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FIELD EVALUATION OF THE WATER WEDGE FOR CUTTING PORTLAND CEMENT CONCRETE PAVEMENTS FOR REPAIR AND RESTORATION OF PAVED SURFACES (REREPS)

by

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The Water Wedge is a portable hand tool designed to demolish rock, concrete, and reinforced concrete. This study determined the suitability for cutting portland cement concrete (PCC) pavements in bomb damage repair situations. Test holes were made in an existing 12-in. PCC pavement, and a series of tests were conducted with two explosive charge cartridges. Results indicate that the Water Wedge is not an effective means of producing a smooth break in a 12-in.-thick PCC slab especially when used away from one or more

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20. ABSTRACT (Continued).

free edges. The time required to accomplish the cut was also considered too long for the repair and restoration of paved surfaces (REREPS) project.

PREFACE

The investigation reported herein is under the sponsorship of the Office, Chief of Engineers, US Army, and is being conducted under Project AT40, Task CO, Work Unit 002, "Repair and Restoration of Paved Surfaces (REREPS)."

This study was conducted at the US Army Engineer Waterways Experiment Station (WES) from March 1983 through October 1983 by the Pavement Systems Division (PSD) of the Geotechnical Laboratory (GL). Personnel of the PSD involved in this study were Dr. G. M. Hammitt II and Mr. D. M. Coleman. This report was written by Mr. Coleman.

This work was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, and under the direct supervision of Mr. H. H. Ulery, Jr., Chief, PSD, GL. The report was edited by Ms. Odell F. Allen, Publications and Graphic Arts Division.

COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	6.894757	kilopascals

FIELD EVALUATION OF THE WATER WEDGE FOR CUTTING PORTLAND CEMENT CONCRETE PAVEMENTS FOR REPAIR AND RESTORATION OF PAVED SURFACES (REREPS)

PART I: INTRODUCTION

Background

1. The Water Wedge is a portable hand tool designed to demolish rock formations, concrete, and reinforced concrete structures. The manufacturer's instruction manual for the Water Wedge states that during operation no seismic or shock waves are generated, and scattering of rock or concrete fragments is minimal. The instruction manual also states that the demolition of large objects requires multiple drilled holes spaced between 12 and 36 in.* apart, depending on the hardness of the material. Although not stated in the instruction manual, conversations with the manufacturer indicate that the device must have at least one free edge nearby for effective cracking.

Purpose

2. The purpose of this study was to determine if the Water Wedge device is a suitable tool for cutting portland cement concrete (PCC) pavements in bomb damage repair situations. Specific objectives of this study were to:

a. Determine the ability of the Water Wedge device to break PCC airfield pavements and cut straight line breaks in concrete slabs.

b. Determine the optimum explosive charge to use in breaking a 12-in.-thick PCC pavement.

c. Determine the optimum hole spacing for rapid linear cutting of a 12-in.-thick PCC pavement.

d. Determine the best methods for producing a straight crack in the PCC pavement.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART II: EQUIPMENT AND PROCEDURE

Water Wedge Device

3. The Water Wedge 1200 device used in this study is shown in Photo 1. The device is 29 in. long, weighs 22 lb, and is manufactured from high strength steel. Photo 2 presents an exploded view of the device with each number keyed to a specific part.

4. The explosive cartridge used to drive the Water Wedge is the Hudco WW120 industrial cartridge.* This cartridge is actually a blank 12-gauge shotgun shell. These power cartridges come in three different loads of 60, 80, and 100 percent.

Firing Procedure

5. To use the Water Wedge device, a 1-5/8-in.-diam. hole is drilled in the pavement, and the hole is filled with water. If the hole is drilled completely through the pavement, the bottom of the hole must be plugged with a rag or other means to prevent the water from escaping. The "working part" of the device is placed into the water-filled hole. A cartridge is placed into the cartridge chamber (6).** The cocking assembly (3) is unscrewed from the striking pin assembly (4) and the exposed end of the plunger (lower portion of part number 3) is pushed against a firm surface to raise the plunger above the top of the housing. The release key (2) is inserted in the hole in the top of the plunger to lock the plunger in the "cocked" position. The "cocked" cocking assembly (3) is then screwed into the striking pin assembly (4). The cocked firing mechanism (parts 3 and 4) is screwed into the cartridge chamber (6) and the complete assembly is screwed into the main body (7) until the bottom of the cartridge chamber is seated firmly against the top of the transfer tube (8). The rope lanyard (1) is then snapped to the release key, and the operator moves back at least 25 ft from the device. The rope lanyard is pulled to fire the device. Photo 3 shows the device in place and ready to fire. After firing, the cartridge chamber and firing mechanism are unscrewed,

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* Hudco Manufacturing, Inc., "Water Wedge 1200 Instruction and Parts Manual." Mentor, Ohio.

** Numbers refer to part number shown in Photo 2.

and the fired cartridge is removed. The device is removed from the hole, and all parts are wiped with a clean cloth. The cap (12) is removed, and the stem (10) and all orifices in the stem and tube assembly (9) are cleaned of any material that may be clogging them.

Cracking Mechanism

6. When the release key is pulled out, the power cartridge (5) ignites, and the expanding gases press the plug in the cartridge through the transfer tube. This action exerts high pressure on the water which is transmitted to the walls of the hole through the outlet holes in the tube assembly. Simultaneously, the high water pressure is transmitted through radial orifices in the stem which presses the rubber sleeve (10) against the walls of the hole preventing ejection of the tool from the hole.

7. According to the manufacturer, the highest pressures and first cracking occur in the material which lies against the orifices in the tube assembly. Because of this, the direction of cracking can be controlled by placing the outlet holes in the direction of desired cracking. The initial crack produced by the initial shot can be made to grow by refilling the hole with water and refiring the Water Wedge with the outlet holes aligned in the same direction as the initial shot.

PART III: TEST RESULTS

Phase I Testing

8. Phase I of this study was conducted to determine the optimum explosive charge required for cracking a 12-in.-thick PCC pavement section and the pattern and extent of cracking resulting from the various charges (60, 80, and 100 percent loads). This was to be done by firing the device in a single hole in the center of a slab.

9. The Phase I testing was performed on the PCC slabs of a bomb damage repair test section. This section was constructed in 1977 as reported in US Army Engineer Waterways Experiment Station (WES) Miscellaneous Paper GL-81-6.* The pavement section consists of 12-in. nonreinforced PCC pavement over a lean clay (CL) subgrade. Laboratory test performed on the PCC at the time of construction indicated a 28-day compressive strength of 5,045 psi. The 28-day flexural strength of the concrete was 705 psi. Six-inch diameter concrete cores taken from the same area in September 1983 indicate an average split tensile strength of 537.5 psi which corresponds to 5,460 psi compressive strength, and flexural strength of 759 psi (see Table 1).**

Test 1

10. Test 1 of Phase I was designed to determine the pattern and extent of cracking after one, two, three, and four shots of a 60 percent charge power cartridge in the same hole. This test was performed near the center of the slab approximately 6 ft from the edge of the slab. A hole was drilled 11-1/4 in. deep, filled with water, and the device discharged. No cracking of the slab was observed on the surface or inside the hole. Some spalling around the top of the hole was observed extending out approximately 1/2 in. in all directions as shown in Photo 4. After discharging the second 60 percent charge, little additional spalling was noted, and the tube assembly was stuck in the hole. No cracking was observed on the pavement surface. After several attempts to remove the device failed, an air hammer was used to break the

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* R. L. Hutchinson, C. L. Rone, and R. H. Densen. 1981 (Sept). "Field Test Evaluation of Regulated-Set Cement Concrete Repair Procedures," Miscellaneous Paper GL-81-6, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

** G. M. Hammitt. 1974. "Concrete Strength Relationships," Miscellaneous Paper S-74-30, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

concrete away from the device. When the device was removed from the hole, the sleeve was bulged and had been forced over the end cap as shown in Photo 5. The device was disassembled and cleaned, and the rubber sleeve was replaced. During cleaning it was found that a large amount of dirt and grit had accumulated in the stem and blocked two of the four orifices causing the sleeve to bulge on the side with the open orifices. Test 1 was discontinued at this time.

Test 2

11. Test 2 was a repeat of Test 1 using the 100 percent charge power cartridges. The first shot resulted in a small amount of spalling around the top of the hole, and the device once again stuck. The spalling extended approximately 1/2 in. away from the hole. No cracking was observed in the pavement surrounding the hole. Once again the device had to be broken out with an air hammer. The rubber sleeve was once again found to be pushed down over the cap as shown in Photo 6. Conversations with the manufacturer indicated that the rubber sleeve should be pushed upward to the extreme top of the stem prior to insertion into the hole. This allows approximately 3/4 in. of travel for the sleeve to contract before it hits the cap.

Test 1A

12. No cracks were generated in Tests 1 and 2; therefore, it was decided to change the approach. In Test 1A, three holes were drilled in the pavement spaced 3 in. apart as shown in Photo 7. The device was discharged in the center hole. The first 100 percent charge shot resulted in only spalling around the top of the holes as shown in Figure 1 and Photo 8. No cracking was observed on the pavement surface or the interior walls of the holes. After the second shot of a 100 percent charge in the center hole, some additional spalling was observed between holes 2 and 3 as shown in Figure 2 and Photo 9. Two hairline cracks were observed inside the center hole at the locations shown by the arrows in Figure 2. These cracks began approximately 1 in. below the pavement surface and extended downward into the pavement. The third shot of a 100 percent charge in the center hole resulted in little additional spalling and no observable change in the width of the cracks. Once again the device was wedged in the hole; however, it was easily removed by jacking it out as shown in Photo 10. Figure 3 shows the extent of spalling at this time.

13. Because of the limited results obtained in these preliminary tests, testing in the center of the slab was discontinued. A 6-in.-diam core was

taken from Test Area 1A. This core included holes 2 and 3. The core was cracked completely through as seen in Photos 11 and 12; however, the crack was not large enough to break the core into two pieces when it was removed from the core barrel.

Phase II Testing

14. Phase II of this study was conducted to determine the best method for producing a straight crack in the PCC pavement. The Phase II testing was performed on a section of 12-in.-thick PCC built in April 1983 as part of a bomb damage repair test section. The pavement section consists of 12-in. non-reinforced PCC pavement over a sand subgrade. Laboratory test performed on the PCC at the time of construction indicated a 28-day compressive strength of 4,955 psi. Six-in.-diameter concrete cores taken in September 1983 indicate a split tensile strength of 549.5 psi which corresponds to 5,610 psi compressive strength and flexural strength of 771 psi. (See Table 1.) The tests of Phase II were conducted on the PCC slab adjacent to a 5-ft-diam crater cut in the slab. Photo 13 shows a typical crater used in these tests.

Test 1

15. Test 1 of Phase II was designed to determine the amount of cracking produced by a 100 percent charge fired in a series of holes along the edge of a crater. The holes were spaced 6 in. center-to-center with hole 0 located 6 in. from the edge of the crater as shown in Photo 14. The first shot was discharged in hole 0 , but no cracking or spalling occurred because the water had drained out of the hole. Shot 2 was discharged in hole 1L with no results; once again the water had run out. In Shot 3 hole 1L was then plugged with a heavy clay (CH) soil to prevent the water from escaping and the device fired again. The results of this firing were hairline cracks extending from hole 1L to hole 2L and approximately halfway to hole 0. In Shot 4 the device was once again fired in hole 1L with additional hairline cracks formed between holes 2L and 3L, 1L and 0, and 0 and 1R. No significant growth in the existing cracks was observed. Photo 15 shows the extent of cracking after Shot 4. Shot 5 was discharged in hole 2L causing hairline cracks to extend from hole 3L to 4L and approximately 4 in. toward hole 5L. Spalling, averaging 1/4 in. deep, extended out approximately 1 in. from the edge of hole 2L as seen in Photo 16. In Shot 6 the device was discharged in hole 0 resulting in spalling

around the top of the hole. The crack extends from hole 1L to hole 1R along previously existing cracks with new hairline cracks formed from hole 1R to hole 4R. Photo 17 shows the extent of cracking and spalling existing at this time. In Shot 7 the device was discharged in hole 0 again resulting in spalling that completely removed the top 3/8 in. of concrete between holes 0 and 1L. The existing cracks between hole 0 and hole 1R widened to approximately 1/16 in. on the surface. The existing crack between holes 1R and 2R appears slightly wider. New hairline cracks are formed from hole 4R to approximately 3 in. past hole 6R and from holes 4L to 8L. Photo 18 shows the extent of cracking at this time. The fourth shot (Shot 8) in hole 0 resulted in no apparent increase in spalling. The crack between hole 0 and hole 1R is slightly wider. New hairline cracks were formed between holes 5R and 6R, 2R and 3R, 3R and 4R, and 4L and 5L. The extent of cracking and spalling present at the end of Test 1 is shown in Photo 19.

16. A core taken from the area between hole 0 and hole 1L was cracked vertically completely through (Photo 20), and the core broke apart when removed from the core barrel. The core was approximately 10 in. long indicating approximately 2 in. of the bottom had been blown loose. The side of the core adjacent to the crater has a horizontal crack about 5-1/2 in. down from the top. Examination of the core hole indicated a slab thickness of 10 in. at hole 0 and extending out about 3-1/2 in. from the center of hole 0. Seven inches from the center of hole 0, the slab was 11-1/4 in. thick. This material was found in the bottom of the core with the largest piece approximately 2 in. by 3 in. by 1 in. in size. A second core was removed from the area between 6L and 7L. This core had a vertical hairline crack extending 7 in. below the top of the core on the side adjacent to hole 6L. The side of the core adjacent to hole 7L had a vertical crack extending only 2 in. below the top of the core.

Test 2

17. Test 2 was designed to determine the effect of firing both devices simultaneously. Two Water Wedge devices were placed in holes drilled 12 in. apart with one hole midway between the devices. These holes were approximately 6 in. from the crater edge. The firing of both devices simultaneously resulted in some spalling around the top of the holes, but no cracking was observed. Both devices were stuck in the holes, and only one of the devices could be removed using a jack. Once again an air hammer was used to remove the concrete from around the device to free it. Examination of the device

upon removal from the hole indicated that the heavy clay used to plug the hole had gotten under the rubber sleeve resulting in the sleeve buckling when the device was fired.

Test 2A

18. Test 2 was repeated with the devices in holes spaced 9 in. apart in holes 6 in. from the crater edge. The devices were fired simultaneously resulting in spalling around the top of both holes along with hairline cracks between the holes. Photo 21 shows the results of Test 2A. A core taken from between the holes indicates vertical hairline cracks extending through the core; however, these cracks did not come completely through as no cracking was observed on the bottom of the core.

Test 3

19. Test 3 was conducted to determine if a 2-in.-deep saw cut along the center line of the holes spaced 6 in. apart would increase the amount of crack growth. The holes were drilled in the PCC slab, and a saw cut was made along the center line of the holes as shown in Photo 22. Hole 0 was located 6 in. from the edge of the crater. The depth of the saw cut varied from 2.0 to 2.25 in. along the line of holes. Shot 1 consisted of a 100 percent charge discharged in hole 0. The resulting crack extended from hole 1L to hole 0 to hole 1R, and followed the saw cut. No spalling was observed around the top of the hole. A second 100 percent charge was discharged in hole 0 which resulted in hairline cracks extending along the saw cut from hole 5R to 3L (Shot 2). The third 100 percent charge discharged in hole 0 resulted in hairline cracks extending out to hole 5L and hole 6R along the saw cut (Shot 3). Some spalling occurred around the top of hole 1L. A core was taken from the area between hole 0 and hole 1L. When removed from the core barrel, the core broke into eight major pieces as shown in Photo 23. The top 2 in. of the core broke into two pieces along the saw cut. Two major pieces resulted from the vertical crack through the core, and four smaller pieces were broken from the side of the core adjacent to hole 0. The bottom 2 to 2-1/4 in. of the core was broken off and remained in the hole as rubble. Visual inspection of the cracks in the core hole indicated no significant difference in the size of the cracks produced in this test and the cracks produced in Test 1. A second core was removed from the area between 5R and 6R. The north side of the core hole has a small vertical crack through the slab, and the bottom 2 in. of the slab

has several horizontal cracks; however, none of the pieces were loose. The side of the core hole adjacent to hole 6R had a vertical hairline crack extending through the slab. Visual inspection of the walls of the core hole indicated no significant difference in the size of the cracks compared to the cracks measured in the core hole from 6L of Test 1. Upon removal from the core barrel, the core was broken into seven major pieces as shown in Photos 24 and 25. The major break occurred along the saw cut; however, the bottom 3 in. of the core was broken off which may have resulted from problems encountered with the drill rig and core barrel while cutting the core.

Test 4

20. Test 4 was performed on Crater 2. A series of holes were drilled at 6 in. center-to-center spacings with the hole nearest the crater 3 in. from the crater edge as shown in Photo 26. The purpose of the test was to determine the effort required to make a straight cut along the edge of the crater, break the PCC mass adjacent to the crater away from the slab, and reveal the condition of the resulting edge. The first three shots were discharged in holes 0, 1R, and 1L, respectively. The first shot resulted in cracking of the slab from hole 0 toward the crater edge and from hole 0 to 1R. The second shot resulted in additional cracking between hole 0 and hole 3L and from hole 1R to hole 4R as shown in Photo 27. Additional shots in holes 2L, 3L, and 4L resulted in additional cracking and a moderate amount of spalling. At this time, the cracks had extended to hole 1W with a crack branching out from 3L toward the crater edge. Photo 28 shows the extent of the cracking and spalling existing at this time. Additional shots were discharged in holes 2R and 4R which resulted in additional cracking from hole 4R to 5R. A series of shots were discharged in holes 5W, 4W, and 3W to produce cracks along the west side of the crater. Another series of 0 shots were discharged in holes 0, 1L, 1R, and 2L. Each of these shots resulted in increased spalling and increases in crack width. Photo 29 shows the cracking and spalling existing at this time. Additional shots discharged in holes 2R, 3R and 4R resulted in some widening of the existing cracks with extensive spalling. With each of these shots, a moderate amount of debris was thrown into the air. Shots in holes 0, 2L, 3L, and 2R resulted in extensive spalling with several cracks visible in the sides of the crater (Photo 30). This final series of shots removed the top 2 in. of concrete between the line of holes and the crater from hole 2L to hole 3R as shown in Photos 31 and 32.

21. After completing the Water Wedge shots, a backhoe was used in an attempt to remove the cracked pieces from between the line of holes and the crater. Only a few small pieces were loosened, and the broken mass of concrete could not be separated from the main slab. A concrete saw was then used to cut away the mass. The mass adjacent to the crater was broken out to reveal the edge shown in Photos 33 and 34. This edge was generally rough. Some protrusions on the face extended approximately 1 in. from the face. The slab thickness at the face varied from 10 in. in hole 1R to 12 in. at the edge of the face.

PART IV: SUMMARY

Results

22. Phase I of this field test was performed to determine: (a) if the Water Wedge device could produce cracks in the center of a PCC slab, (b) the optimum charge required to produce these cracks, and (c) the optimum hole spacing to produce a complete break in the slab. In these tests, a hole was drilled in the center of a 12-in.-thick PCC slab, and the device discharged several times in the holes. No cracks were produced in either of the first two tests using 60 percent and 100 percent charges. Both tests were discontinued when the device stuck in the hole and had to be broken out with a pneumatic hammer. The next attempt to crack the slab was made by discharging three 100 percent charges in the center hole of three holes spaced 3 in. center-to-center. This resulted in some spalling and the formation of hairline cracks between the holes. These cracks were not large enough to cause a core taken from this test site to break apart.

23. Phase II of the test program was conducted to determine the best method for producing a straight crack in a PCC slab adjacent to a simulated crater. A 5-ft-diam crater was cut in a 12-in.-thick PCC pavement, and holes were drilled at 6-in. center-center spacings, with the center hole 6 in. from the crater edge. Several shots discharged in the center hole resulted in cracking along the line of holes. Investigation of these cracks indicated that, except for the area adjacent to the center hole where a good separation was obtained, the cracks extending through the slab were very small and not large enough to completely separate the concrete. A 2-in.-deep saw cut along a second line of holes adjacent to the crater resulted in similar cracking with no significant increase in crack width.

24. The final test was performed to determine the effort required to make a straight crack and completely separate the PCC on the crater's edge from the remaining slab. A total of twenty-three 100 percent charges were discharged in various holes surrounding the crater. Extensive spalling and cracking resulted from these shots; however, the cracks were not significant enough to allow the slab to be separated. Removal of the PCC from between the crater and crack revealed a rough edge with some protrusions extending approximately 1 in.

Time Requirements

25. The time required to drill one hole and arm and fire the Water Wedge device averaged approximately 9 min. Approximately 4 min was required to drill a hole 11 in. deep in the PCC slab using a pneumatic hammer drill, and an average of 5 min is required to arm the device, fill the hole with water, and fire the device. There is an approximately 5-min lag time between shots to allow time to remove the spent shell and clean the device. After every fourth or fifth shot, the device should be completely disassembled and thoroughly cleaned to prevent a buildup of grit in the transfer tube and stem. This disassembly and cleaning require at least 10 min.

PART V: ANALYSIS

26. From analyzing the results of this field study, it was determined that:

a. The Water Wedge device is a relatively simple, sturdy tool for breaking rock and other unconfined materials; however, it was not designed to be used in materials that are completely confined. The device produces wide cracks that extend completely through the slab when fired in the corner of a slab where no other materials are adjacent to the edges, but no significant cracking is produced if the shot is attempted away from these edges.

b. The Water Wedge device must be kept clean. Small soil particles or other grit can enter the stem or the area between the stem and sleeve and clog the orifices causing the sleeve to permanently bulge when the device is discharged. This bulging of the sleeve then causes the device to stick in the hole. This is a serious drawback to using the Water Wedge device. During the testing program, the device became stuck six separate times. Three times the device was removed using a jack, three times the PCC had to be broken from around the device before it could be removed.

c. The best results on high-strength concrete are obtained when the holes are spaced no more than 6 in. apart and located as close as possible to the edge of the crater and multiple shots made in each hole. This is another obstacle to using the Water Wedge to cut bomb damaged pavements, as upheaval from the explosion would not allow easy access to the crater edge.

d. A 2-in.-deep saw cut along the center line of a series of holes will increase the distance the crack propagates with each shot but has little effect on the width of the resulting cracks compared to a series of holes without a saw cut.

e. The best cracking obtained in this series of tests was not adequate to completely separate the mass of concrete adjacent to the crater from the slab.

f. The edge resulting from the cracking produced by the Water Wedge device is uneven, and some grinding or saw cutting will be required to produce a smooth edge.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

27. Based on the results of this field test of the Water Wedge device, it is concluded that:

- a. The Water Wedge device is not an effective means of producing a smooth break in a 12-in.-thick PCC slab, especially when used away from one or more free edges.
- b. The time and effort required to produce cracks in these PCC pavements are extensive when compared to the results achieved.

Recommendations

28. Based on the results of this study, it is recommended that:

- a. The Water Wedge device be dropped from consideration as a means of cutting bomb damaged pavements prior to repair.
- b. An additional study be performed to determine the feasibility of using the Water Wedge for breaking large masses of concrete pavement debris.

Table 1

Concrete Strength Data

Test Number	Test Location	During Construction: Flexural Strength Beams,*psi 28-day	90-day	Compressive Strength psi** 7-day	28-day	90-day	Cores Removed From Pavement September 1983: Core Number	Average Diameter D in.	Average Length L in.	Applied Load P lb	Tensile Splitting Strength, T psi†	Correlated Flexural Strength psi††	Correlated Compressive Strength psi‡	Unit Weight psi‡‡
Phase I Section South Lane Item 1	Old BDR	705	792	3,750	5,045	5,910	1	5.90	12.35	65,000	568	790	5,842	144.6
							2	5.90	10.0	47,000	507	728	5,078	141.6
							Average				537.5	759	5,460	143.1
Phase II Section Item 4	New BDR	-	-	-	4,955	-	1	5.90	11.60	65,500	609	832	6,356	146.6
							2	5.90	12.33	56,000	490	710	4,865	148.7
							Average				549.5	771	5,610	147.7

* Flexural test beams were 6 by 6 by 36 in. and were subjected to third-point loading. Strength values shown are for one value at 28-day age and the average of two tests for 90-day age. No flexural test beams were taken on new BDR section.

** Compressive strength tests were conducted on cylindrical samples 6 in. in diameter and 12 in. high. Values shown for old BDR section are the average of two tests. Values for new BDR section average 6 tests. No 7-day or 90-day cylinders were made on the new BDR section.

† Tensile Splitting Strength: T $T = \frac{2P}{\pi LD}$

†† Correlated Flexural Strength: R $R = 210.5 + 1.02T$

‡ Correlated Compressive Strength: f$_c'$ $f_c = -1275 + 12.53T$

‡‡ Unit Weight: γ $\gamma = \frac{\text{Weight of Core}}{(0.25\ \pi D^2 L)/1728}$

Correlations taken from WES MP S-74-30 "Concrete Strength Relationships" by G. M. Hammitt.

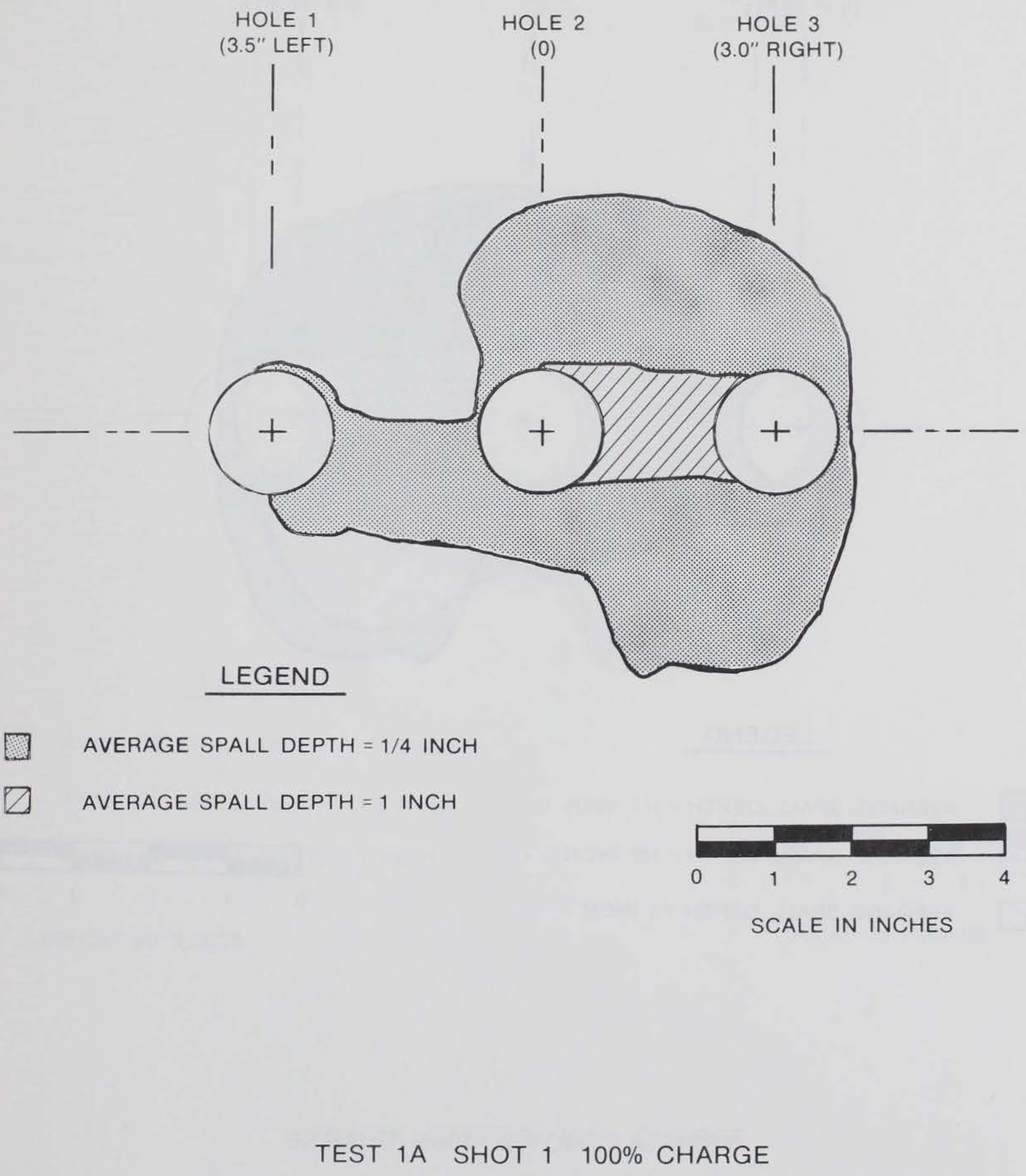


Figure 1. Spall depths after test 1A, shot 1

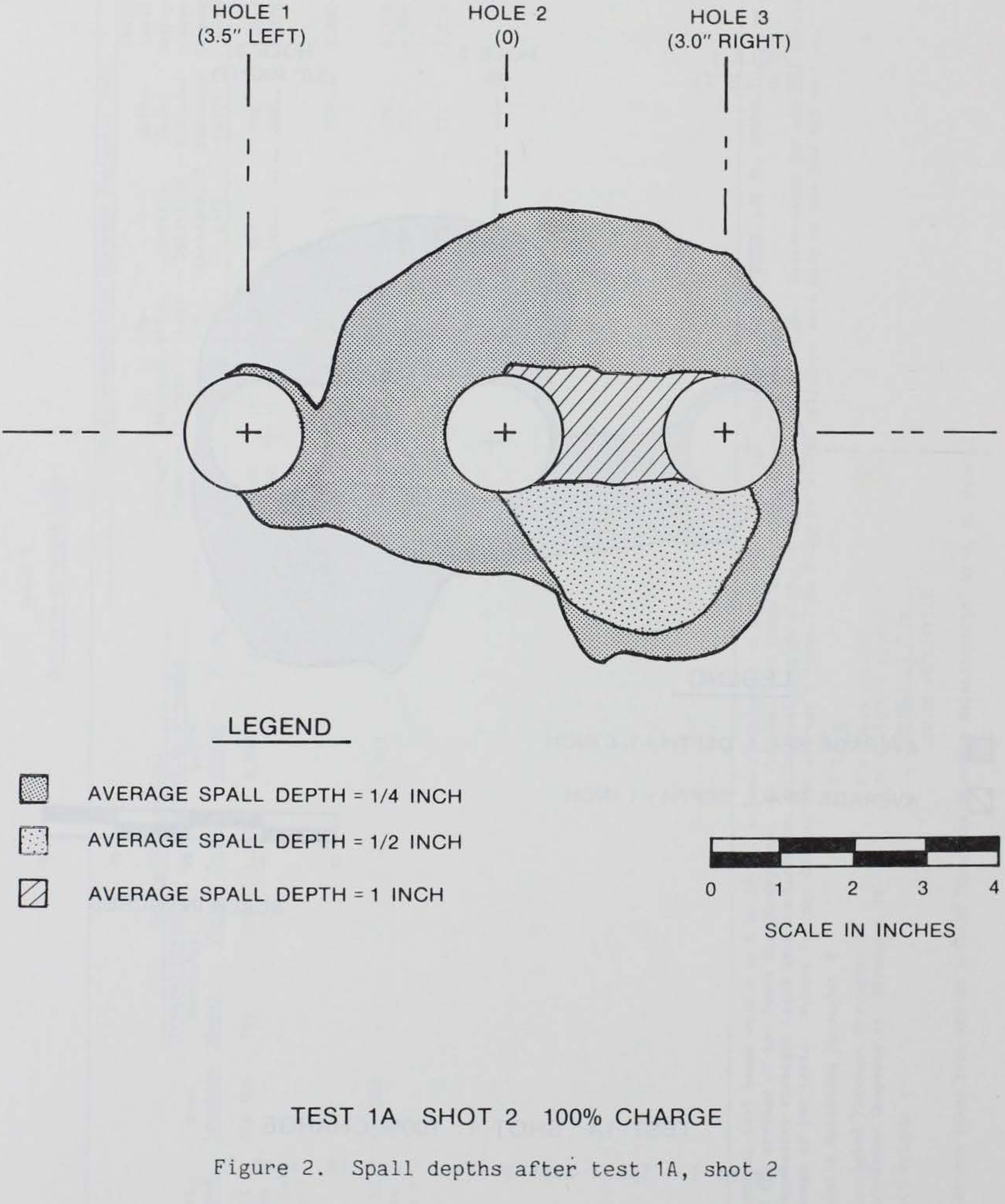
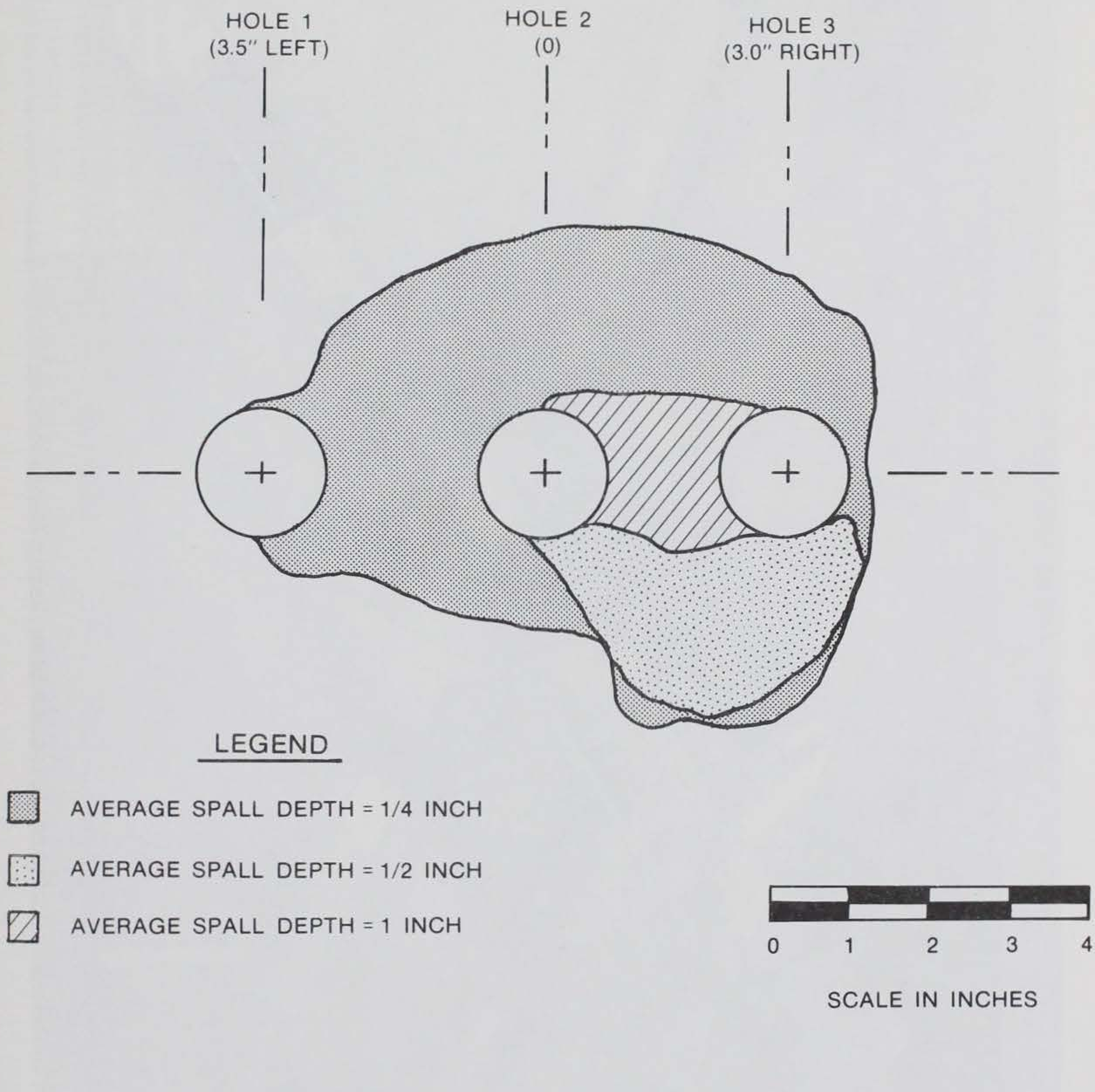


Figure 2. Spall depths after test 1A, shot 2



TEST 1A SHOT 3 100% CHARGE

Figure 3. Extent of spalling after test 1A, shot 3

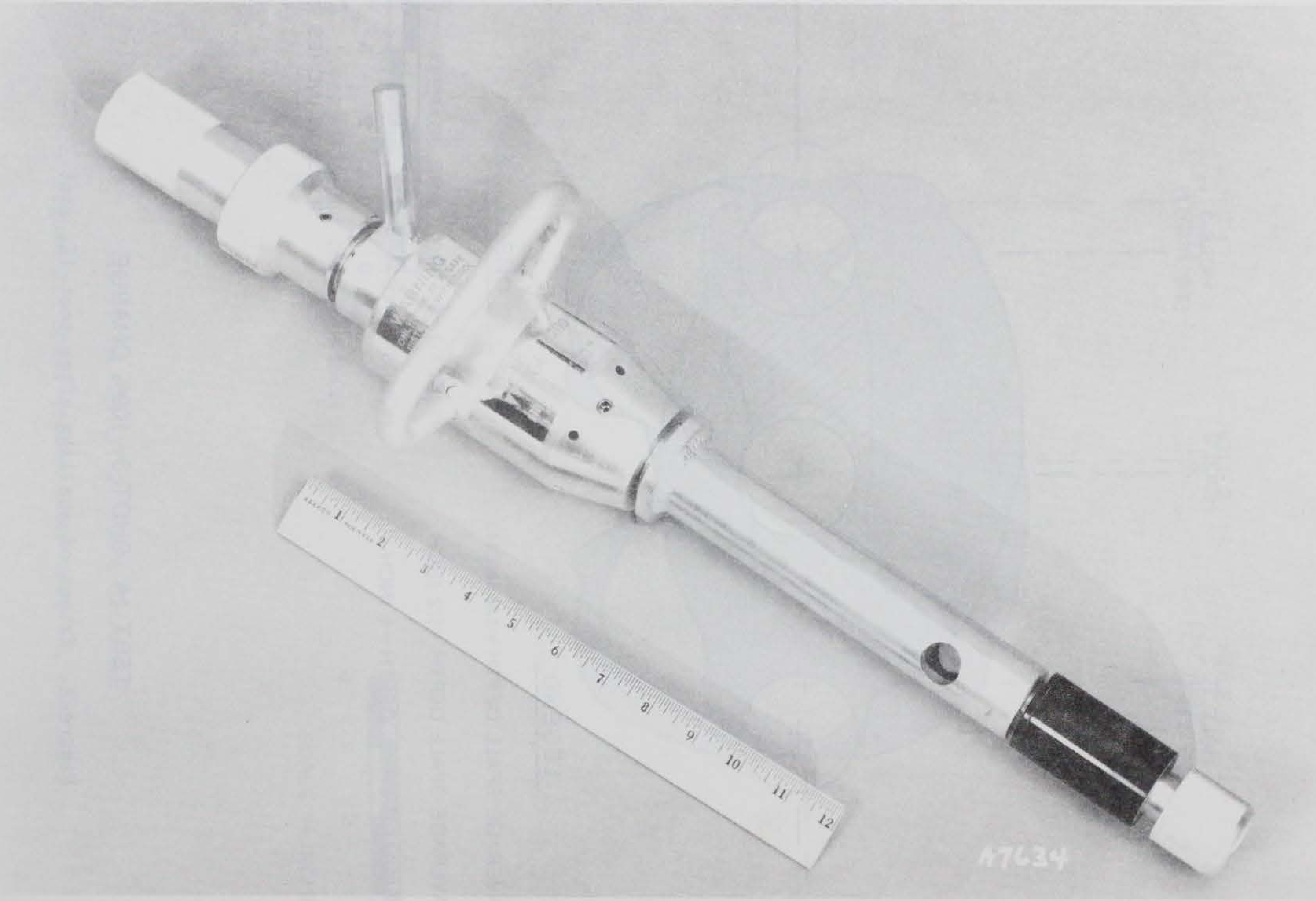


Photo 1. Assembled Water Wedge device

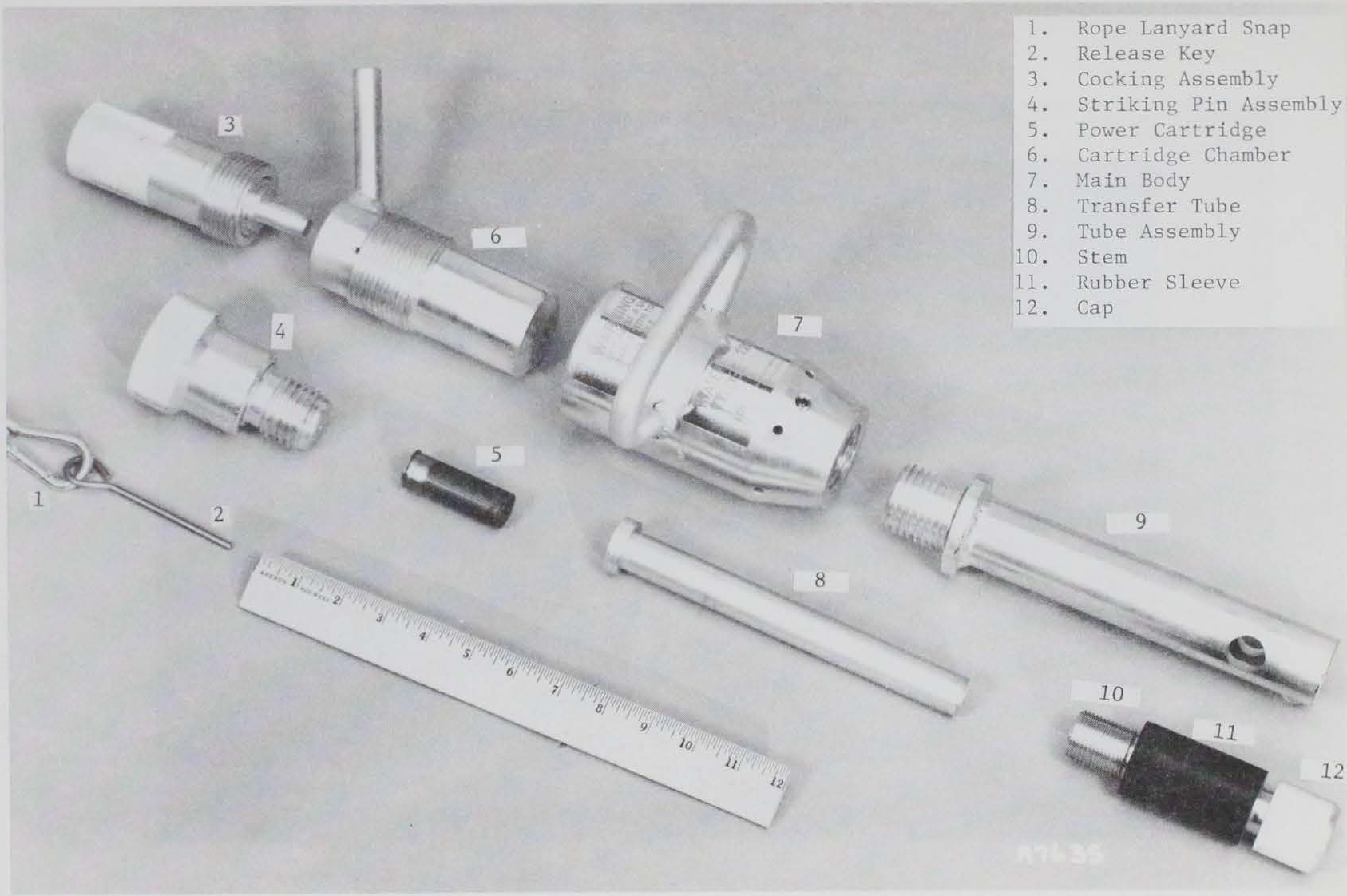


Photo 2. Exploded view of Water Wedge device

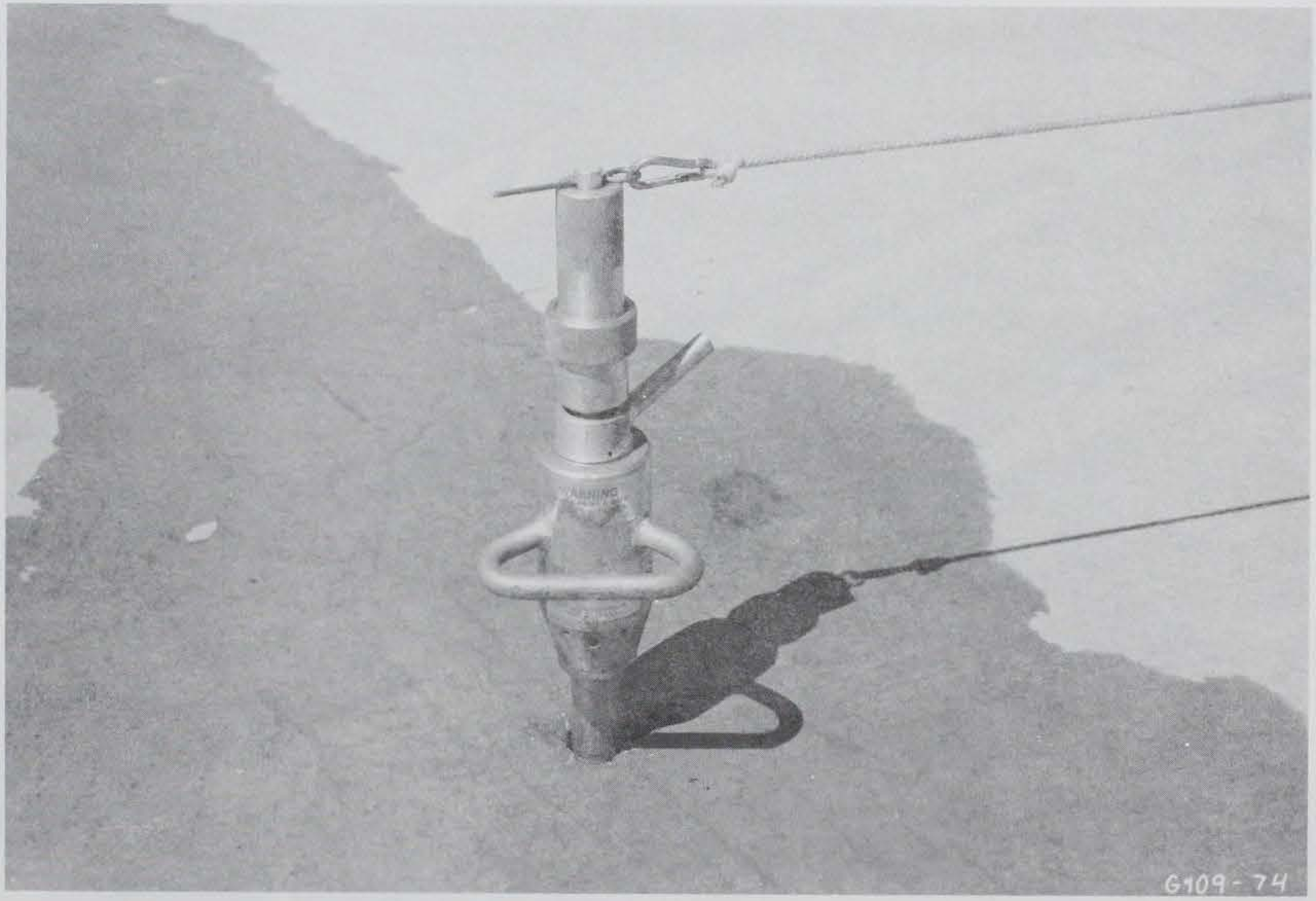


Photo 3. Device ready to fire

Photo 4. Spalling around hole after test 1, shot 1

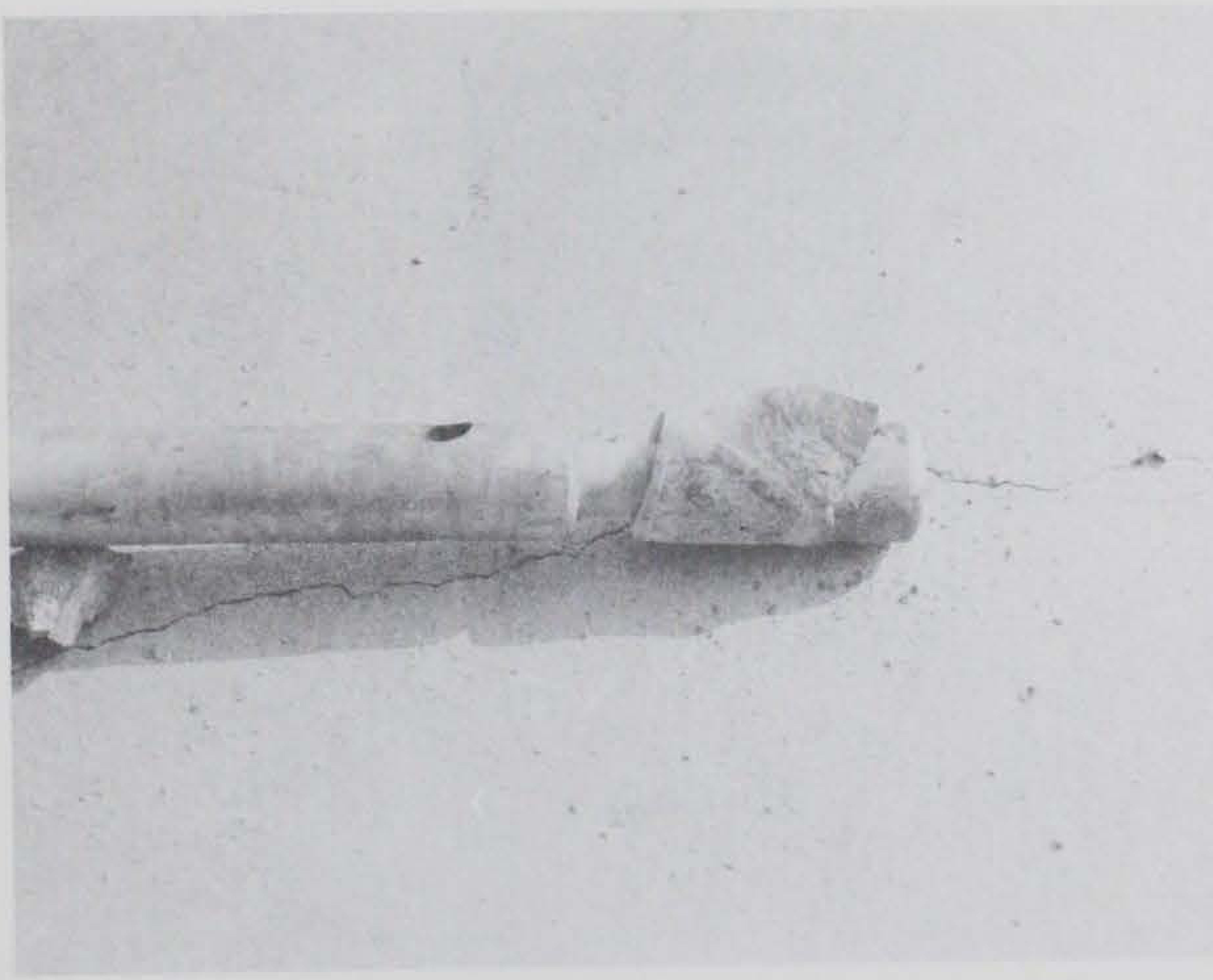


Photo 5. Rubber sleeve forced over end cap, test 1, shot 2

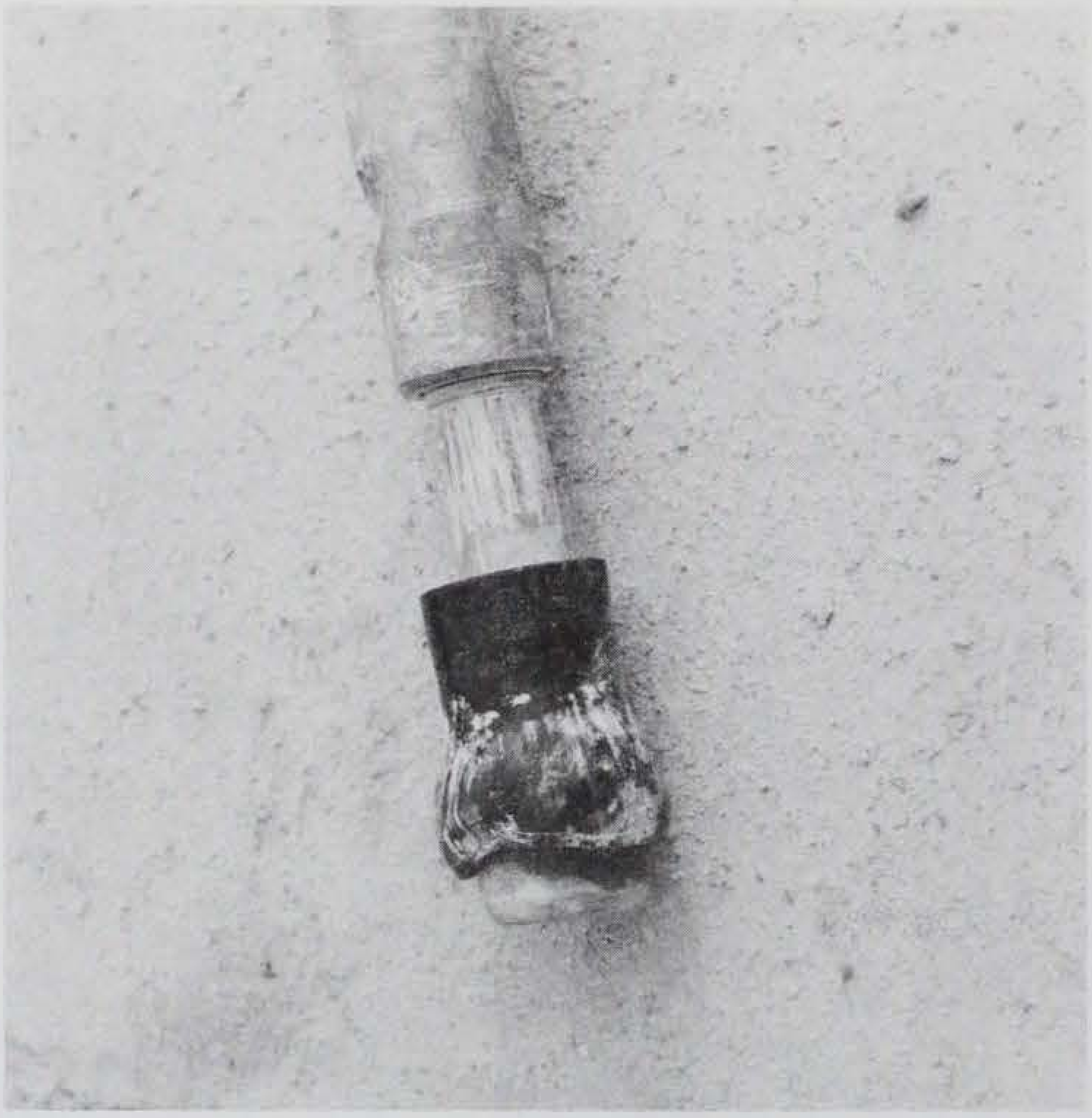


Photo 6. Rubber sleeve forced down over cap, test 2

Photo 7. Holes in pavement prior to test 1A

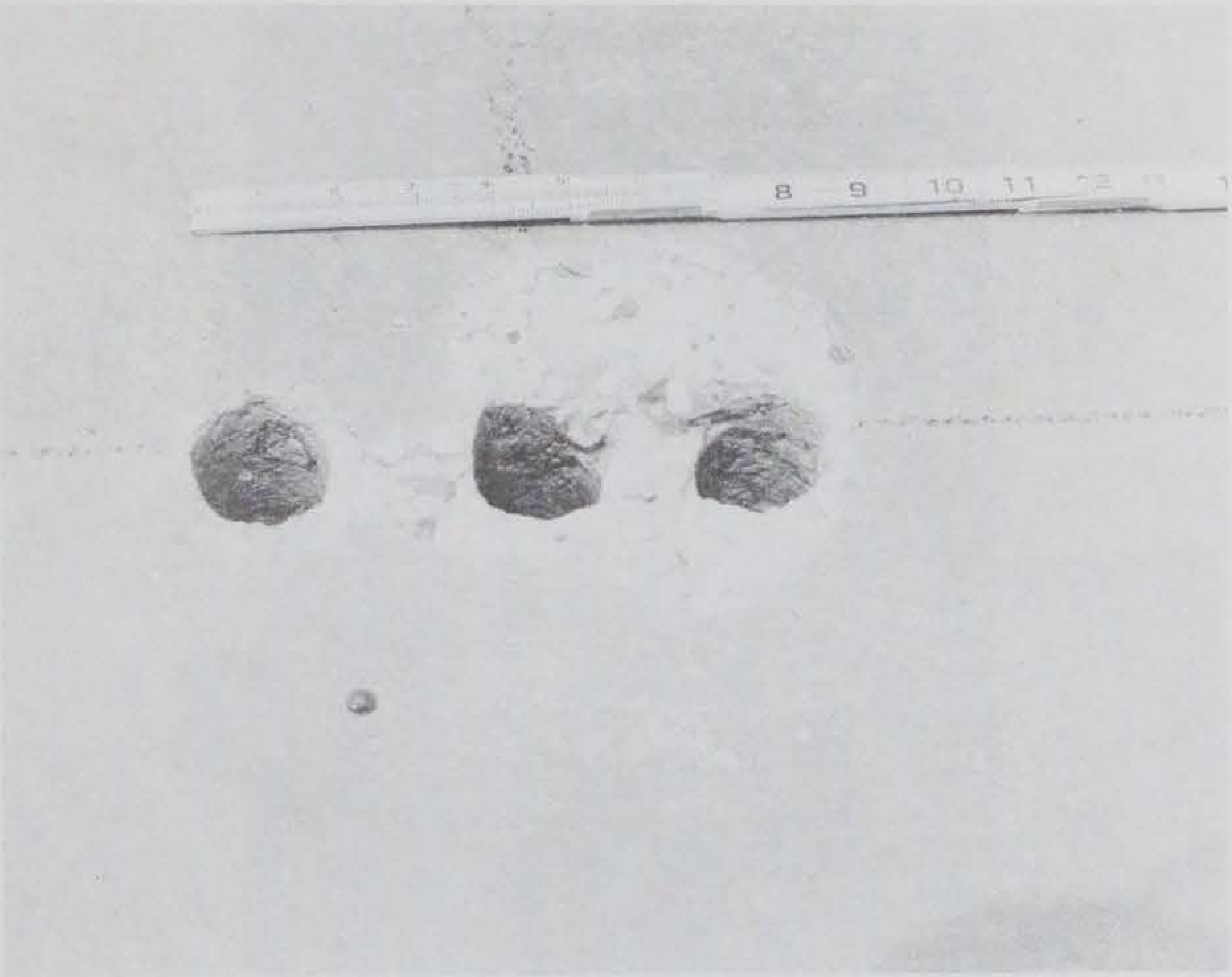


Photo 8. Spalling resulting from test 1A, shot 1

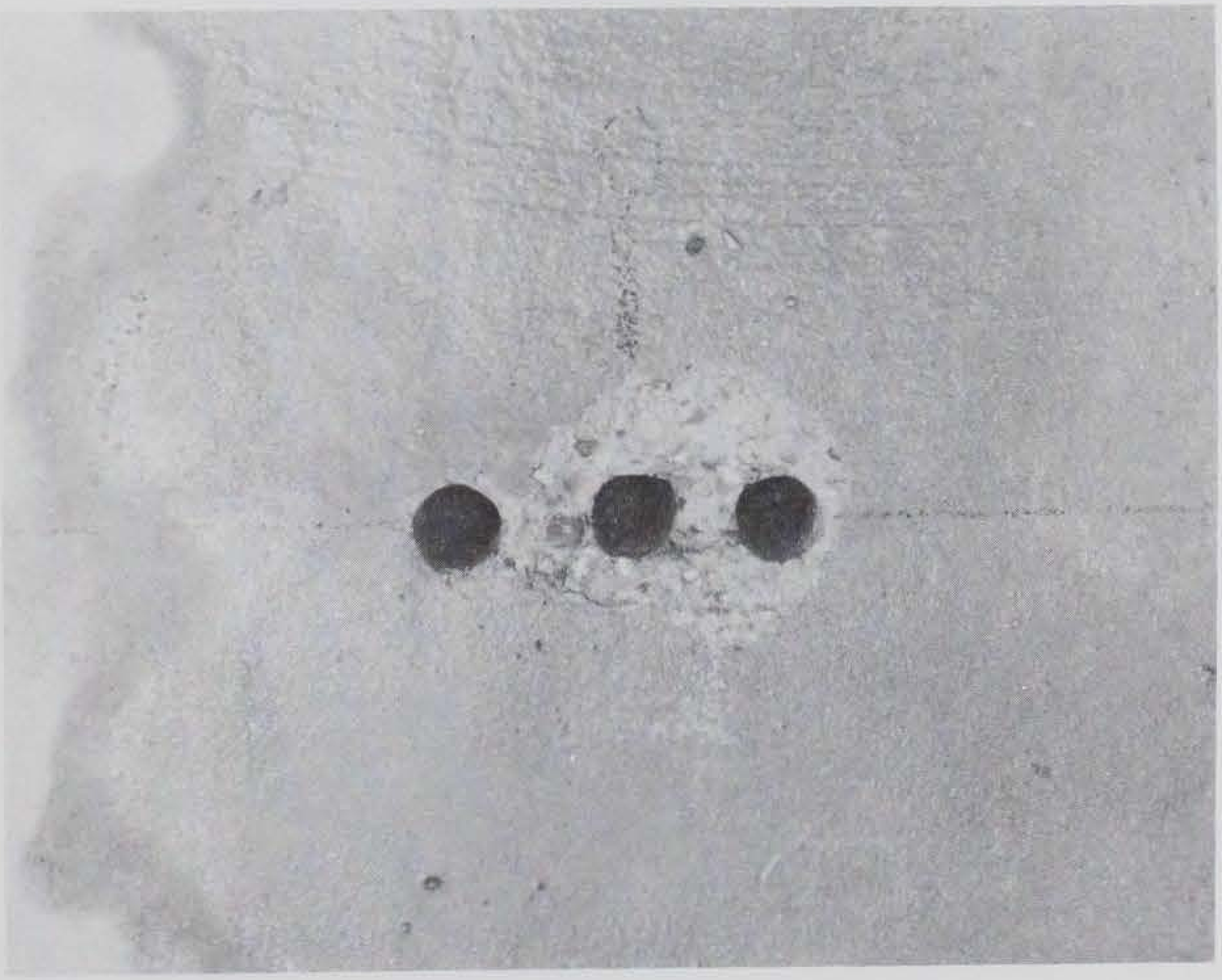


Photo 9. Spalling resulting from test 1A, shot 2

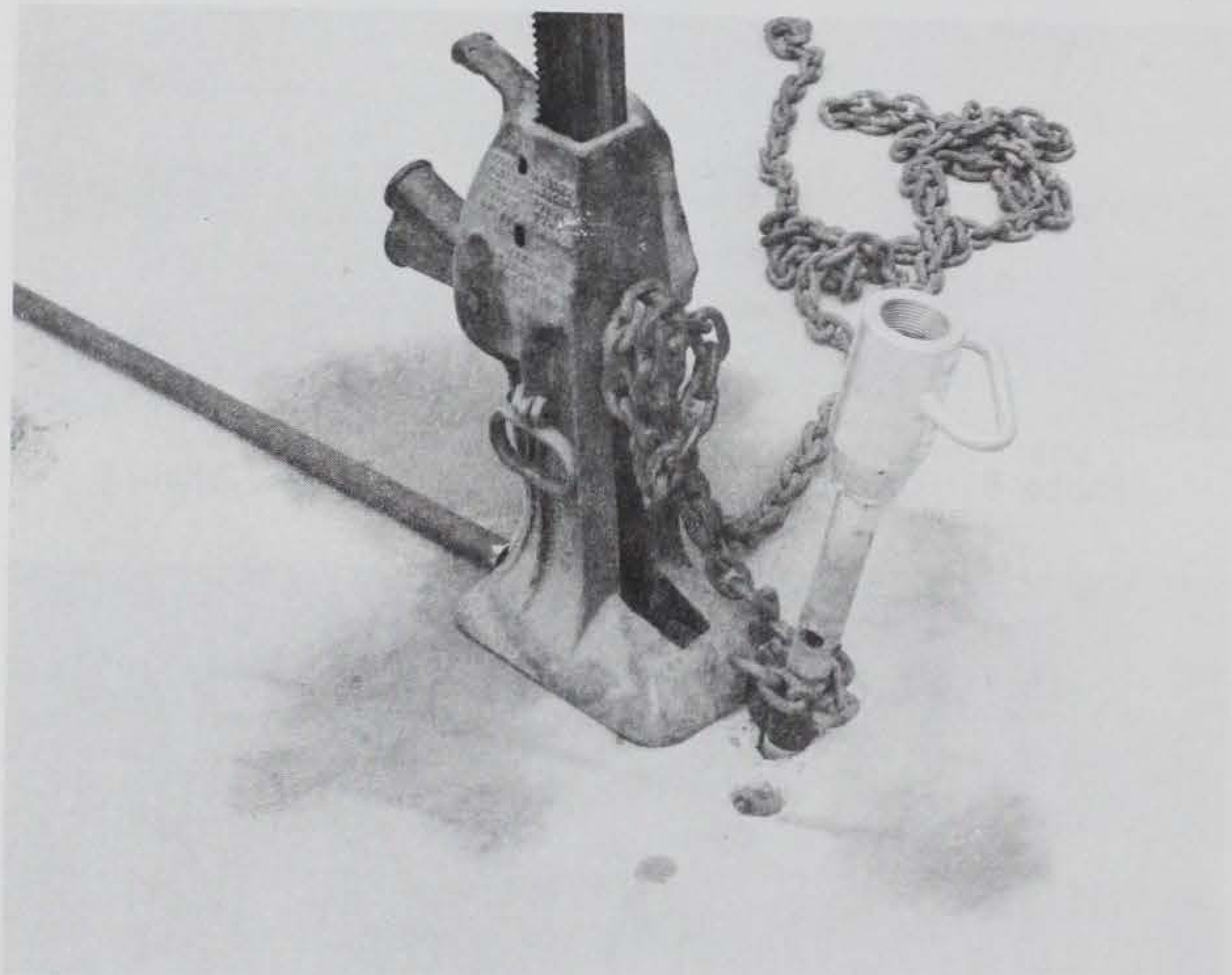


Photo 10. Removing stuck Water Wedge device with jack, test 1A, shot 3

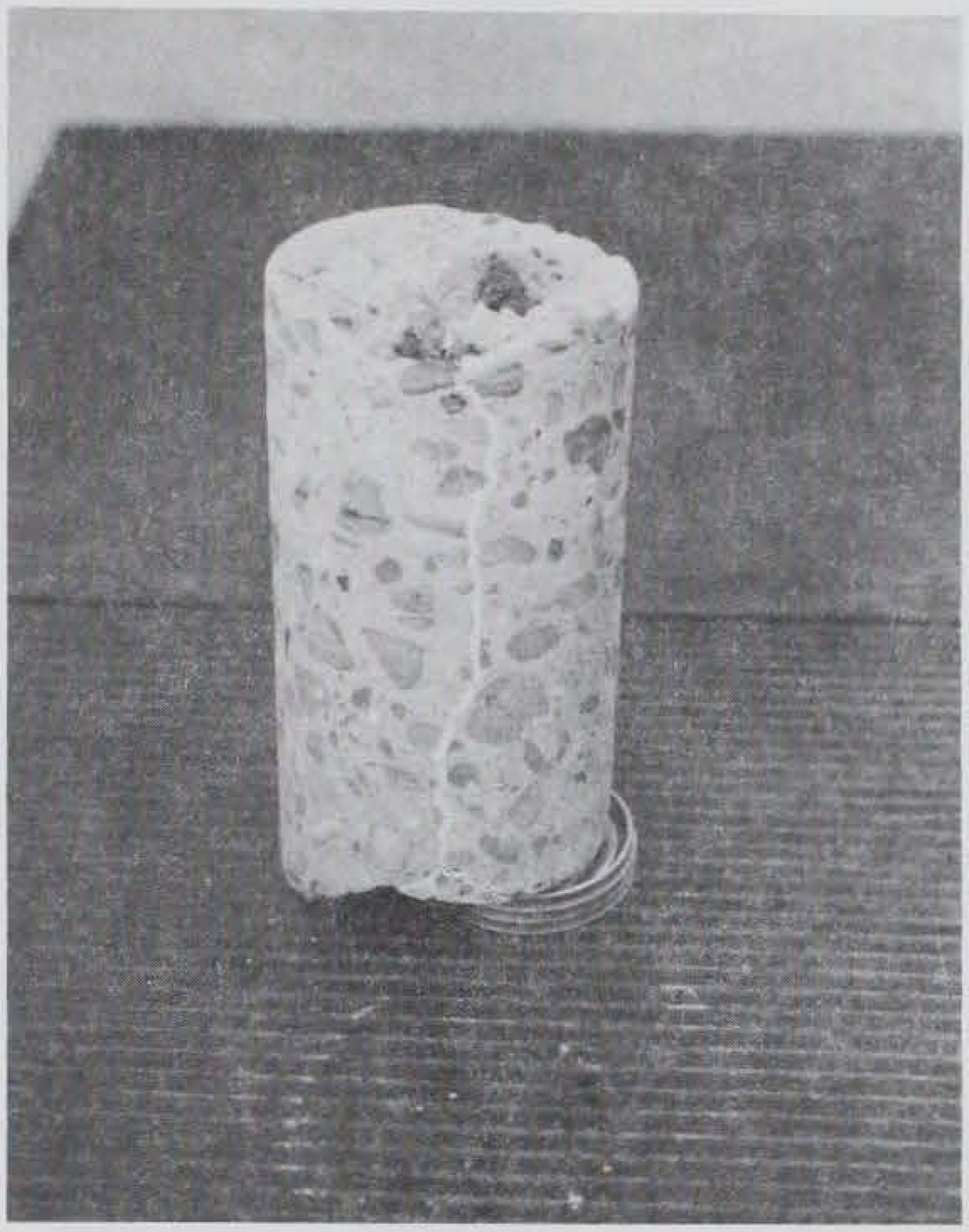


Photo 11. Core taken from test 1A (west side between holes 1 and 2)

Photo 12. Core taken from test 1A (east side between holes 2 and 3)

Photo 13. Typical crater

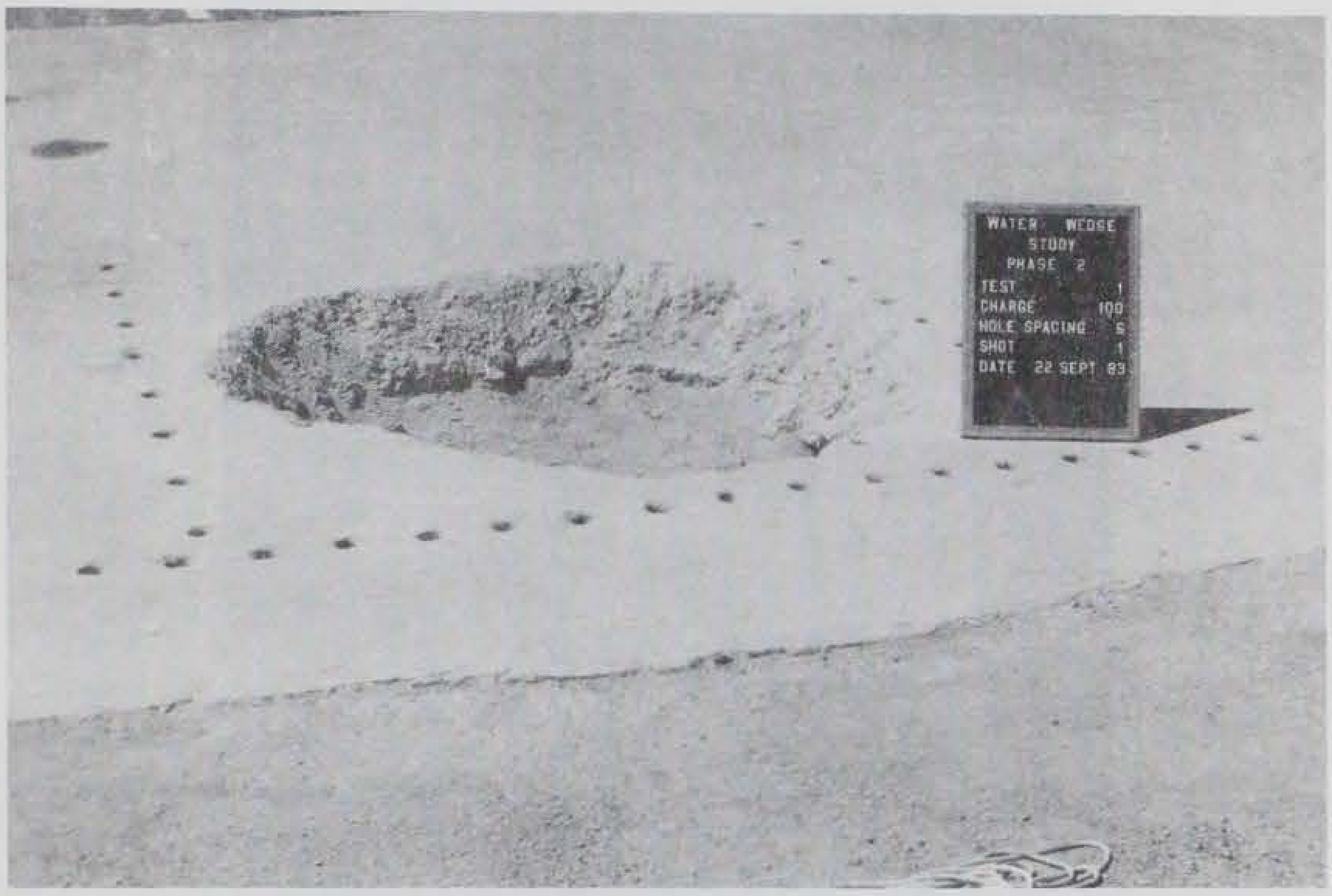


Photo 14. Overall view of test 1 prior to shot

Photo 15. Extent of cracking after test 1, shot 4

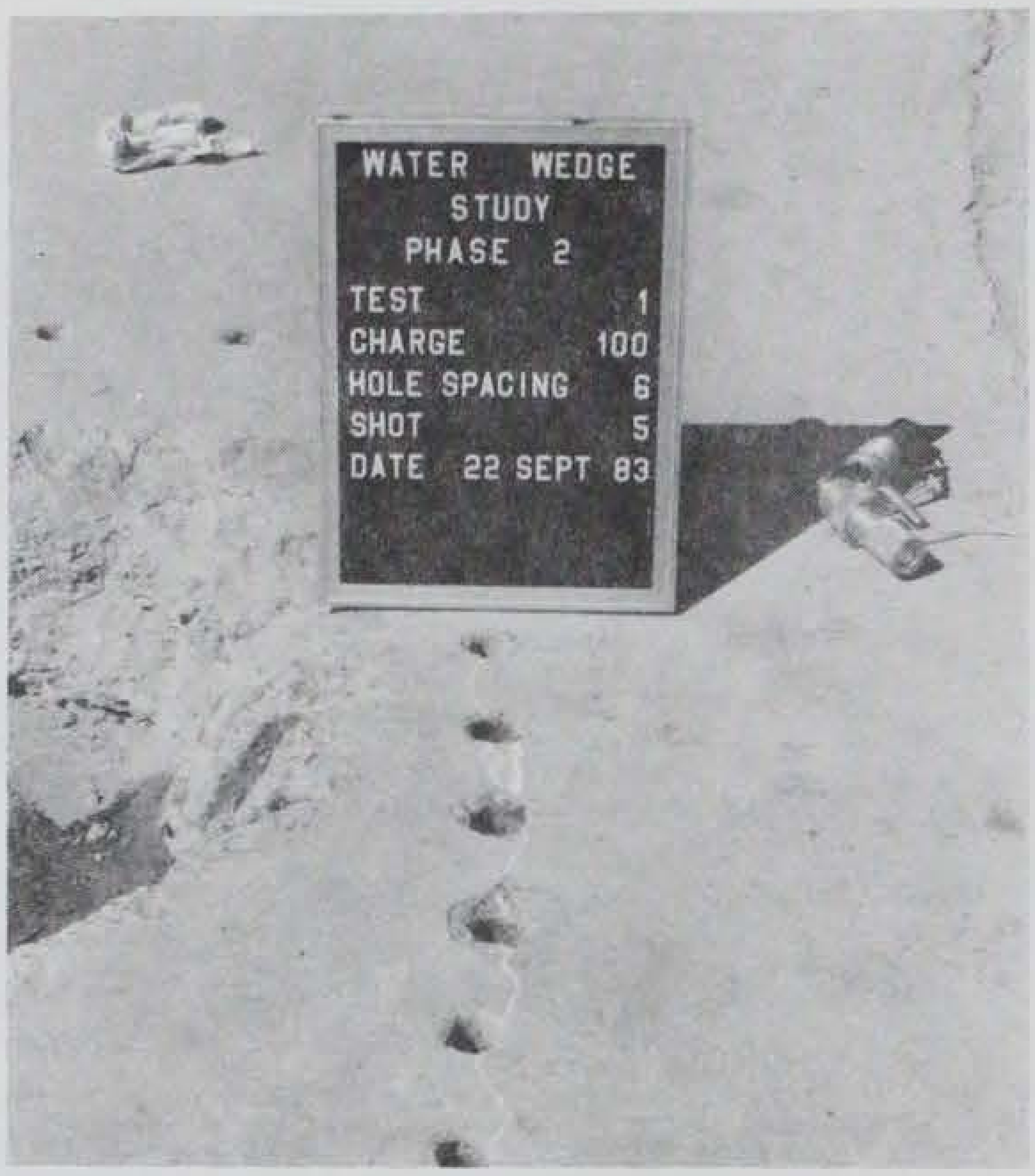


Photo 16. Extent of cracking and spalling after test 1, shot 5

Photo 17. Extent of cracking and spalling existing after test 1, shot 6

Photo 18. Extent of cracking after test 1, shot 7

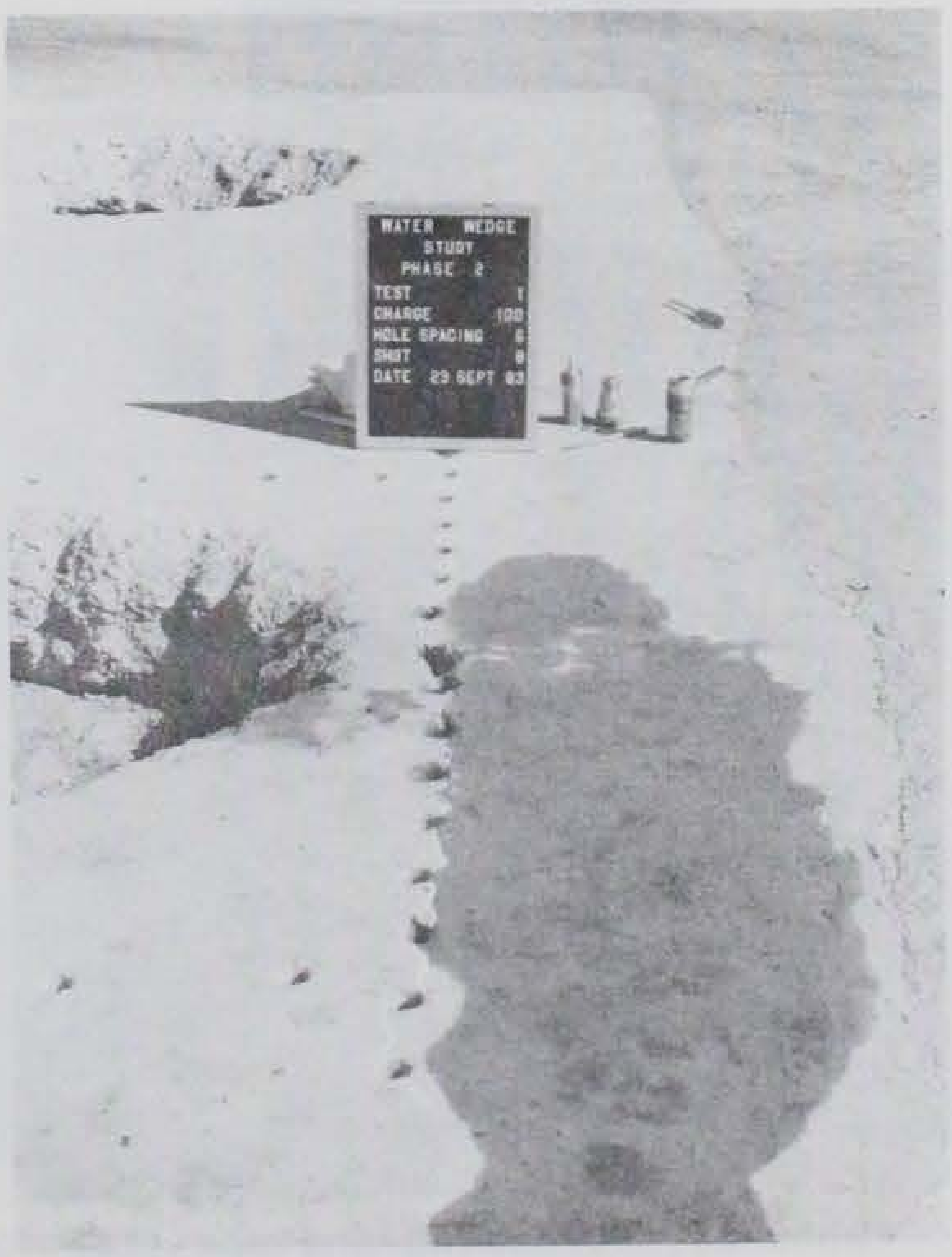


Photo 19. Cracking and spalling after test 1, shot 8

Photo 20. Core removed from area of hole 0, test 1

Photo 21. Cracking and spalling resulting from test 2A

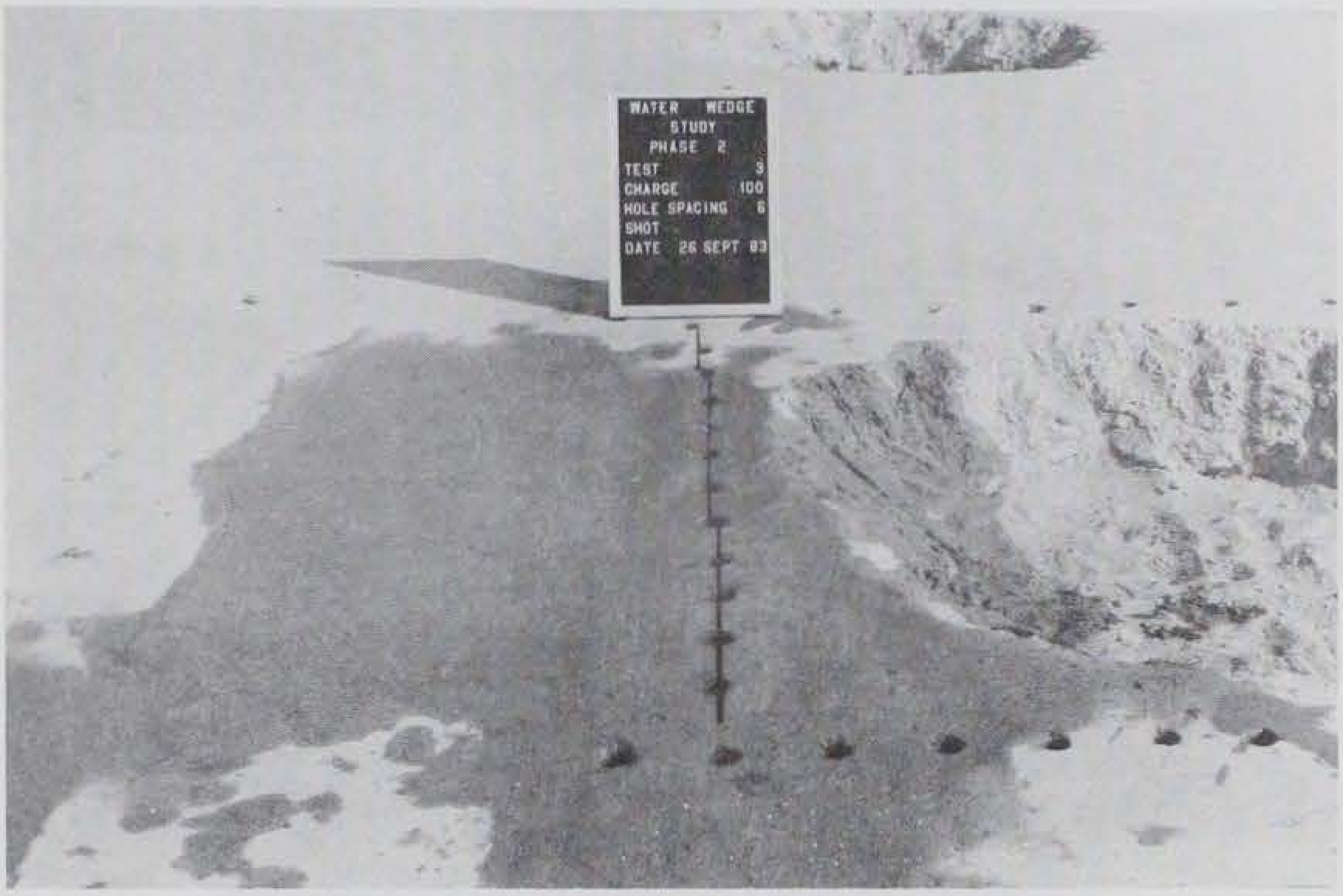


Photo 22. Overall view of site 3 before test

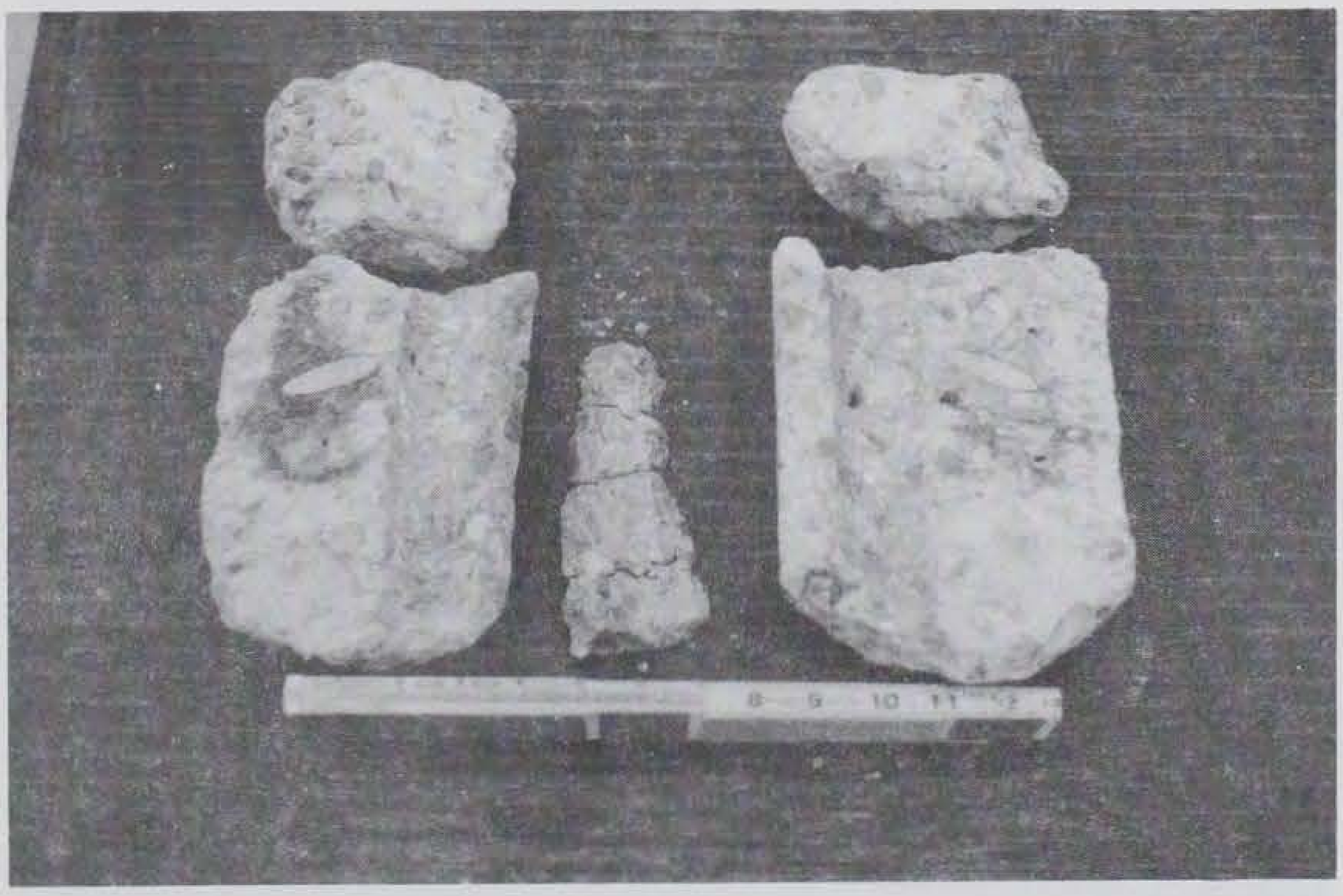


Photo 23. Core removed from test 3, hole 0

Photo 24. Core removed from test 3, hole 5R (6R side)

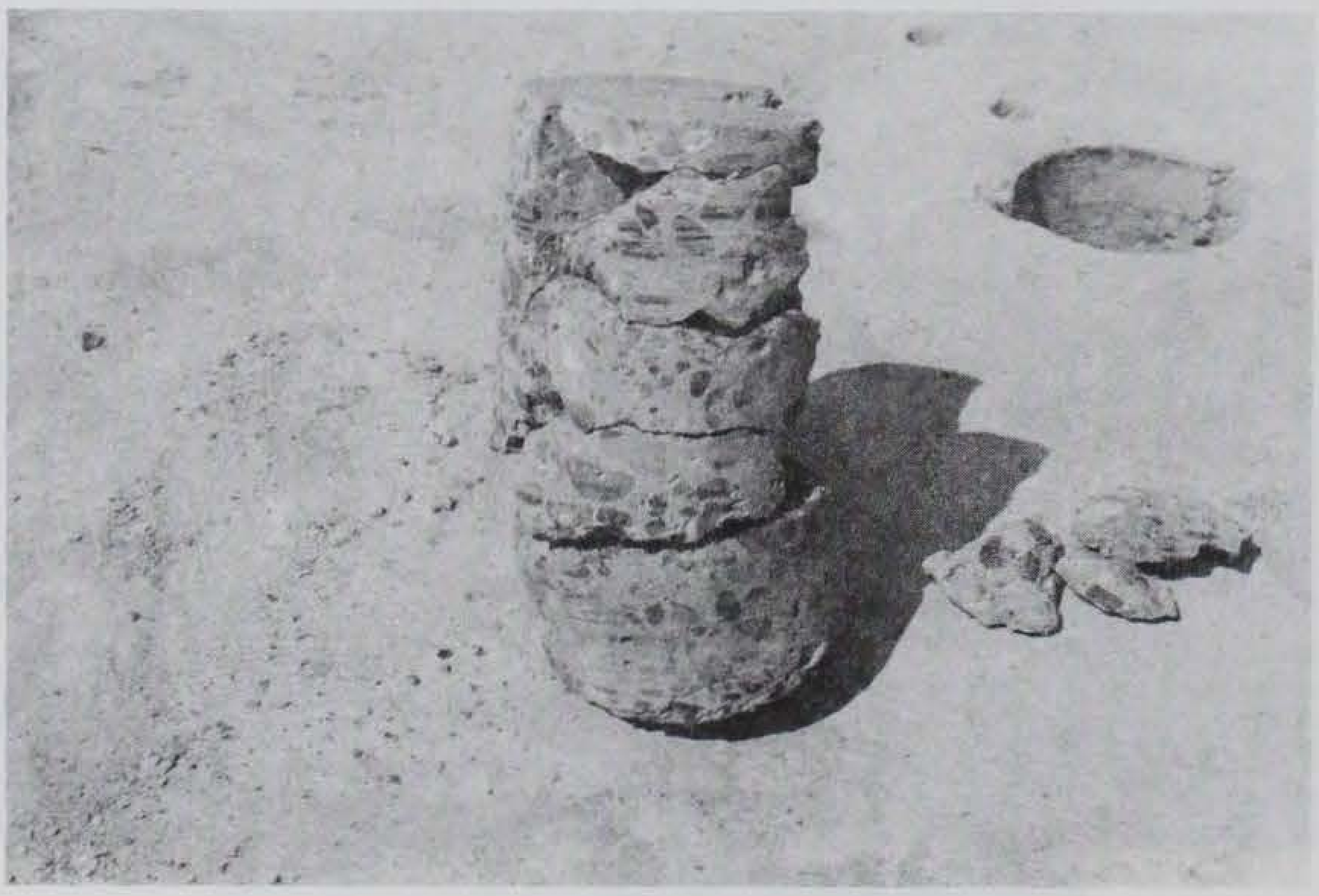


Photo 25. Core removed from test 3, hole 5R (4R side)

Photo 26. Crater 2, test 4 site

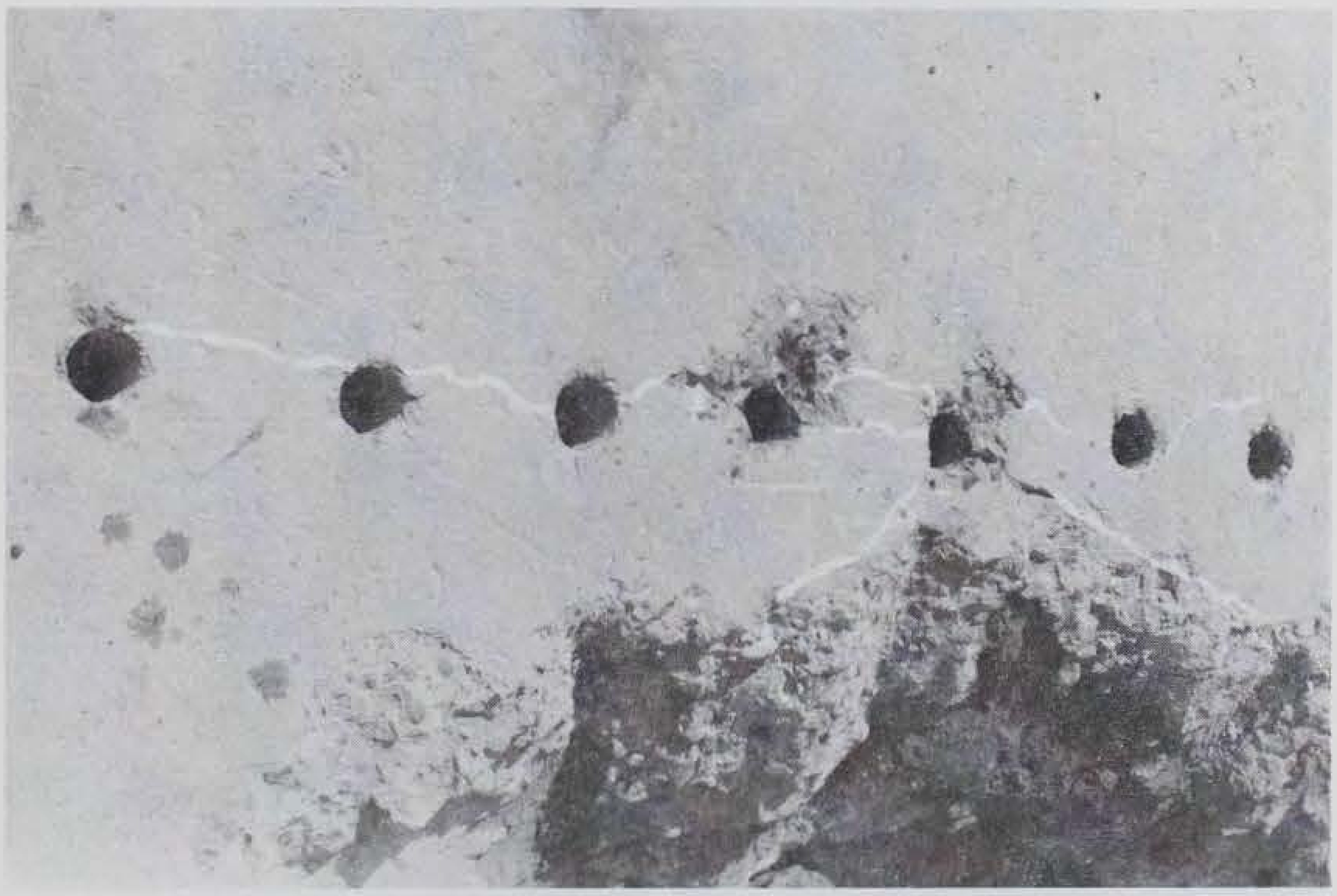


Photo 27. Extent of cracking after shot 2, test 4

Photo 28. Extent of cracking and spalling after shot 6, test 4

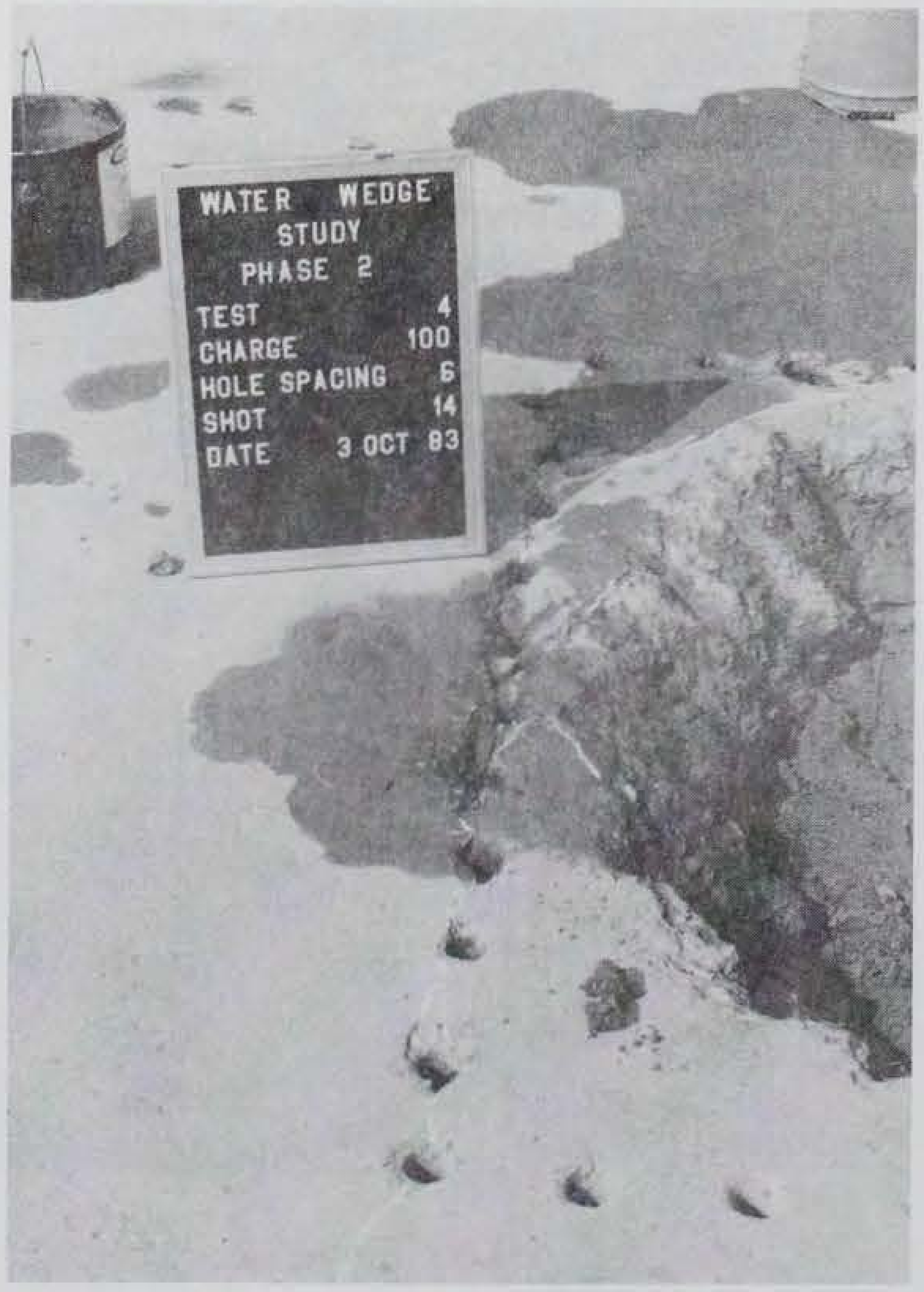


Photo 29. Extent of cracking and spalling after shot 15, test 4

Photo 30. Cracks occurring in wall of crater after shot 23, test 4

Photo 31. Extent of spalling after shot 29, test 4

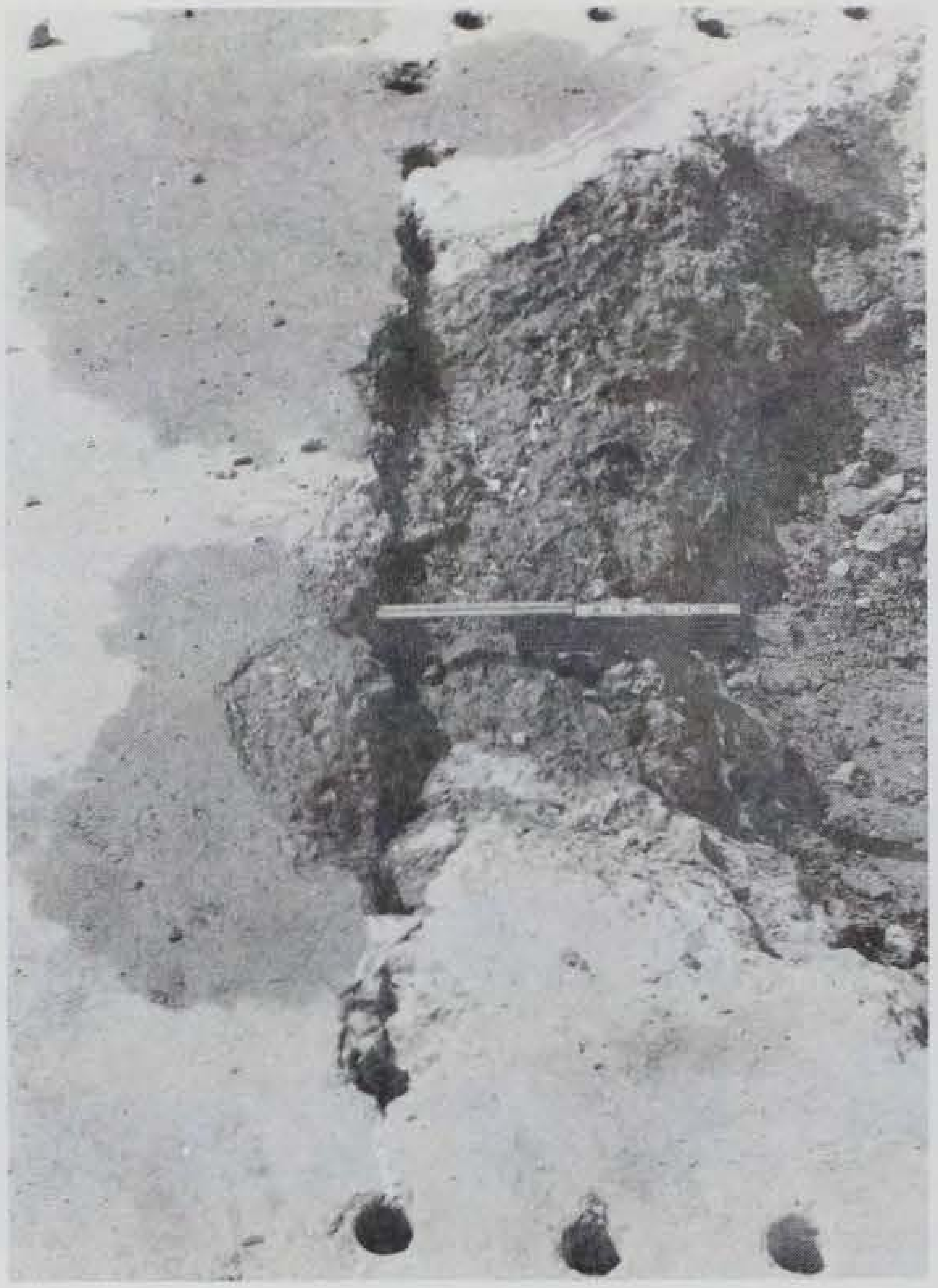


Photo 32. Extent of cracking and spalling after shot 29, test 4

Photo 33. Edge resulting from Water Wedge cutting

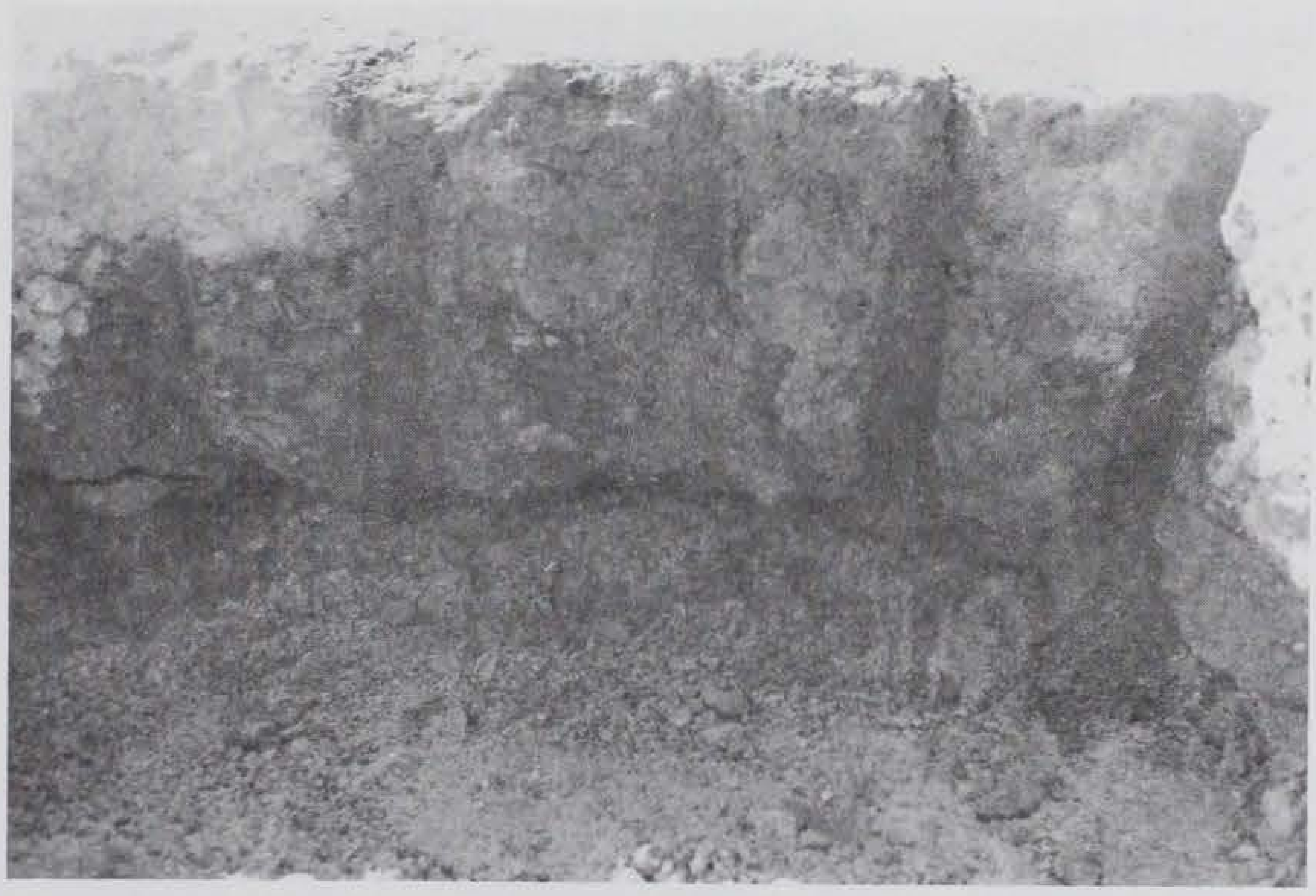


Photo 34. Edge resulting from Water Wedge cutting