposited backfill material at end of test. Mine cavity submerged. Mine roof was lifted from the pillars by the pump pressure. (Preliminary test—distorted model scale)

Figure 5. Test 2. Pressure in the mine cavity resulting from slurry pumping caused the roof to raise above the pillars, allowing slurry to flow over the tops of pillars. Mine submerged and dipping 5°. (Distorted model scale)

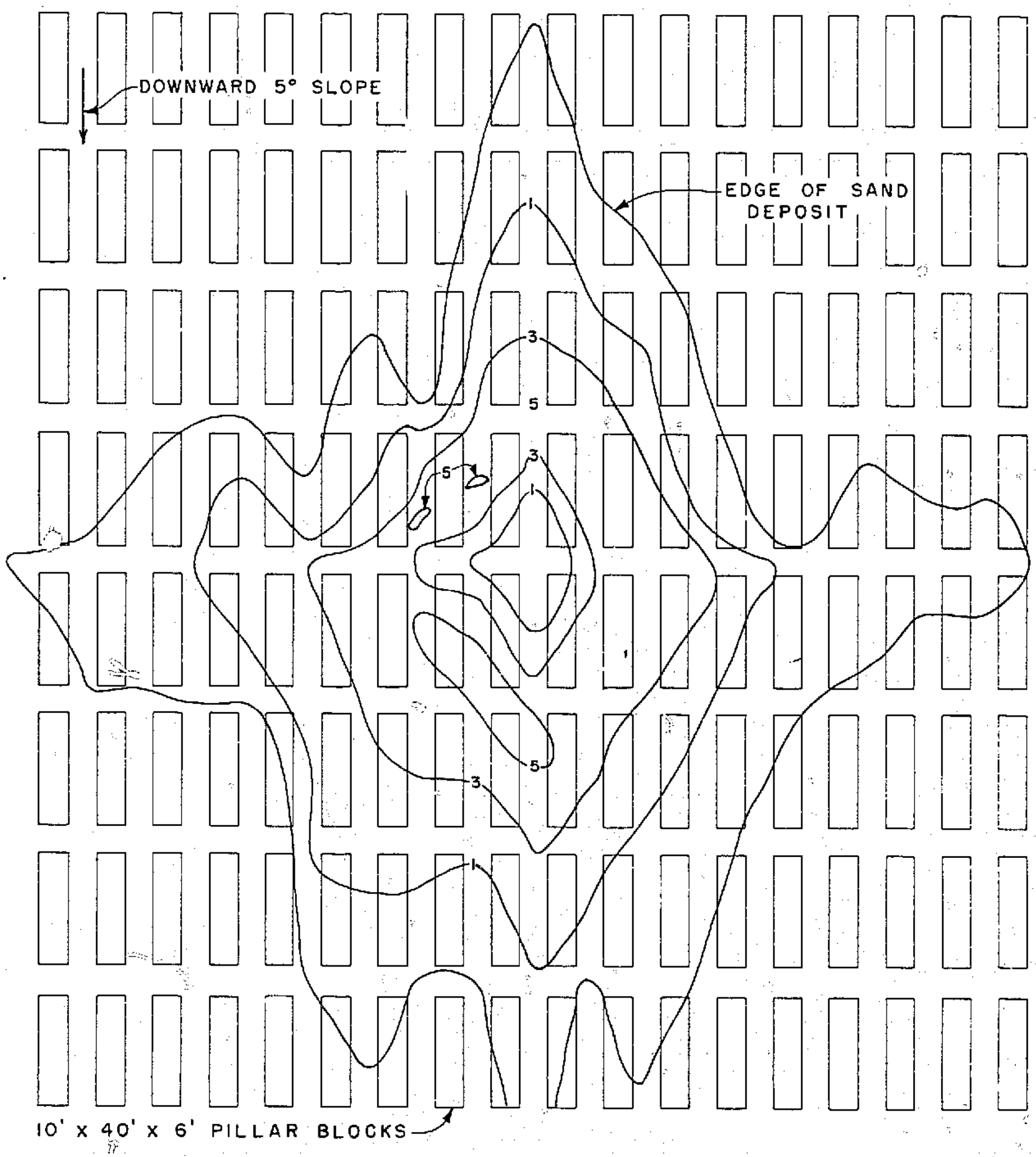


Figure 6. Test 3. Contour map of backfill deposit at end of test. Mine cavity submerged. Mine roof was bolted tight to the pillars. (Distorted model scale)

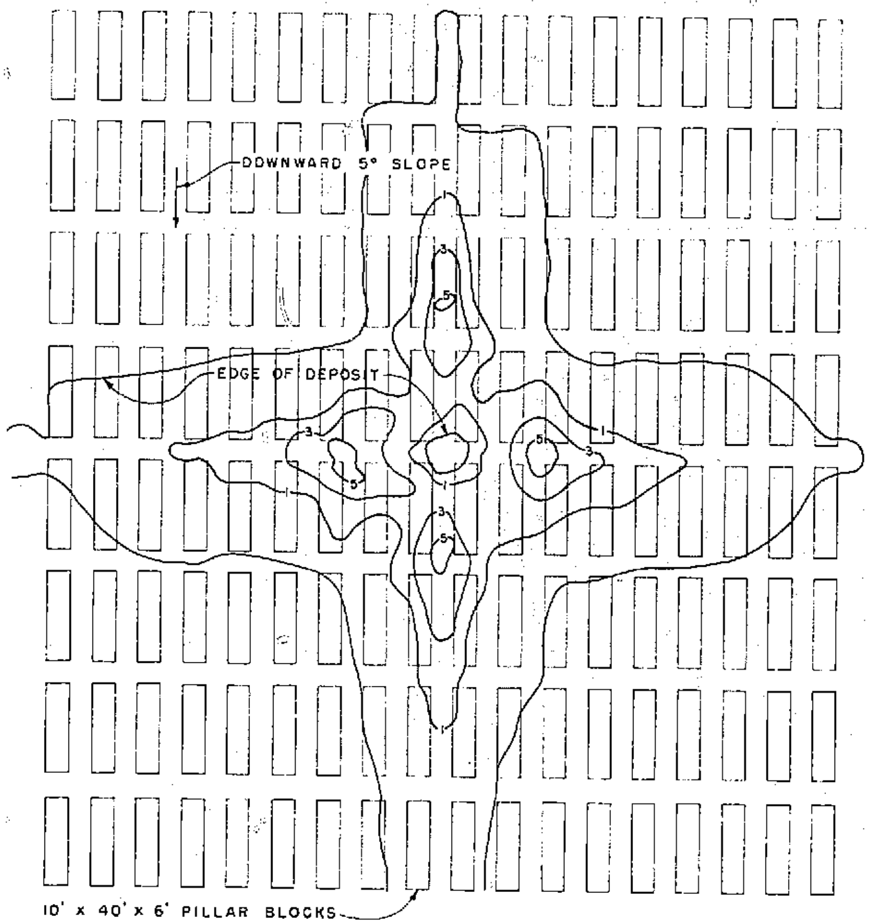


Figure 7. Test 4. Contour map of backfill deposit at end of test. Mine cavity submerged. The pattern of deposit is typical for a small amount of backfill material. (Distorted model scale)

Figure 8. Test 4. The position of the pump intake was changed before test started, causing only a small deposit in the mine cavity during the test. Mine submerged and dipping 5°. (Distorted model scale)

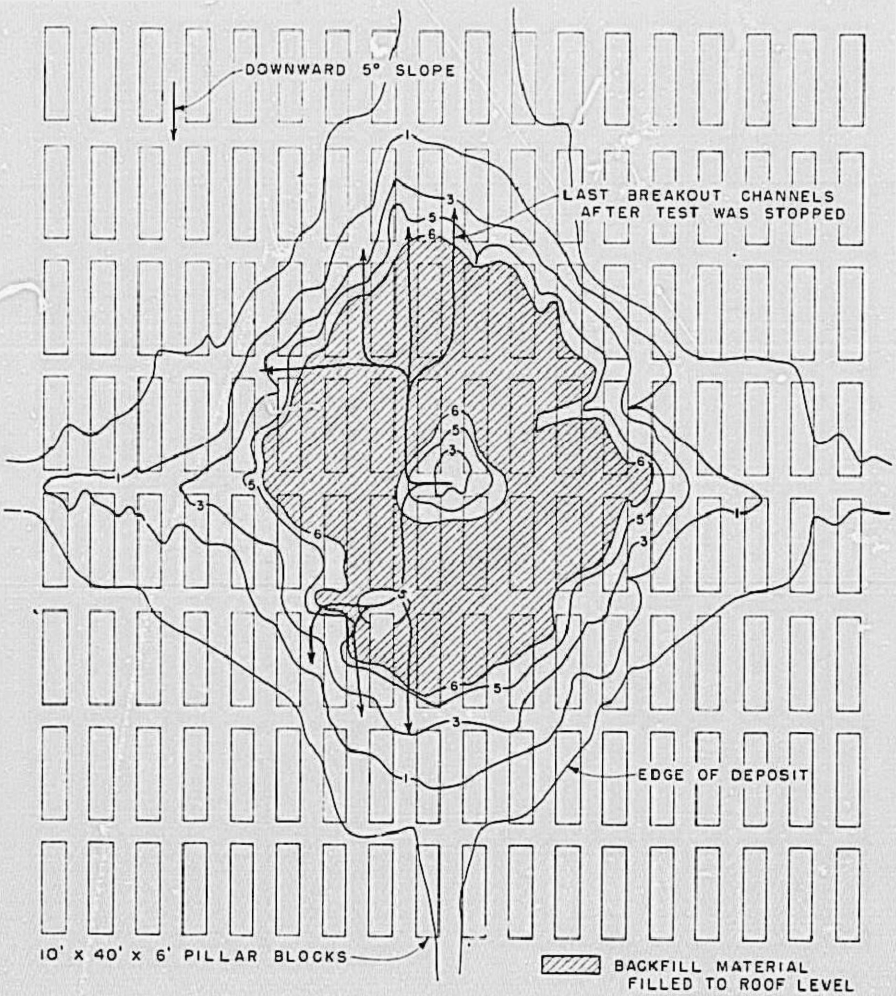


Figure 9. Test 5. Continuation of test 4. Contour map of deposit pattern at end of test. Mine cavity submerged. Compare deposit pattern with figure 7. (Distorted model scale)

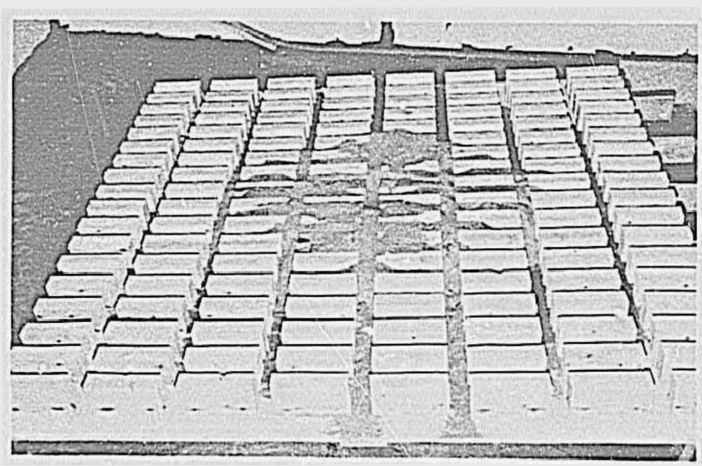


Figure 10. Test 5. This test was a continuation of test 4 in which the backfill deposit was allowed to continue. Mine submerged and dipping 5°. (Distorted model scale)

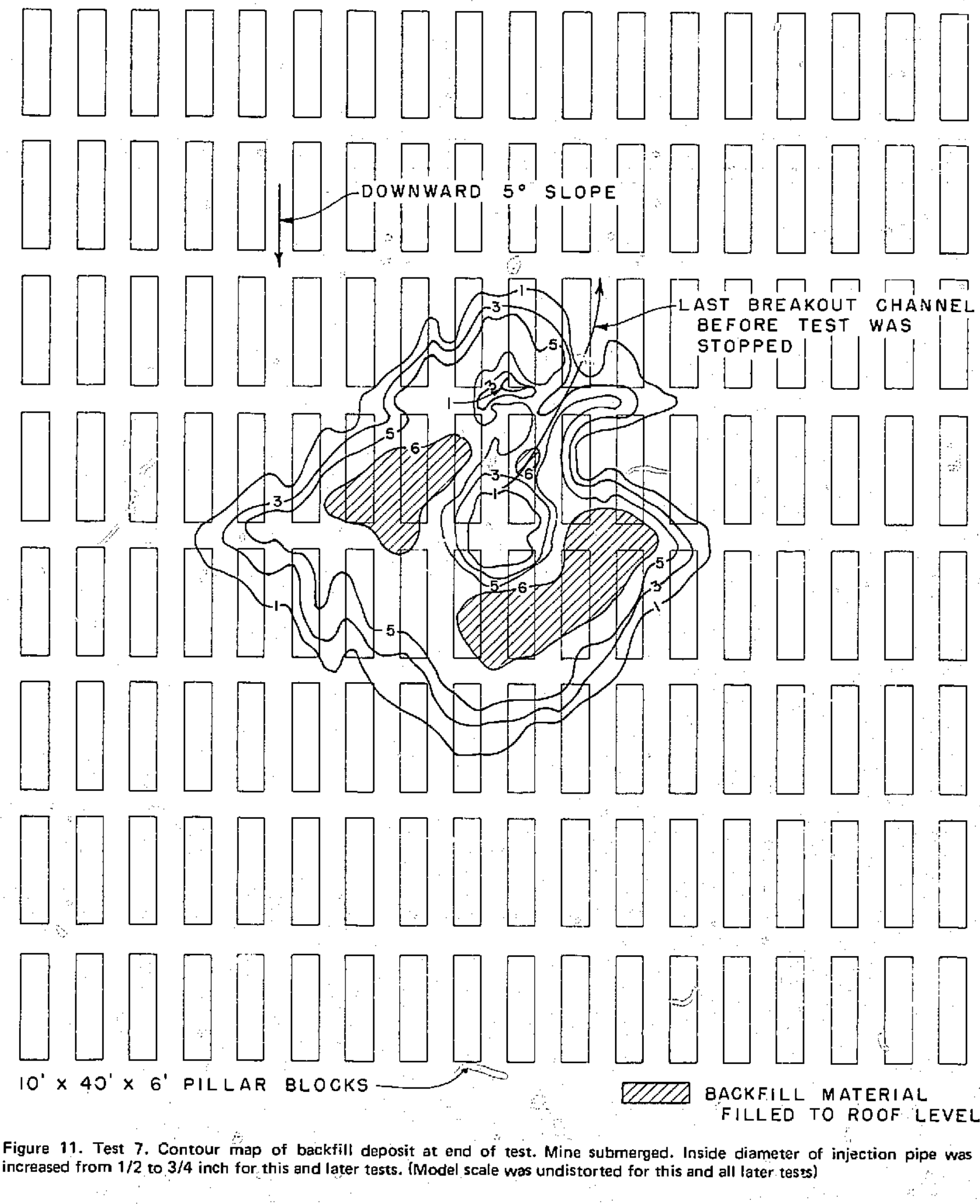
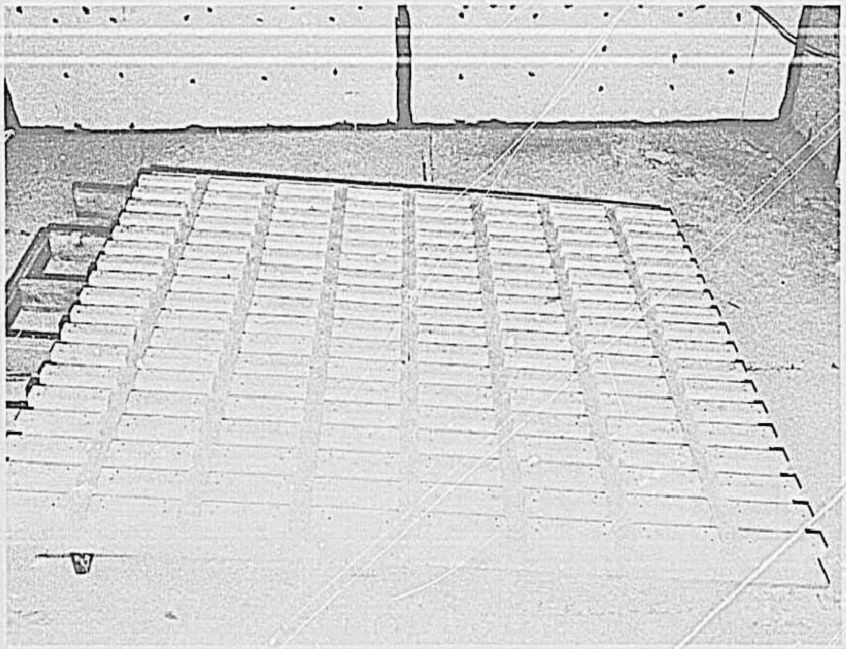


Figure 11. Test 7. Contour map of backfill deposit at end of test. Mine submerged. Inside diameter of injection pipe was increased from 1/2 to 3/4 inch for this and later tests. (Model scale was undistorted for this and all later tests)



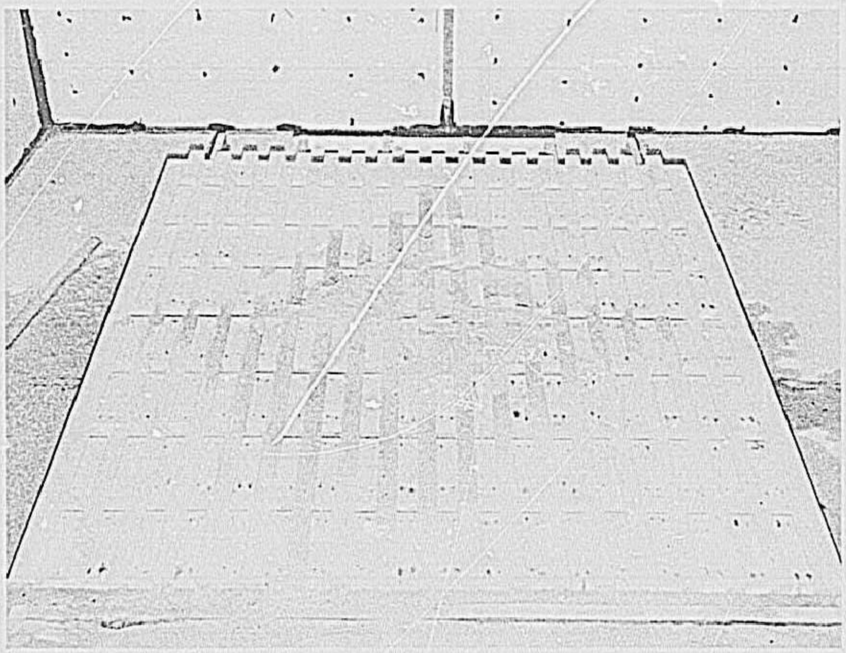


Figure 12. Test 7. Mine pillars and cavity were changed to give an undistorted scale $1^m:48^p$ for this test and all later tests. Mine submerged and dipping 5°.

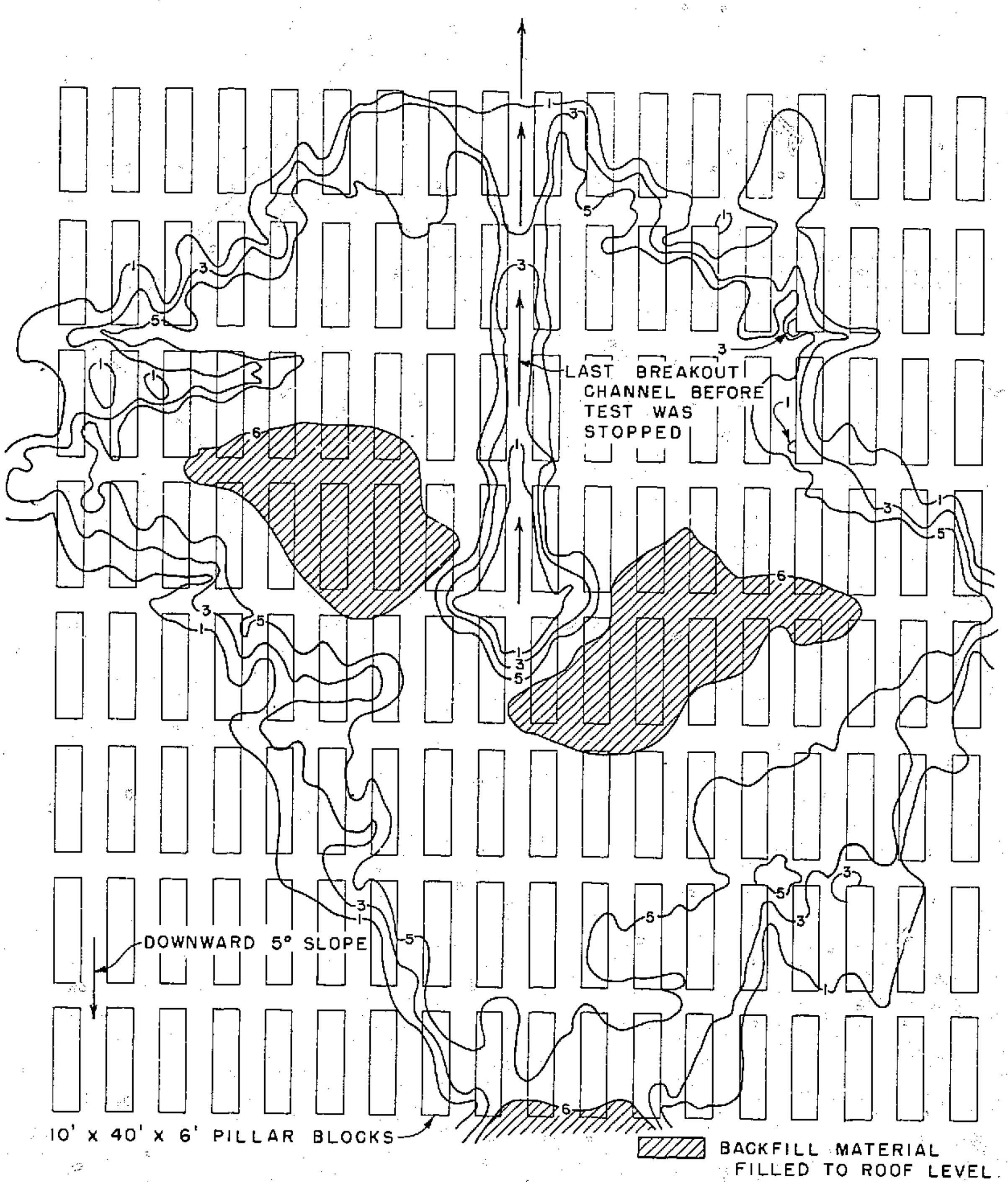


Figure 13. Test 8. Contour map at end of test. Mine submerged. Flow along the last breakout channel occurred at the end of the test. Full flow of the injection pipe down one channel caused equilibrium conditions for sediment transport in one channel to occur. Note that breakout channel flows upslope.

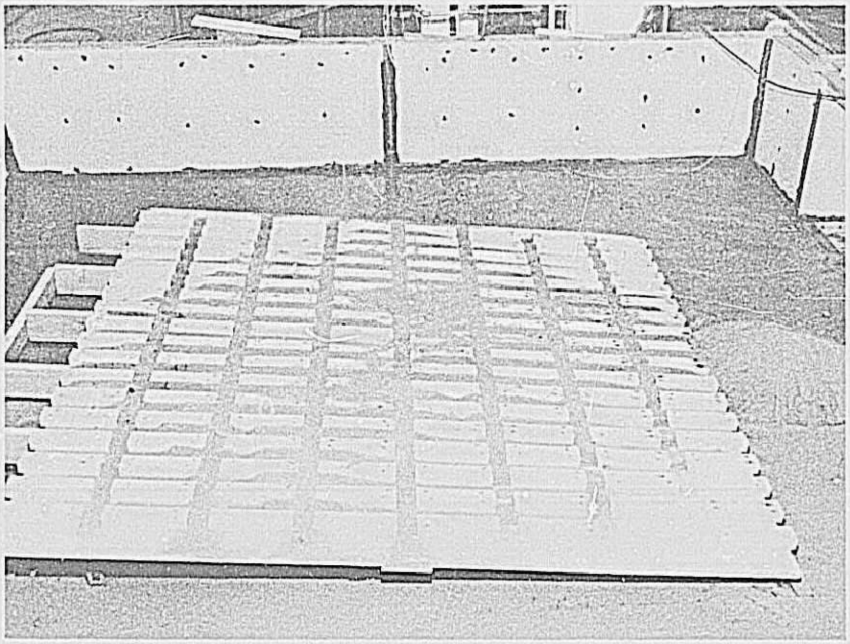


Figure 14. Test 8. Backfill material filled the mine cavity up to or near the roofline over a comparatively large area, see figure 13. The slurry concentration was 11.4 percent by weight for this test. Mine submerged and dipping 5°.

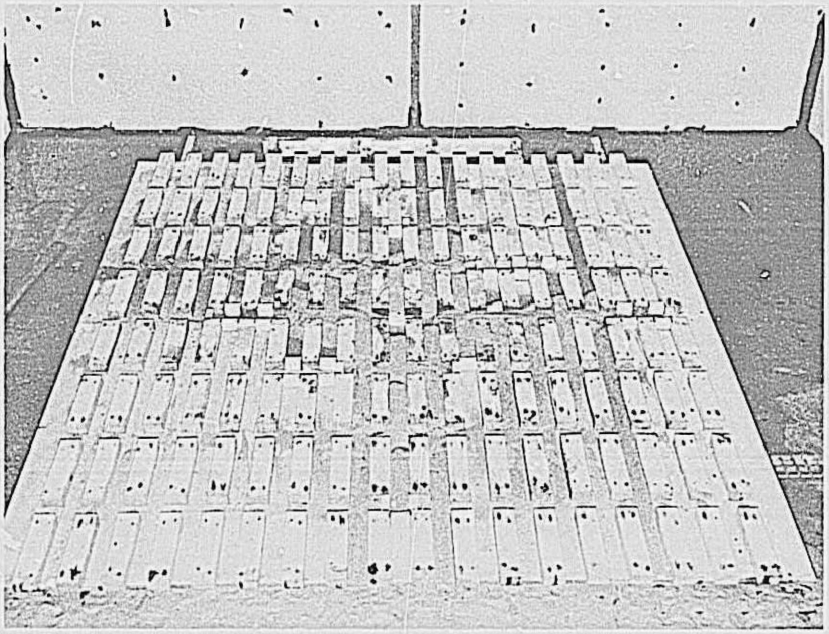


Figure 15. Test 9. First test in the series of three tests, 9–11. Blind entries were simulated by blocking corridors at various places. Mine submerged and dipping 5°.

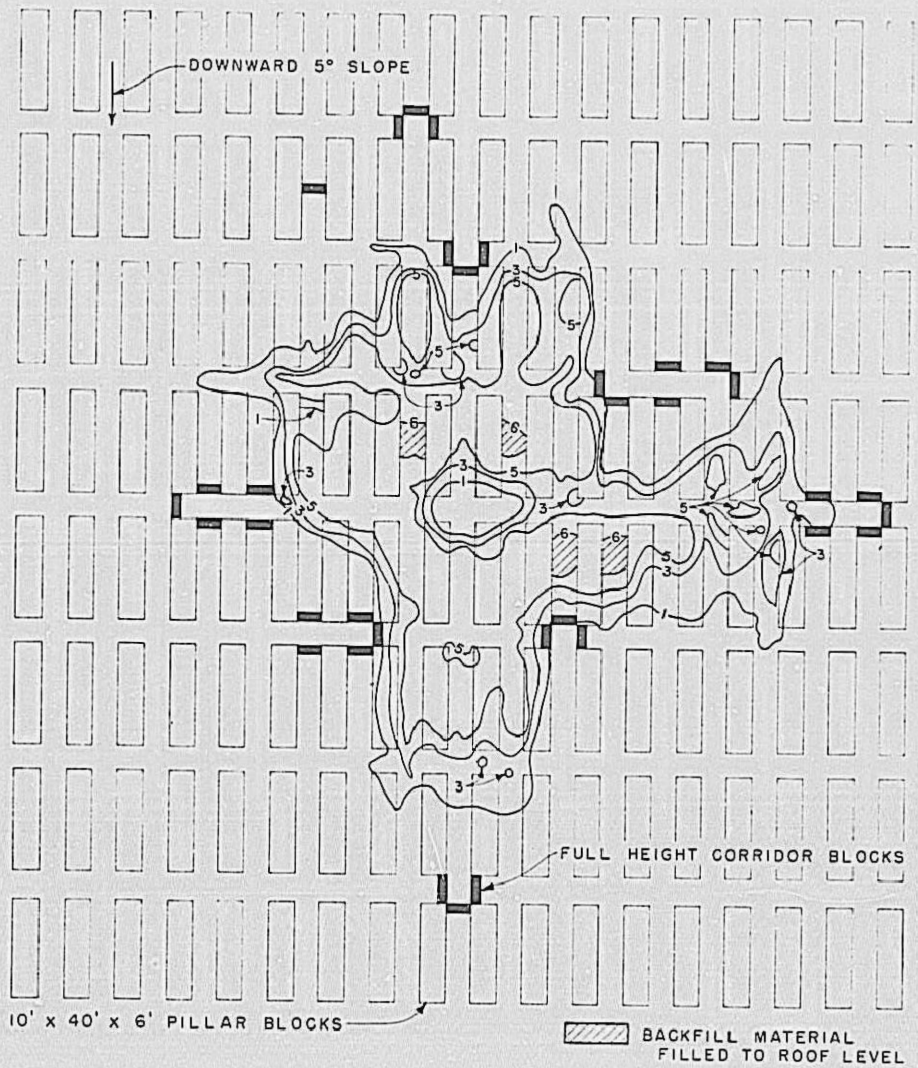


Figure 16. Test 9. Location and pattern of blind entries simulated by solid blocks in the corridors. Contour map shows deposit pattern of backfill at the end of test 9.

Figure 17. Test 11. Corridor 8 is pointed out in which the total injection flow was concentrated after backfill material filled to the roof around the injection hole. Mine submerged and dipping 5°. Last test in series of three tests, 9-11.

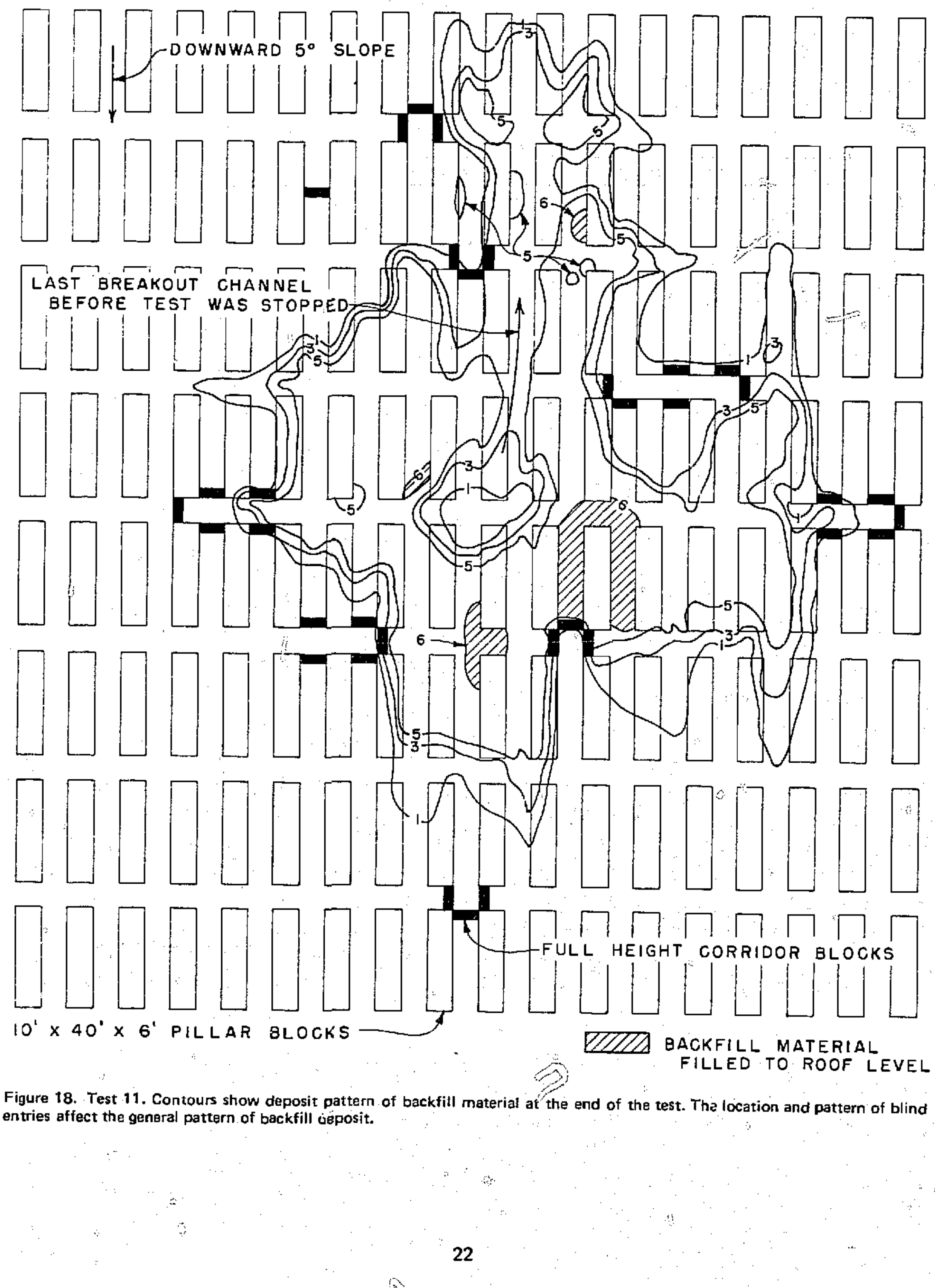


Figure 18. Test 11. Contours show deposit pattern of backfill material at the end of the test. The location and pattern of blind entries affect the general pattern of backfill deposit.

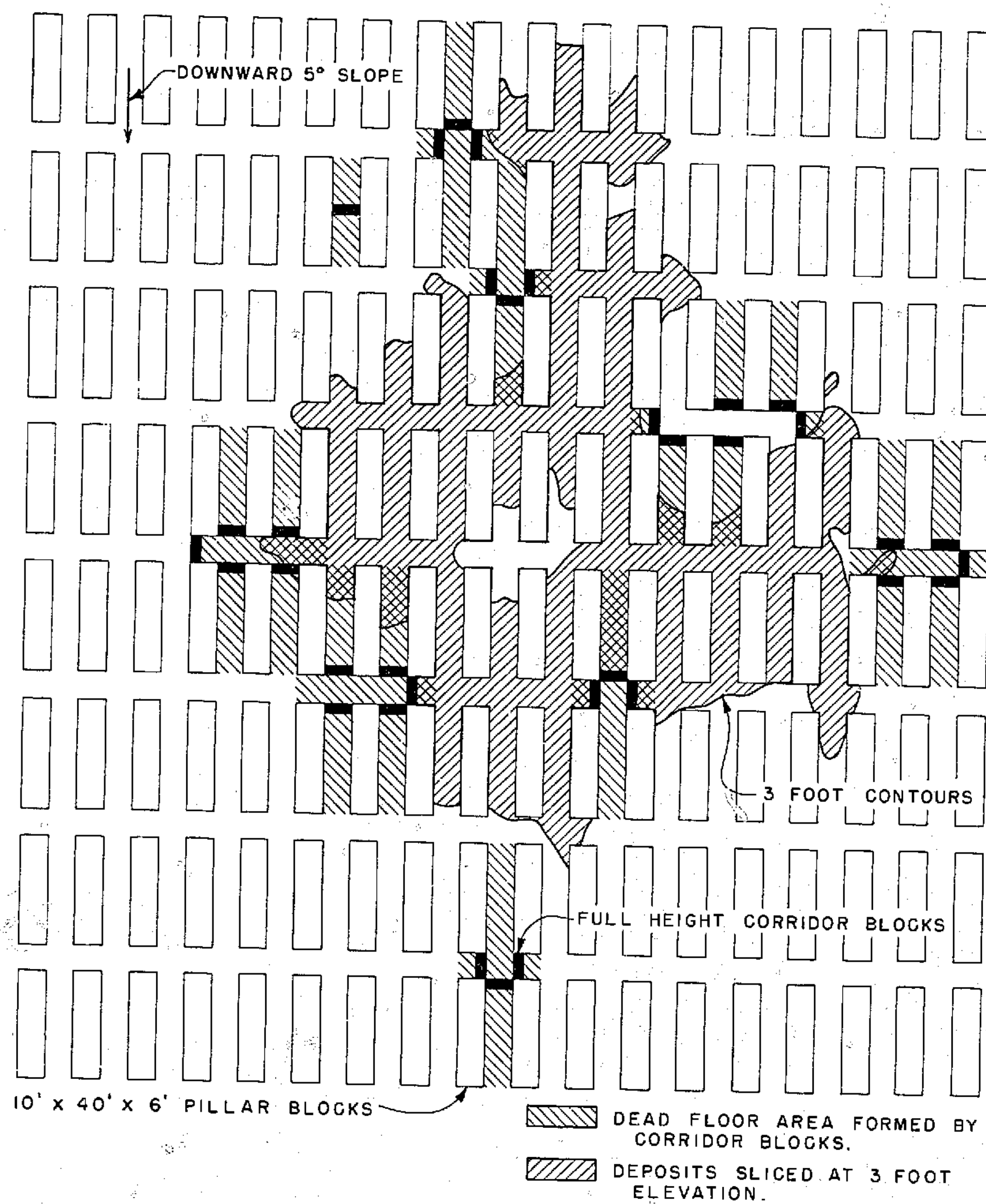
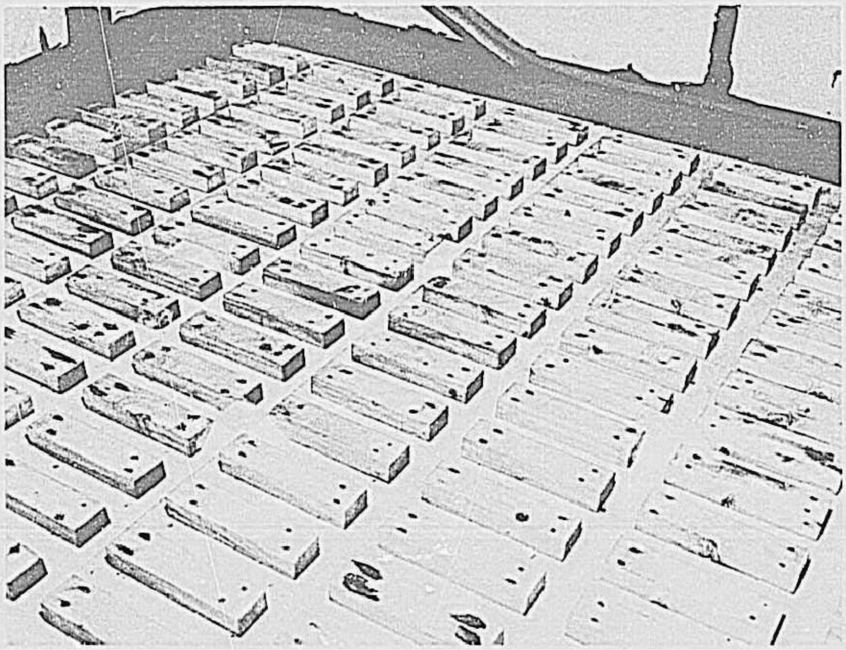
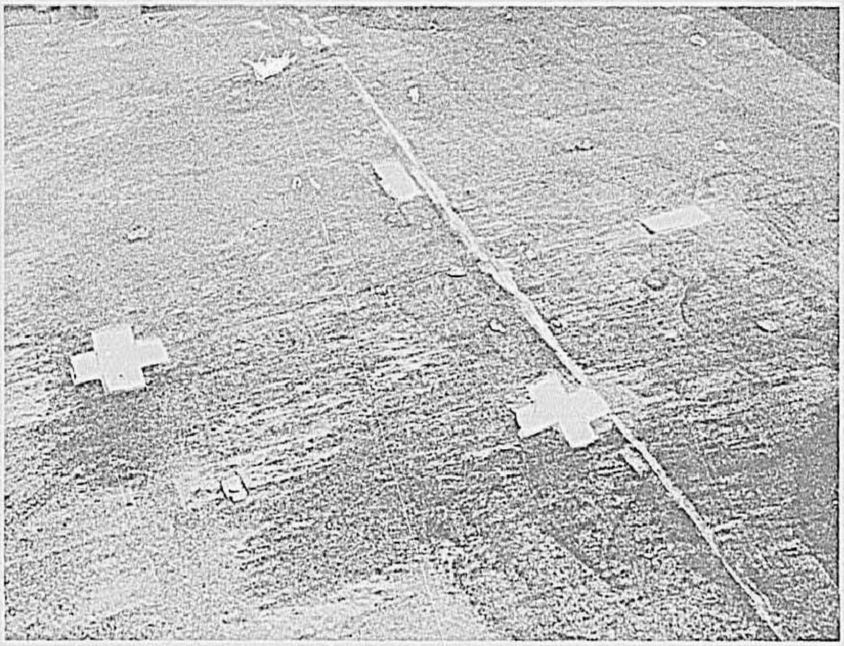


Figure 19. Test 11. Deposits above the 3-foot contour elevation cover a large area around the injection hole. Overlapping crosshatching indicates entry of fill material into blind entries.



Pillars and simulated roof falls.



Roof and openings for cavities

Figure 20. Test 17. Mine pillars and roof before tests simulating roof falls and cavities over the roof falls.

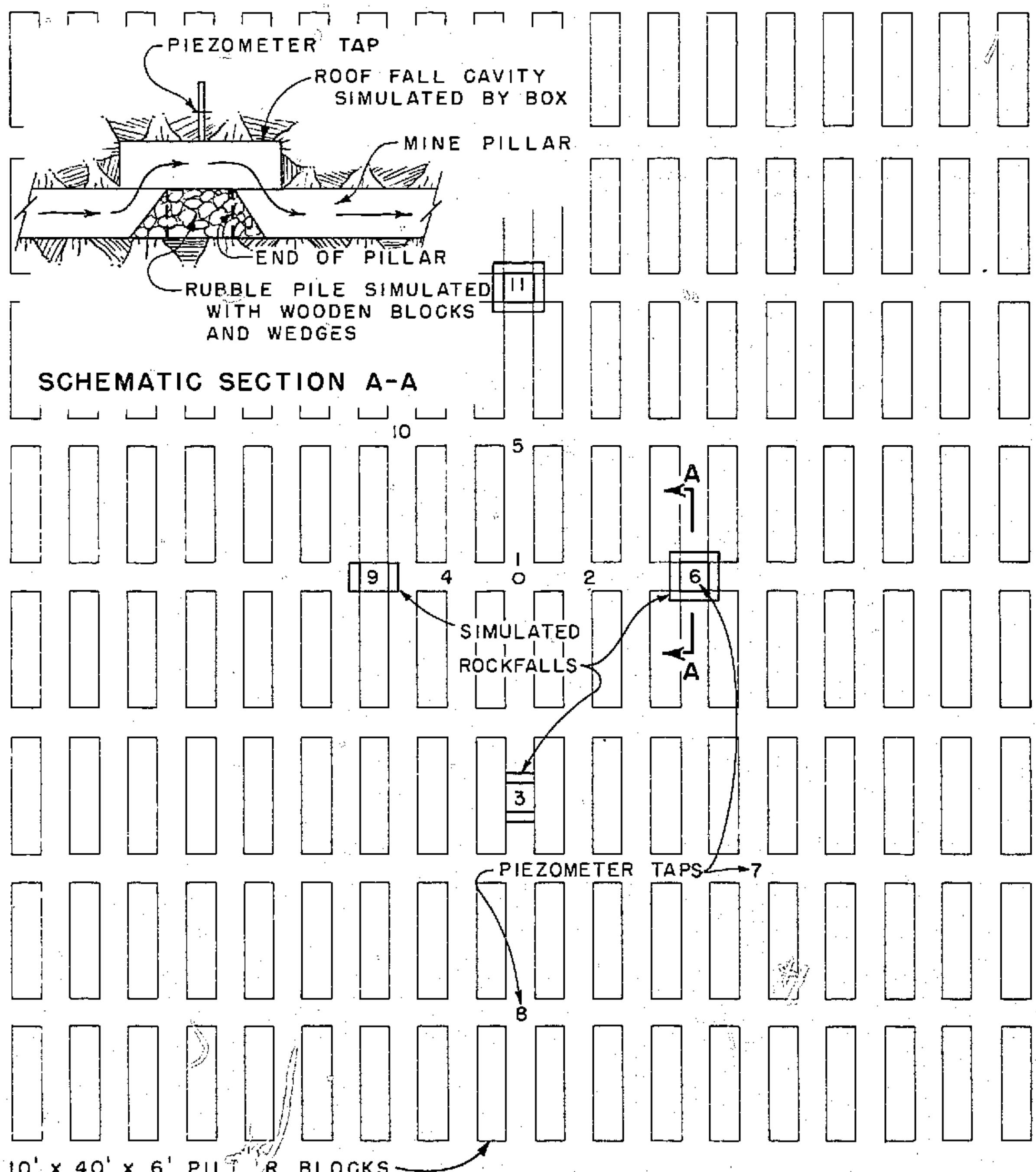


Figure 21. Test 17. Cross section and layout for tests with roof falls and roof cavities over roof falls.

Figure 22. Test 17. Deposit pattern of backfill at the end of the test. Note backfill deposited in cavities over roof falls.

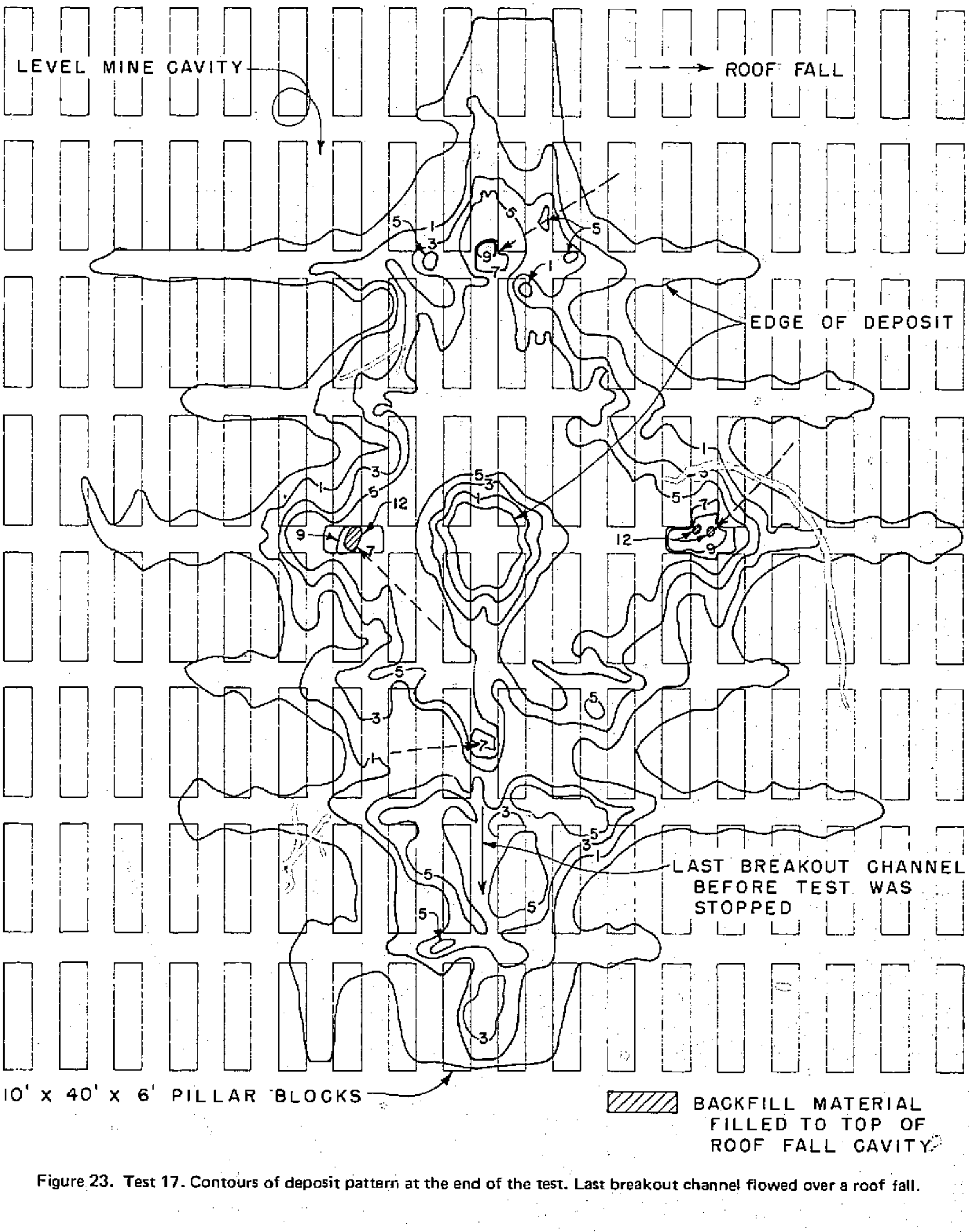


Figure 23. Test 17. Contours of deposit pattern at the end of the test. Last breakout channel flowed over a roof fall.

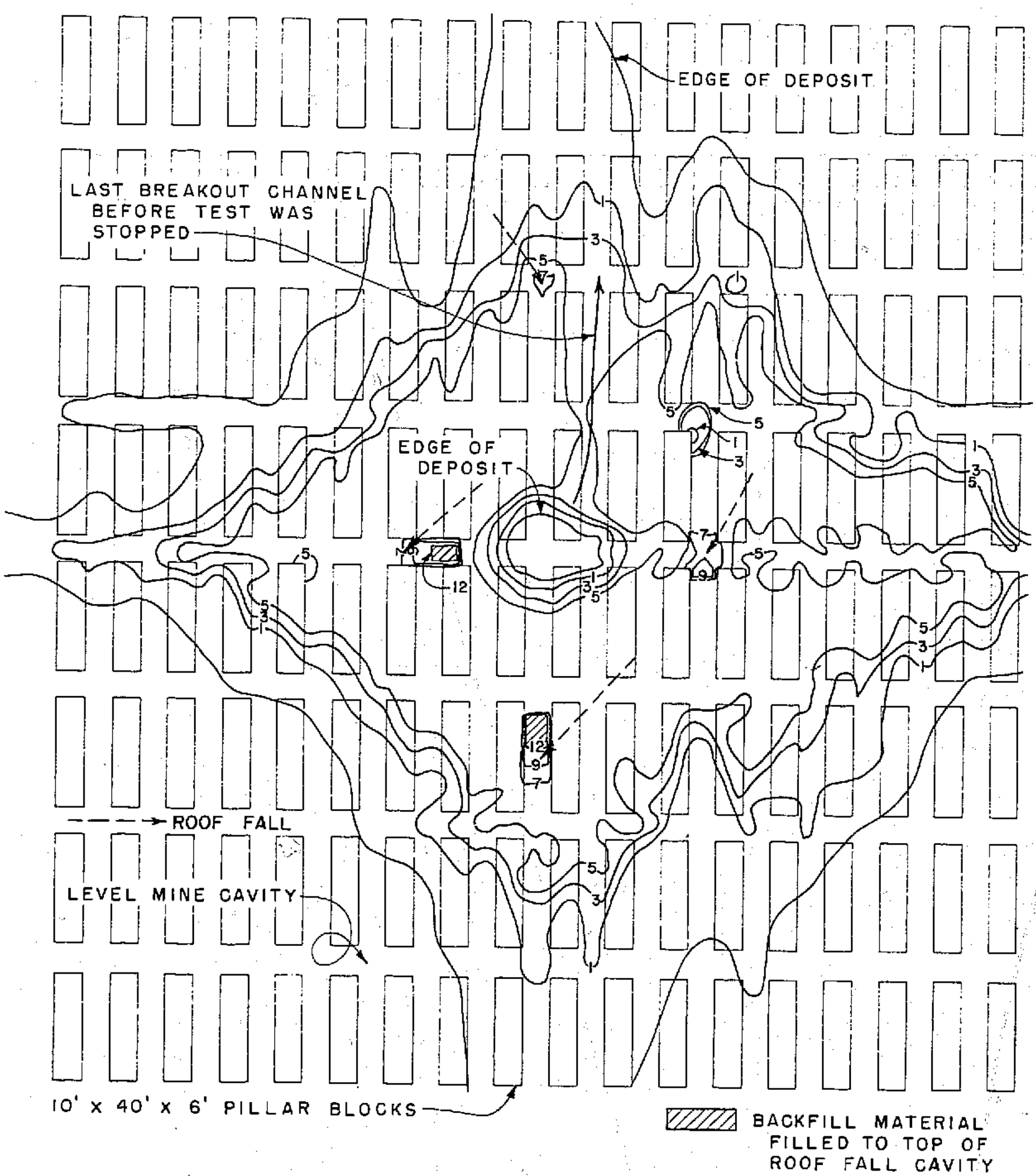


Figure 24. Test 18. This test was a duplicate of test 17 except test 18 had a higher injection velocity and a higher slurry concentration. Note breakout channel in a corridor adjacent to a rockfall.

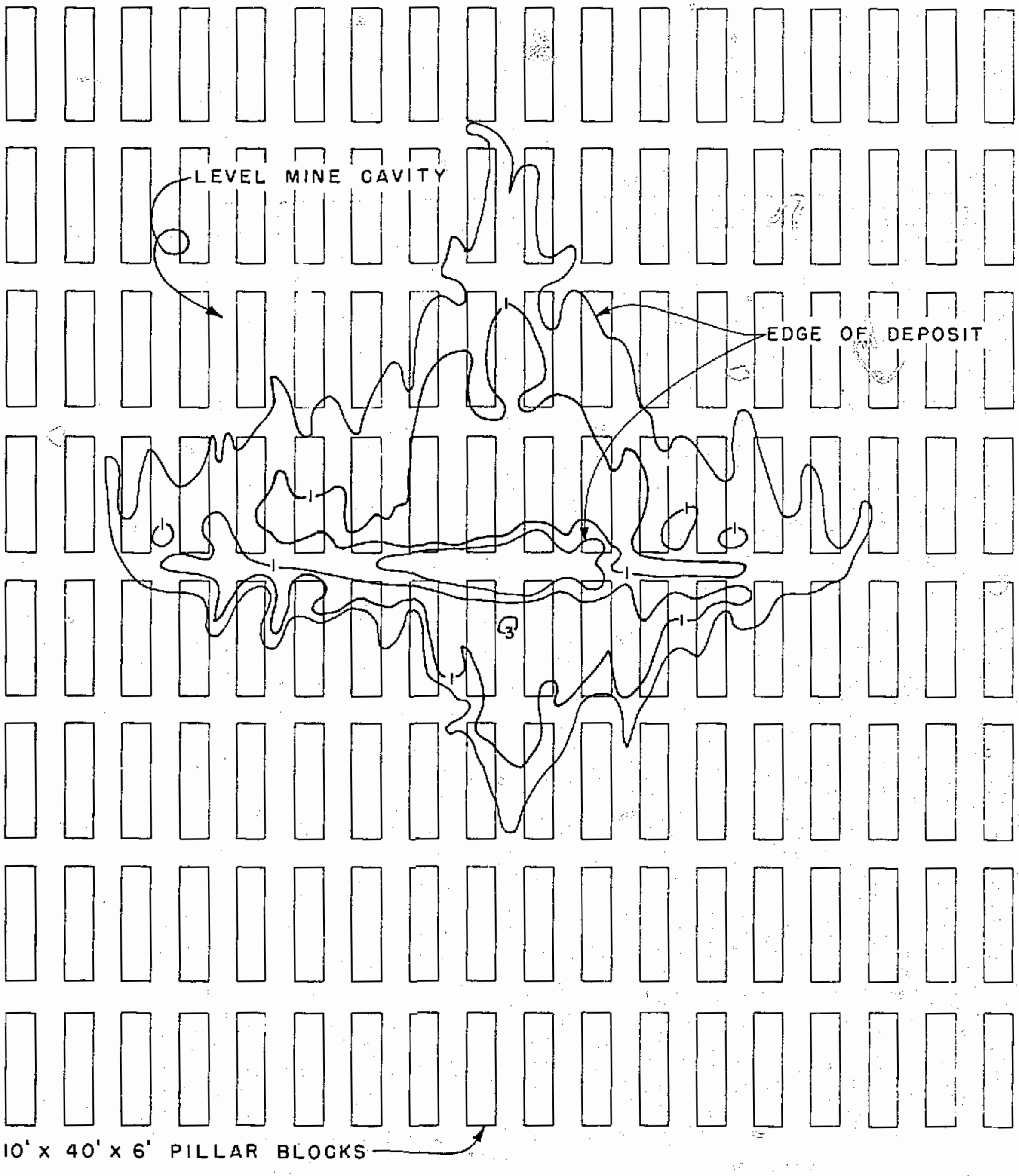
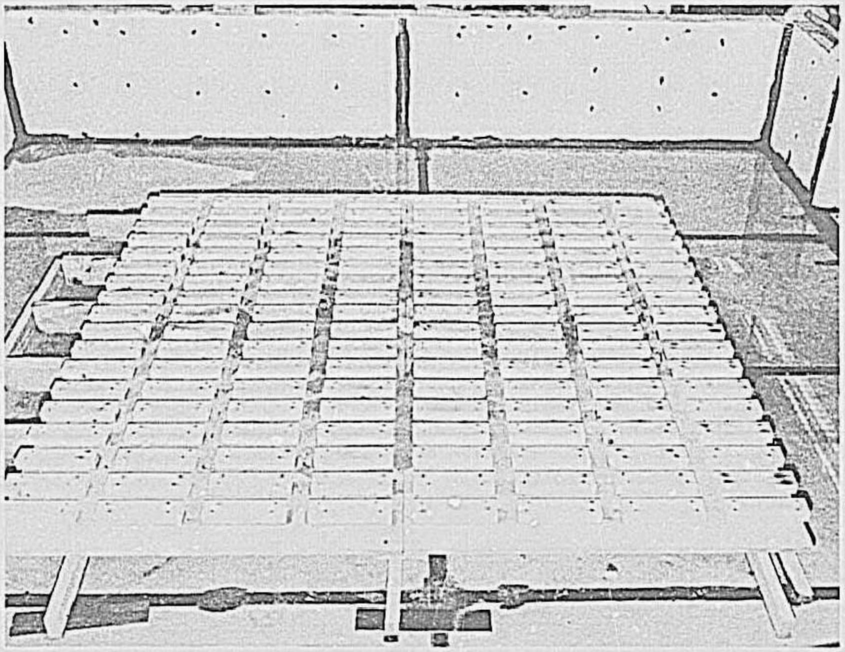


Figure 25. Test 12. The first of a series of four tests, 12-15, made in a dry cavity with a level floor. Contour map shows backfill deposit pattern at the end of the test.



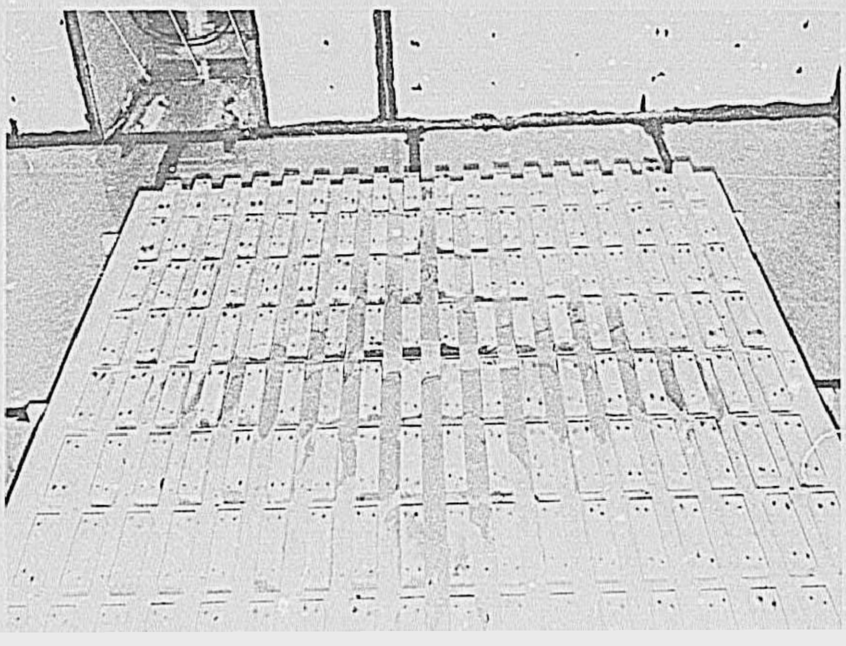


Figure 26. Test 12. The low height of deposit is a result of injection into a dry cavity with a level floor.

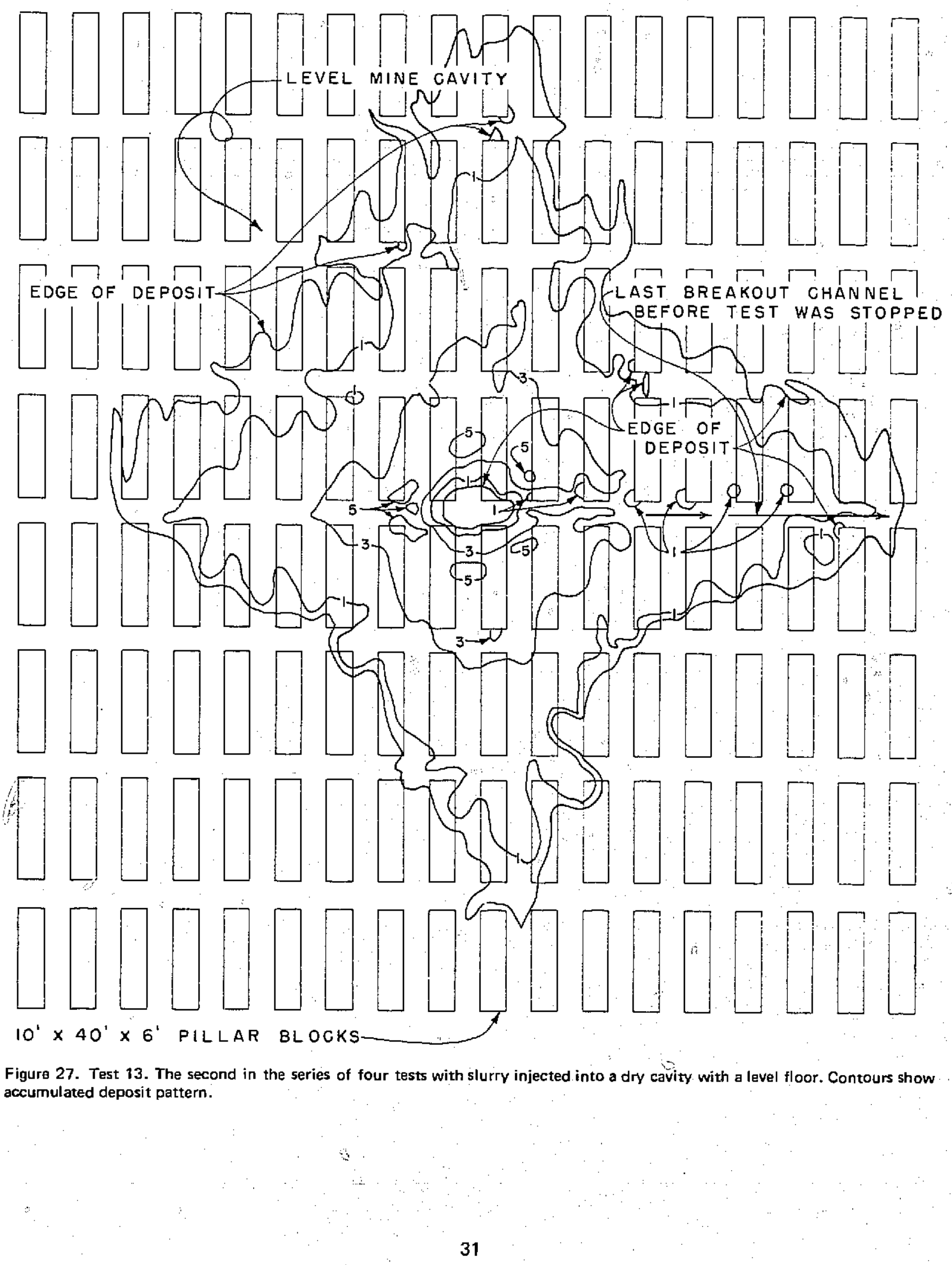
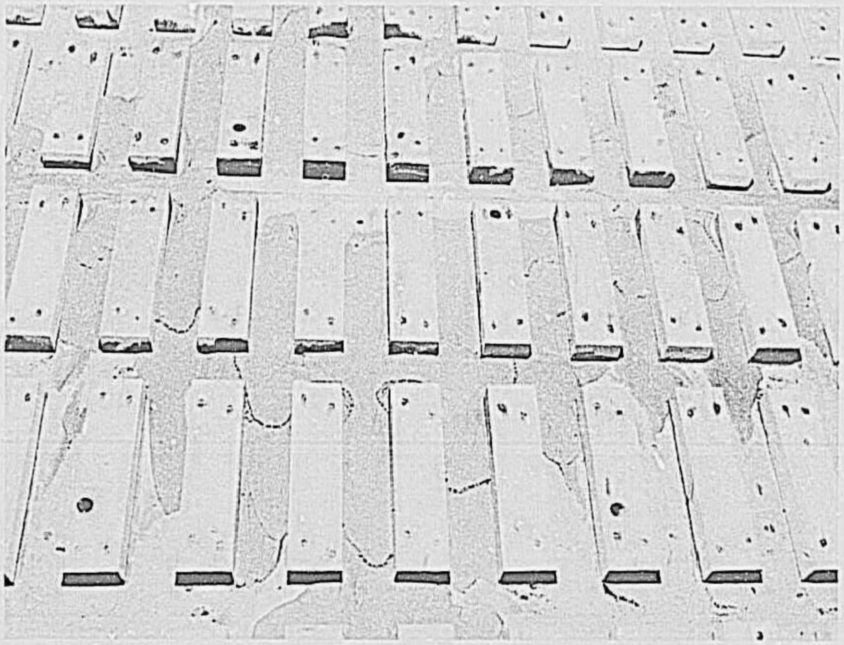


Figure 27. Test 13. The second in the series of four tests with slurry injected into a dry cavity with a level floor. Contours show accumulated deposit pattern.



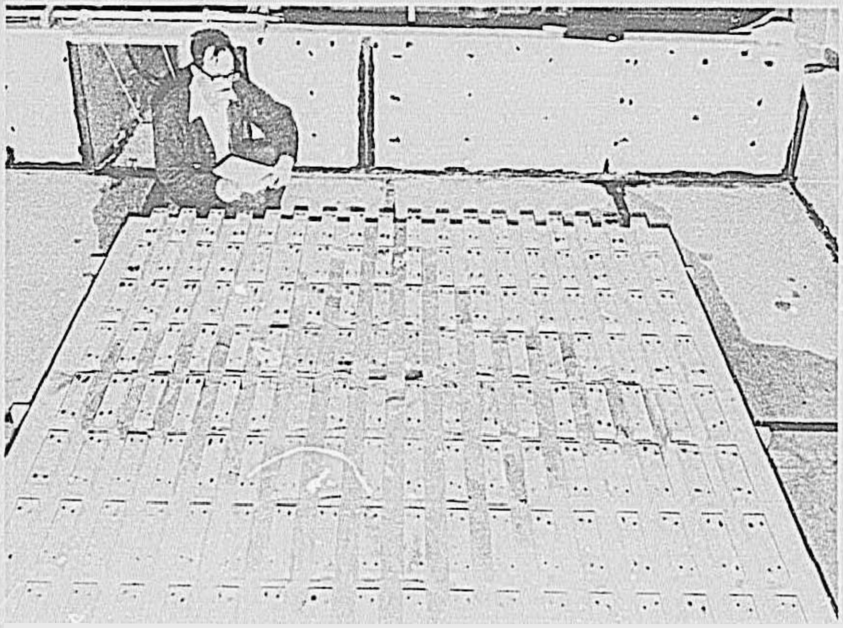


Figure 28. Test 13. Accumulated deposit after the second in the series of four tests shows shallow deposits and flat slopes on the surface of the deposited backfill material.

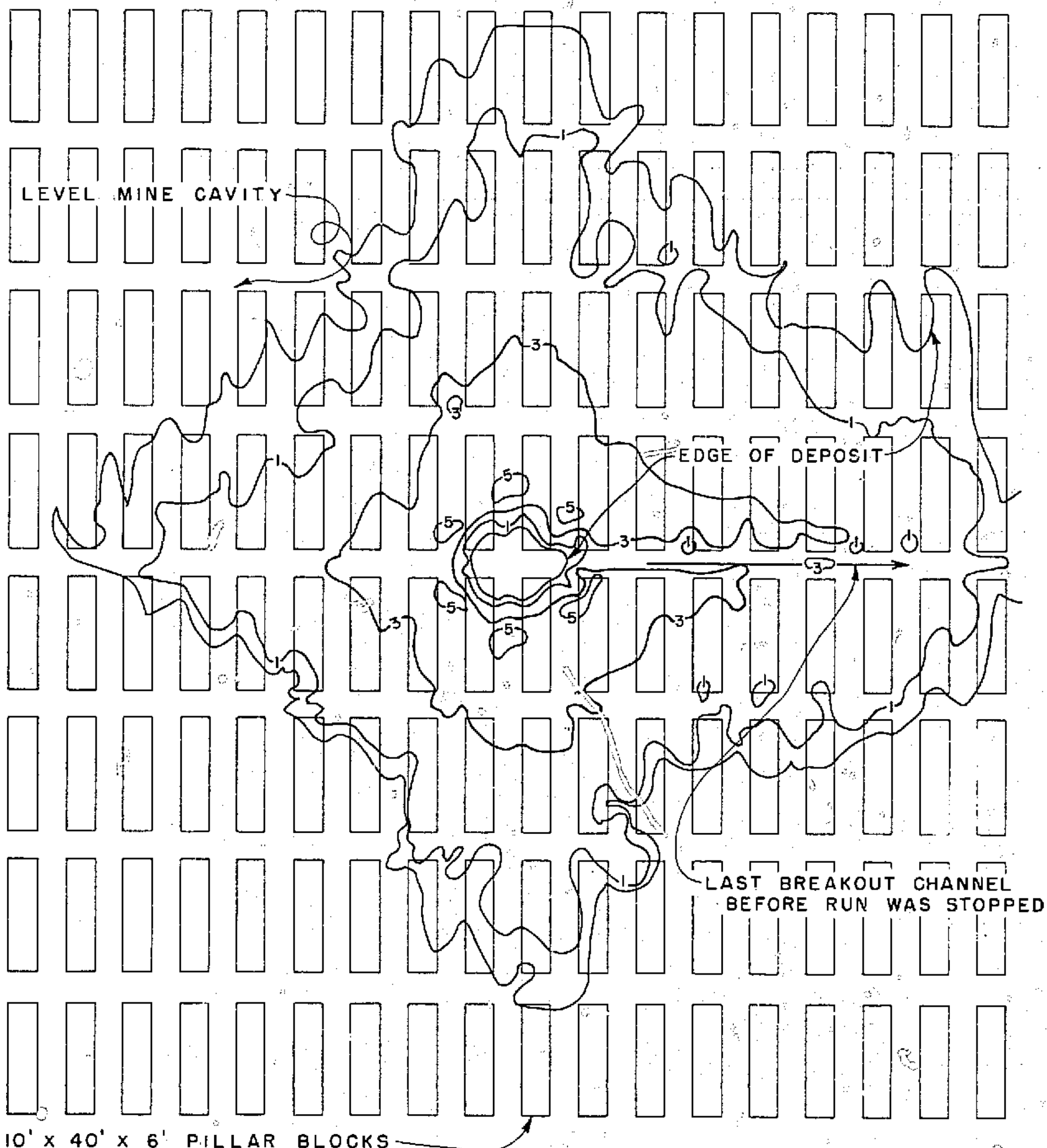


Figure 29. Test 14. The backfill material continues to build up as the third in the series of four tests is completed in a dry cavity with a level floor.

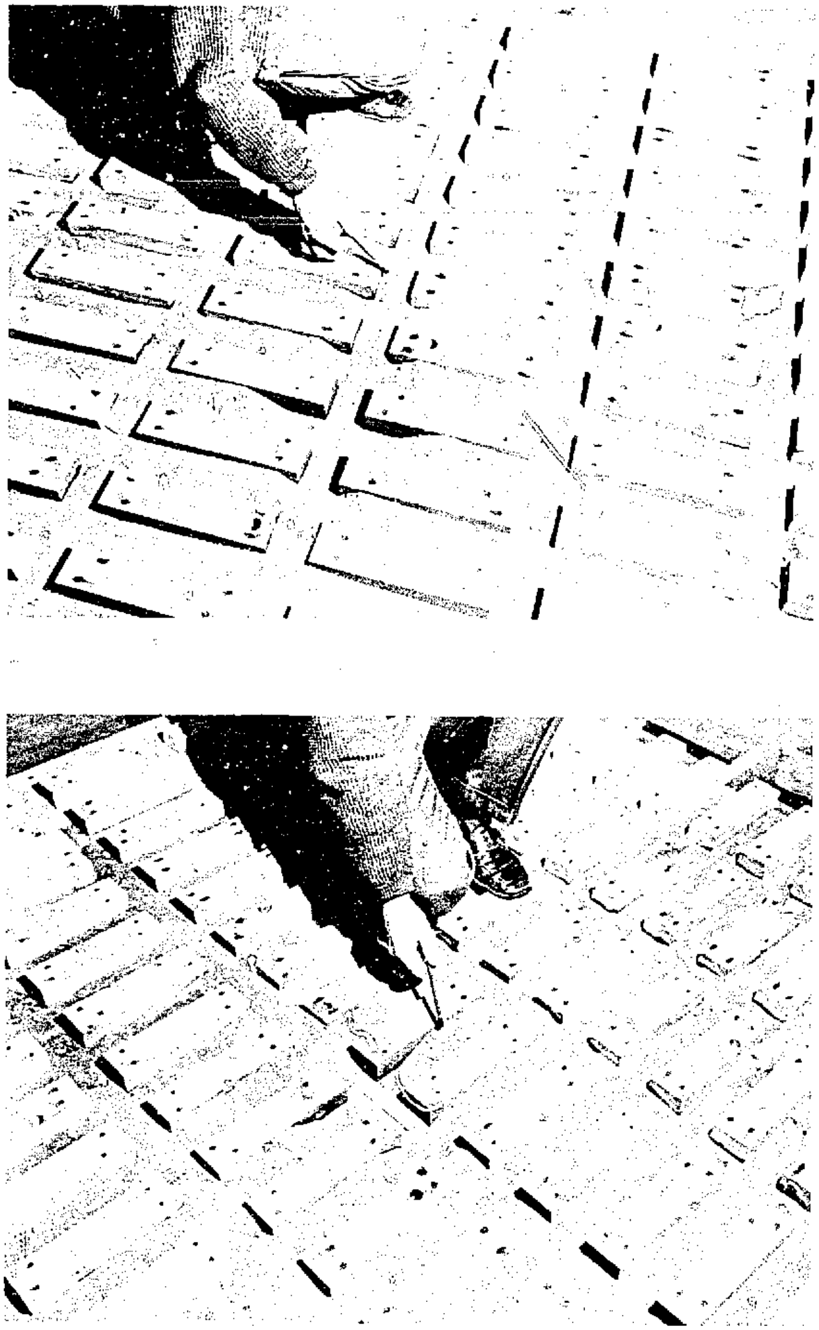


Figure 30. Test 14. Deposit around the injection hole is uniform in a dry cavity with a level floor.

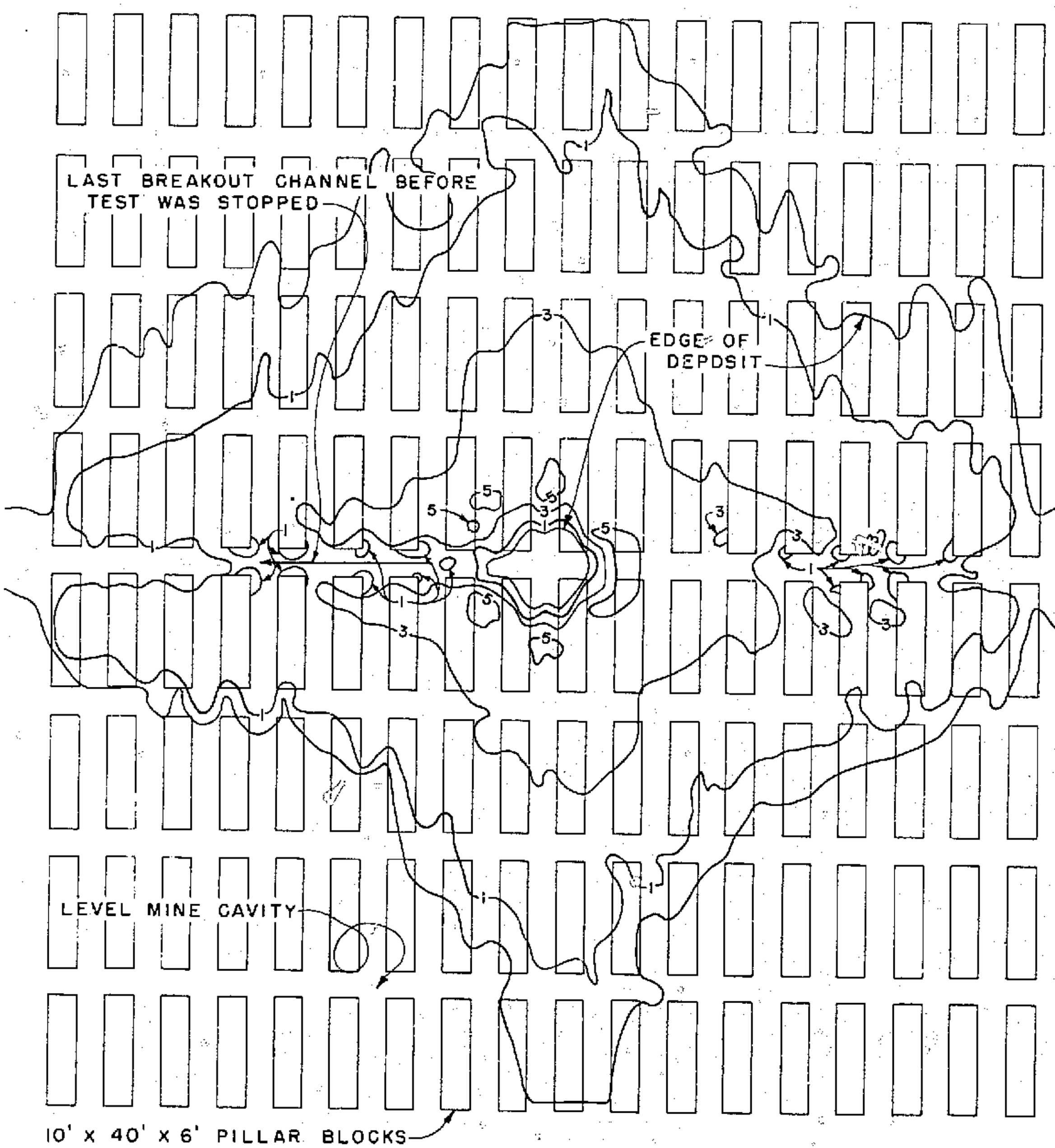


Figure 31. Test 15. Contour map showing backfill deposit at the end of the series of four tests. Note the last breakout channel before the end of the test.

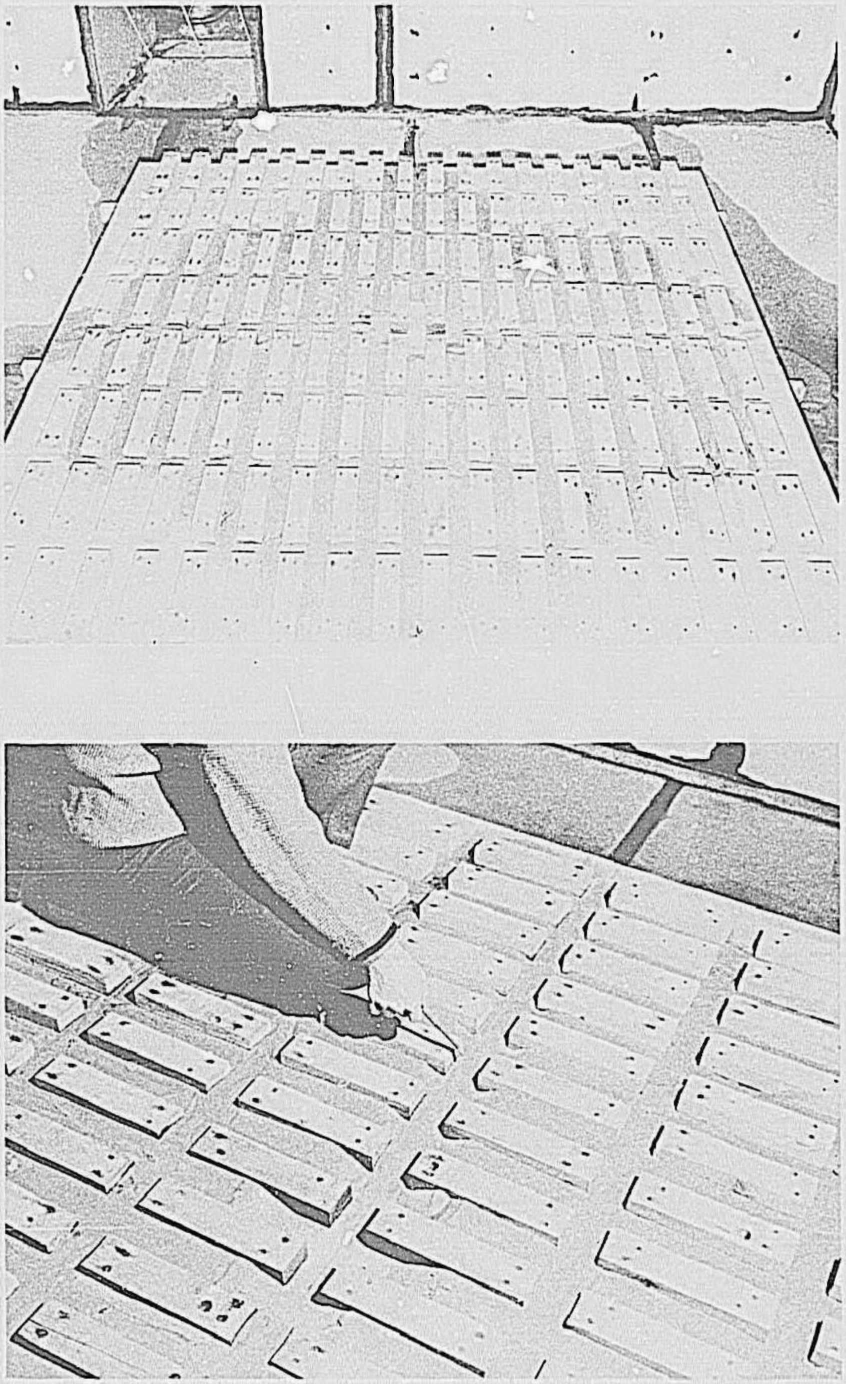


Figure 32. Test 15. Backfill material has built up near the roof close to the injection point at the end of the series of four tests in a dry mine with a level floor.

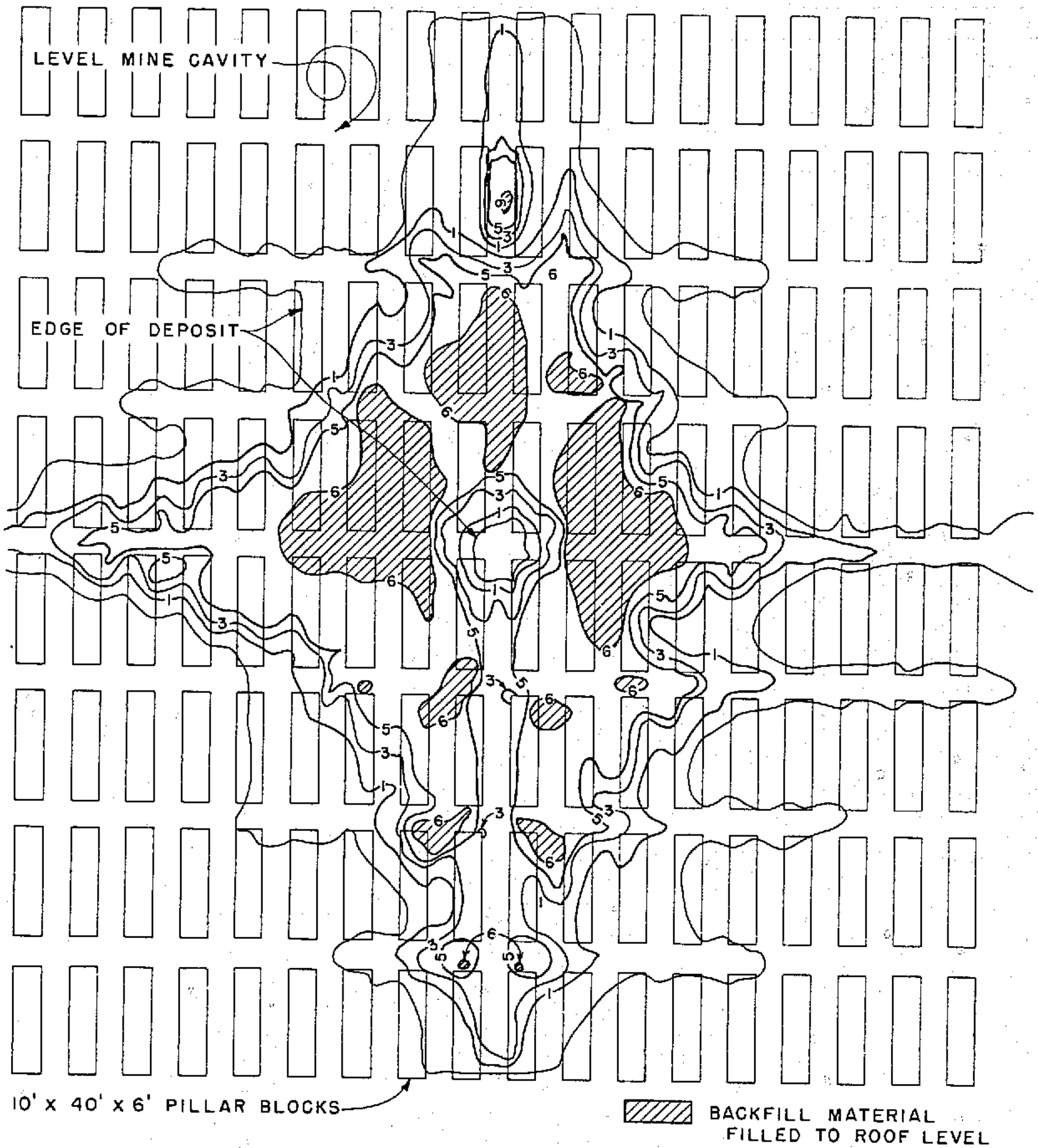


Figure 33. Test 16. Contour map of deposited fill material at end of test. Compare the deposit pattern on this level mine test with test 8 (fig. 13) in a sloping mine.

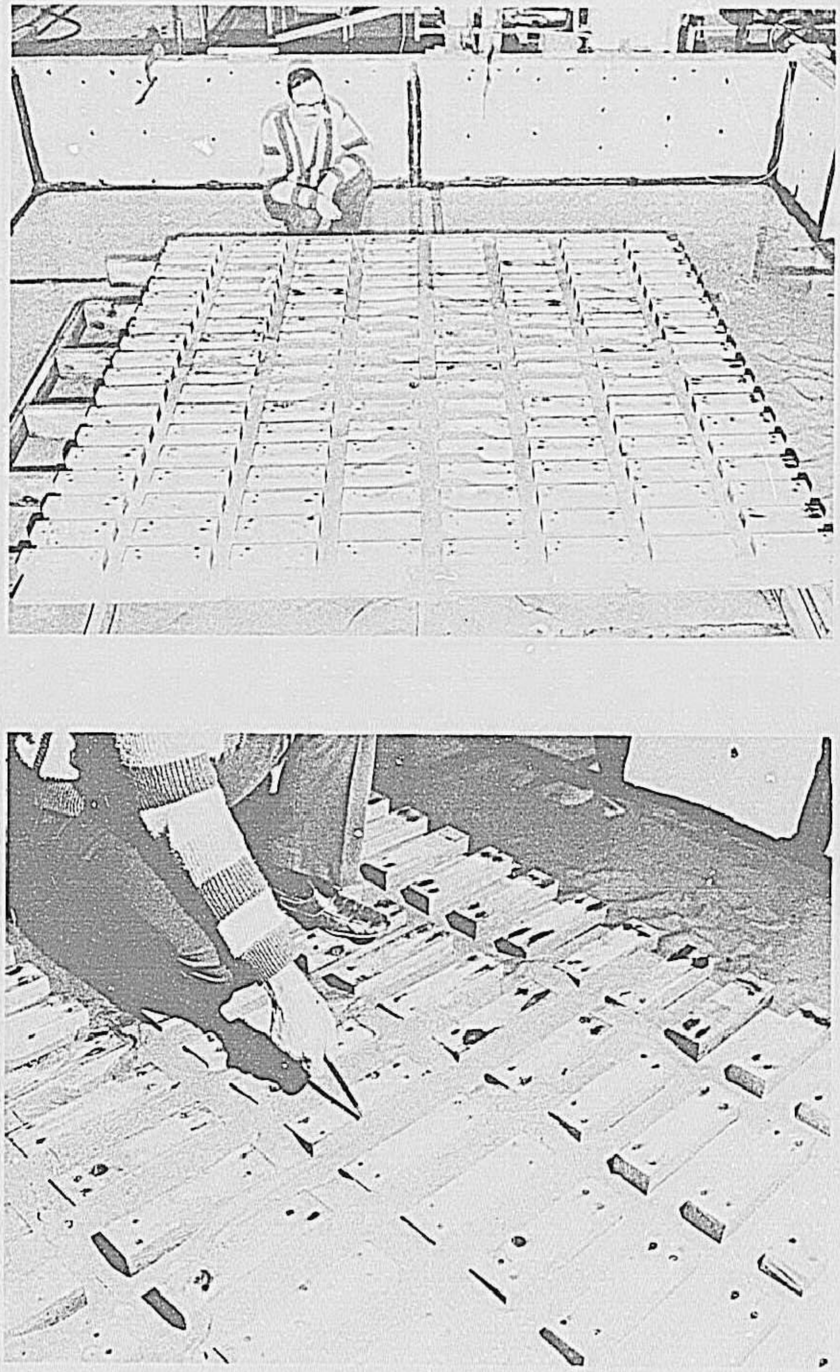


Figure 34. Test 16. the final breakout channel is pointed out on the photograph. Test was for a mine with a level floor and submerged.

7-1750 (3-71)
Bureau of Reclamation

CONVERSION FACTORS–BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	$^*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	$^*4.4482 \times 10^5$	Dynes

Table II--Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

GPO 859-045

ABSTRACT

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REC-ERC-75-3
CARLSON, E J
HYDRAULIC MODEL STUDIES FOR BACKFILLING MINE CAVITIES
(Second Series of Tests)
Bur Reclam Rep REC-ERC-75-3, Div Gen Res, Mar 1975. Bureau of Reclamation, Denver, 38 p, 34 fig, 1 tab, 7 ref

DESCRIPTORS—/ hydraulic models/ *backfills/ *mines/ *hydraulic mine-filling/ cavities/ scale (ratio)/ models/ sands/ fines/ velocity/ pressure/ injection/ injectors/ *slurries/ back pressure/ hydraulic pressure/ deposition/ hydraulic transportation
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