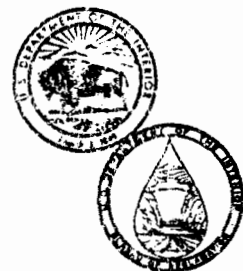


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POLYMER IMPREGNATION AND COLLECTION OF UNDISTURBED SOIL AND ROCK SAMPLES

**Engineering and Research Center
and
Mid-Pacific Region
Bureau of Reclamation**

March 1979



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**Major work and funding by the Auburn-Folsom
South Unit, Central Valley Project Construction Office,
Mid-Pacific Region**

by

W. Glenn Smoak

Max J. Stodolski

March 1979

Concrete and Structural Branch
Division of Research
Engineering and Research Center
Denver, Colorado



UNITED STATES DEPARTMENT OF THE INTERIOR

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On November 6, 1979, the Bureau of Reclamation was renamed the Water and Power Resources Service in the U.S. Department of the Interior. The new name more closely identifies the agency with its principal functions — supplying water and power.

The text of this publication was prepared prior to adoption of the new name; all references to the Bureau of Reclamation or any derivative thereof are to be considered synonymous with the Water and Power Resources Service.

The information contained in this report regarding commercial products may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product by the Bureau of Reclamation.

PREFACE

This report describes a unique application of concrete-polymer materials technology. This technology, though originally developed for enhancing the strength and durability of portland cement concrete, was modified and successfully used to permit the acquisition of undisturbed geological samples that were subsequently used to petrographically determine the time of last movement in the sample zones.

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ABBREVIATIONS

AMVN	[1]* - 2,2-azobis-(2,4-dimethyl valeronitrile)-a polymerization initiator.
BP	[2] - Benzoyl peroxide - 98 percent - a polymerization initiator.
CoN	[3] - Cobalt naphthenate - 6 percent - a polymerization promoter.
DMA	[4] - Dimethylaniline - a polymerization promoter.
DMpT	[4] - Dimethyl-para-toluidine - a polymerization promoter.
MEKP	[2] - Methyl ethyl ketone peroxide - 60 percent - a polymerization initiator.
MMA	[5] - Methyl methacrylate - a low viscosity acrylic monomer.
PMMA	- Polymethyl methacrylate - a solid polymer of MMA.
PVC	- Polyvinyl chloride - a vinyl chloride polymer or plastic.
RVE	[6] - Dow Derakane vinyl ester 8084 - a relative high viscosity rubberized vinyl ester resin, experimental at this time.
TMPTMA	[7] - Trimethylolpropane trimethacrylate - a trifunctional monomer used to provide a cross-linked structure to PMMA.
VE-470	[6] - Dow Derakane vinyl ester VE-470 - a relatively low viscosity vinyl ester resin used to prepare castings and laminated glass fiber composites.

*Numbers in brackets refer to suppliers of that product, see appendix B, "Partial List of Suppliers."

INTRODUCTION

As a result of a 5.7-Richter magnitude earthquake that occurred near Oroville, California, in August 1975, the Bureau of Reclamation elected to re-evaluate the seismic inputs for the design of Auburn Dam. A contract for this purpose was awarded to Woodward-Clyde Consultants. The Bureau of Reclamation project geology staff, utilizing consultants, also began an extensive seismic study by expanding the extensive geologic knowledge gained during preconstruction investigation and excavation for the dam foundation.

Various investigations by the Bureau involving extensive excavations and coring were performed in these new studies. This report will not discuss these studies, but, due to the minimal stratigraphic data available at the Auburn site and complexity of the Sierran foothills geology, it became desirable to obtain undisturbed samples of material across the fault, designated F-1, and across the Maidu East shear zone in an attempt to petrographically determine the time of last movement in these areas.

Conventional sampling techniques were attempted with great care but without significant success. Personnel at the Auburn project then suggested that the sample areas be impregnated with an acrylic plastic system, using a surface impregnation technique similar to that developed for concrete. The acrylic plastic, they believed, could consolidate or freeze the sample material as it existed in place and permit removal of the desired undisturbed samples.

The polymer impregnation process developed for concrete involves drying the area to receive monomer to the depth of desired penetration. Moisture occupies the space into which it is desired to place monomer and effectively blocks monomer penetration. Although it is a time-consuming procedure, numerous laboratory and field tests have demonstrated that drying is an essential step. After an area has been dried, it must be allowed to cool before impregnation. If cooling is not accomplished, the heat sensitive monomer will cure or polymerize on the surface and not penetrate to the desired depth.

Impregnation is accomplished by soaking or ponding a monomer system composed of 95 percent MMA and 5 percent TMPTMA by mass.¹ A heat

sensitive polymerization initiator or catalyst AMVN is added to the monomer system just prior to use. Normally, the concentration of initiator is 1/2 to 1 percent of the monomer system. After the monomer system has penetrated to the desired depth, heat is used to activate the polymerization initiator and cure the monomer in place. This impregnation process was developed for use on sound concrete as found on new spillways or highway bridge decks.

The process times, temperatures, and quantities are as follows:

Drying — A 4- to 8-hour heatup period to a surface temperature of 120 °C (250 °F), followed by 8 hours of drying at 120 °C (250 °F) surface temperature is required.

Cooling — Normally a 12- to 18-hour period is required to cool the surface to 40 °C (100 °F).

Impregnation — The monomer system is applied at the rate of 3.9 kg per m² (0.8 lb per ft²) of surface followed by a 4- to 6-hour soak period.

Polymerization — A 4- to 6-hour heatup period to a surface temperature of 70 °C (158 °F) followed by 4- to 6-hours polymerization at 70 °C (158 °F) surface temperature is required.

Field trials using the surface impregnation technique were performed at two geologically different sites; two similar impregnation and sample removal techniques were developed. This report describes the successful technique developed and used for each site. The appendix describes the various trials, some with negative results that were used to develop the successful or recommended procedures.

SUMMARY AND CONCLUSIONS

This report shows that polymer impregnation can be used to strengthen and protect portions of shear zones to permit acquisition of undisturbed samples for thin section analysis and testing.

Using a polymer impregnation technique similar to that developed for concrete, polymer penetrations of 50 mm (2 in) to 150 mm (6 in) were achieved in the treated shear zones. The deeper penetrations were accomplished with a drying cycle of 48 hours

¹Each percent of constituent designated throughout this report is a measurement by mass.

or longer, at a surface temperature in excess of 200 °C (390 °F). The monomer application rate with the 95-5 MMA-TMPTMA monomer system and 1 percent AMVN polymerization initiator averaged about 38 kilograms per square meter (7.8 lb/ft²) of surface area. This very high application rate resulted from the high porosity of the clay, rock, and sand in the shear zone and the presence of cracks and fractures which allowed the monomer to drain from the treated zone. Normally, soak periods of 45 minutes to 1 hour gave adequate penetration. Polymerization was accomplished by the heat retained in the ground after drying. Best results were achieved by applying monomer when the 125-mm (5-in) deep temperature had cooled to the 60 to 63 °C (140 to 145 °F) range.

Attempts to provide field-treated samples with additional impregnation with the MMA monomer system in the laboratory were not successful. The drying and monomer soak caused the samples to crack and expand, destroying the original structure. An undetermined chemical reaction also occurred during the long impregnation and polymerization cycle exposure to monomer. This reaction caused a distinct color change in the sample. Additional laboratory work would be needed to define this reaction.

A coating procedure was developed using two vinyl ester resin systems to obtain a partial impregnation on both in-place shear zone surfaces and samples in the laboratory. These systems strengthened the samples and enhanced the visibility of the surface features.

The treatment systems described could have broad application for use in a variety of geologic and soil mechanics studies. Also, since the materials used in the treatment process involve certain safety hazards, consultation with engineers experienced in use of the system should precede any attempts to treat soils and rock.

TREATMENT TECHNIQUE FOR WEATHERED SANDY GRAVEL; MAIDU EAST ZONE

The Maidu East displacement zone trends north-south and is nearly vertical. As exposed in trench ST-68, the zone consists of three apparent displacements, each about 3 m (10 ft) apart. The main "shear" displays an apparent vertical displacement of about 4.5 m (14-1/2 ft) and the apparent total

zone displacement is about 5.5 m (18 ft). The material in the zone is a weathered sandy gravel containing abundant clay. The structural materials of the zone are loosely bound together by the cohesive properties of the clay.

Numerous cobbles in the material of the zone made removal of undisturbed samples very difficult to impossible with conventional sampling techniques. An overall view of trench ST-68 with the rain-eroded main displacement is apparent on the right or south wall (fig. 1)². A detailed view (fig. 2) of that wall shows the types of soil material in the zone. This material was essentially saturated with water from frequent rains before and during the polymer treatment process.

The exposed surfaces of this type material will normally have been disturbed by natural or manmade events such as erosion or excavation. It thus becomes necessary to sample to some depth below the surface. At the Maidu East zone, a sample or impregnation depth was not rigidly specified, but Bureau project geologists requested that a penetration of 100 to 125 mm (4 to 5 in) be attempted in the material at the bottom of trench ST-68. Inspection of the areas of specific interest indicated that a sample area approximately 1 m (3 ft) on a side would enclose the geological structures desired for study. The ground surface of the sample area was gently cleaned of debris such as loose cobbles, clay balls, and organic trash. Thermocouple temperature sensors were placed on the surface and at 25-, 75-, and 125-mm (1-, 3-, and 5-in) depths near the center of the area to be impregnated. Temperature data from these sensors were recorded continuously, both to provide a temperature history of the area during the impregnation process and for use in controlling the various steps of the process. A gas-fired, infrared radiant heater approximately the same size as the sampled area was suspended over the area on a tripod and used to provide drying heat to the gravel surface. The heater is shown in place over an area adjacent to a smaller trench in the bottom of trench ST-68 (fig. 3). Temperature control was accomplished both by varying the gas supply pressure and the height of the heater above the treatment area. This heater was modified for this project by removing the wheels and handles from a portable asphalt pavement patcher. It operated flawlessly throughout the project due to its simple design. Electric infrared heaters could probably be adapted similarly for this type of application. The

²All figures are at the end of the report. (Appendix figures are with the appendix text.)

heater had a very high heat output and was easily capable of raising the ground surface temperature to over 200 °C (400 °F) in 10 to 15 minutes.

The drying time and temperature required for successful impregnation is a function of type of material to be dried, surrounding material, and desired depth of penetration. Water content of the undried material, at least within limits normally encountered in the field, is not of much importance because it requires essentially the same time to dry material containing, for example, 5 percent moisture as material containing 25 percent moisture. Obviously, if the material is experiencing artesian pressure (or flowing water, such as could occur in a saturated seam of material bounded by rock, or at the bottom of a foundation excavation) the source of supply water must be eliminated prior to drying.

The best results were obtained in the Maidu East material by drying for 30 to 48 hours at a surface temperature of 150 to 200 °C (300 to 400 °F), provided that during this period the temperature at the 125-mm (5-in) depth attained 90 to 100 °C (195 to 210 °F) for a period of 4 to 6 hours.

Although not specifically proven, it is our opinion that sufficient drying for excellent impregnation can be accomplished by raising the temperature at the depth of maximum desired penetration to 100 °C (212 °F) and maintaining that temperature for 4 hours.

Following drying, the area was cooled to 60 to 65 °C (140 to 150 °F) at the desired depth of impregnation. This temperature is very significant because the monomer system begins to polymerize or cure within this range. If cooling is continued to lower temperatures, additional heat will be required for polymerization. If temperatures much higher than 60 to 65 °C (140 to 250 °F) are attempted, the monomer system may polymerize prematurely and result in less than desired penetration.

Depending upon the structure, material being treated, and climatic conditions, cooling will normally require 10 to 18 hours. During the cooling period, a plywood wall approximately 100 mm (4 in) high was constructed to form a monomer reservoir around the area to be treated (fig. 4). The plywood was carefully cut to closely conform to the ground contours and sealed to the ground surface. It was important to achieve a good seal to prevent waste of monomer, contamination of adjacent areas, and for safety.

To accomplish a tight seal, assuming the plywood fairly accurately matched the ground surface contours, plaster of paris was mixed and placed in a 75-to 100-mm (3- to 4-in) wide, 25-mm (1-in) deep band on the ground surface upon which the reservoir would rest. A heavy bead of silicon rubber caulking was applied to the corners on the inside and onto the bottom edge of the walls of the reservoir. The reservoir was then carefully pressed into the soft plaster of paris and left to harden in place. Touchup applications of plaster of paris were made as required. After the plaster had hardened, it was usually necessary to apply a thin layer of silicon rubber caulking to the inside edge of the wall-to-plaster contact area and to any other areas that appeared insufficiently sealed. The reservoir was constructed and sealed 3 to 4 hours prior to monomer application to give the caulking and plaster ample time to cure.

Due to the highly fractured and jointed nature of the material treated at the Maidu East zone, it was necessary to provide additional sealing to the ground surface outside the reservoir. A relatively low viscosity vinyl ester resin system³ composed of VE-470 with 1.5 percent MEKP initiator, 0.5 percent CoN promoter, and 0.125 percent DMpT promoter was mixed at the site. This system was spread around the outside perimeter of the reservoir. The resin flowed into, and sealed, the cracks and joints against monomer leakage. This resin system had a very short pot life of 6 to 8 minutes, and a final curing time of 15 to 30 minutes. Due to the short pot life, it was necessary to thoroughly mix and spread the system very quickly.

To pond the monomer for impregnation on a steeply sloped sampling area (fig. 5), a stepped or partitioned reservoir was constructed (fig. 6). The partition was sealed to the ground surface just as were the outer perimeter walls.

The monomer system used for impregnation was composed of 95 percent MMA and 5 percent TMPTMA. The heat sensitive polymerization initiator, AMVN, was added to the monomer system at a concentration of 1 percent of the monomer just prior to application.

Immediately after mixing, the monomer system was poured into the reservoir (fig. 7). The best

³The use of the terms "resin" and "monomer" in this report reflect terminology established by the respective manufacturers.

results were obtained with an application rate of about 38 kg per m² (8 lb per ft²) of surface area. Normally, the total volume of monomer was added in two to three applications to keep from topping the reservoir. Upon the second application of monomer, a 50- to 75-mm (2- to 3-in) thick layer of dry mortar or pit run sand was poured into the reservoir. This sand leveled the irregular ground surfaces and made subsequent sample removal easier. It also served as an evaporation reduction barrier for the monomer and assured uniform monomer distribution to the higher elevations of the sample area. Care was taken to maintain the sand in a fully saturated state until polymerization began.

Heat retained in the sample initiated the polymerization reaction. Due to natural cooling, the upper levels were cooler than the lower levels; monomer was thus able to soak through the upper levels and did not begin to polymerize until it reached the much warmer lower levels. The start and progress of the polymerization reaction was monitored by observing data from the thermocouple sensors.

Monomer polymerization is an exothermic chemical reaction. Heat generated by polymerization at the warm deeper levels of the sample caused progressive polymerization up into the shallower levels and ultimately reached the monomer-saturated sand layer on the ground surface. A sheet of polyethylene was placed over the reservoir during impregnation and polymerization to reduce monomer evaporation and retain heat. Normally, polymerization began at the 125-mm (5-in) depth within 45 to 80 minutes after monomer application. The sample area was then left undisturbed to cure until the following day.

The samples were removed and prepared by removing the reservoir and cleaning the sample area of loose debris, diamond sawing the samples into 50-mm (2-in) thick vertical slabs, removing the slabs from the ground, and applying a resin coating to the slab surfaces. The resin improved the sample grain, visibility and added a protective coating.

A commercial concrete sawing firm was contracted to cut out the samples. The contractor made vertical cuts parallel to the boundary of the displacement zone, and then made transverse vertical cuts, 50 mm (2 in) apart, between the boundary cuts. The contractor used an air-powered, water-cooled, 914-mm (36-in) diameter diamond-tip blade saw (fig. 8). The saw guide tracks were mounted using bolts anchored into drilled holes with the ground

surface crack sealing resin system previously described. When the sawing was completed, excess material surrounding the sample area was removed with shovels and pry bars. In several places, an air-powered bushhammer with a wedge bit was used to carefully remove harder debris. This work continued until the first outside cut face of the sample was fully exposed (fig. 9). The clay material that was of geologic concern can be clearly seen at the center of the face. The dark material at the top of the face is the polymerized impregnation sand which formed a strong supporting backbone of polymer concrete for the sample. Water was used to gently wash the cutting debris from the sample face. The impregnated zone, which shows as a dark tan layer 25 to 35 mm (1 to 1 1/2 in) deep (fig. 9) increased toward the center of the sample area. As the outer slabs were removed the polymer penetration increased to the desired depth.

Several slab removal techniques were developed depending upon the intended end use of the slab. Slabs of significant geologic interest thus designated for thin section petrographic analysis, were protected by bonding a 6-mm (1/4-in) thick clear acrylic plastic sheet to the exposed faces prior to removing the slab. A high viscosity vinyl ester resin system, composed of RVE with 4 percent MEKP initiator, 1.3 percent CoN promoter, and 0.5 percent DMpT promoter, was prepared and thickly painted onto the faces of the slab and the precut plastic sheet. A thick bead of silicon rubber caulking was also placed around the side and bottom perimeters of the plastic sheet. The plastic sheet was then pressed against the face of the slab and held there with various materials of opportunity at the site. The uncured silicon caulking compressed, formed a retaining seal for the resin system, and permitted very close contact between the slab and the plastic. Additional resin system was poured onto the top of the slab which flowed down between the slab and plastic interface and filled any residual voids. The resin system cured and bonded the plastic to the slab in 30 to 60 minutes. Visibility through the plastic and resin was excellent. A horizontal cut was then made with a knife at the bottom of the slab, and the test slab gently rotated to the horizontal position for removal.

Slabs not designated for thin section analysis were cleaned and coated with a thick layer of the RVE system. This clear amber-colored coating, when cured, provided improved visibility of the features of the slabs and strength for removal. Horizontal cuts were made at the bottom of the slabs which

were then rolled over onto 25-mm (1-in) thick plywood for removal.

To further enhance the usefulness of this sampling technique, a fully representative face of each sample area was left in place at the site for future observation. These faces and the sample areas were cleaned of saw mud, debris, loose clay, and cobbles, and allowed to assume a surface dry condition. The exposed surfaces were then coated with a lower viscosity vinyl ester resin system which penetrated the surfaces 3 to 13 mm (1/8 to 1/2 in) depending upon how long the face was dried. Several applications of this system were necessary to penetrate, seal, and coat the surfaces. The VE-470 resin with 2 percent MEKP initiator, 0.05 percent CoN promoter, and 0.4 percent DMpT promoter was used for this purpose. This resin system preserved the true colors of the face, since it did not develop the amber color of the RVE system, and it provided a measure of waterproofing and erosion protection. After the slabs that were removed were taken to the laboratory, all remaining uncoated faces also received this resin coating. The coating improved the visibility of the structural and color features similar to the manner in which varnish or lacquer adds depth and visibility to well-sanded wood. Two slab samples are shown (fig. 10) after they had been removed from the field, coated, and sawed into smaller sections for transportation to the petrographic laboratories.

TREATMENT TECHNIQUE FOR HARD ROCK; F-1 FAULT ZONE

The major dam foundation fault, F-1, extends sinuously from the top of the left dam abutment (near the toe) into the channel at the North Fork of the American River, where it crosses over the heel of the dam and continues upstream of the right abutment. The fault generally dips 35 to 50° southwest and strikes generally north 30 to 80° west. This fault (fig. 11) is a complex of thin gouge zones, dikes, altered amphibolite, chlorite schist C, and quartz-calcite veins. The average cumulative thickness of sheared material in the zone is about 1 m (3 ft). The cumulative thickness of gouge within the zone varies from about 100 to 3 mm (4 to 1/8 in).

The project geologists requested that an attempt be made to remove an undisturbed sample from the F-1 fault zone at a location where its total thickness, including gouge and sheared rock, was

at a minimum. At the site selected, the total thickness of the fault is less than 75 mm (3 in) and the gouge zone proper varies from about 8 to 16 mm (0.3 to 1.5 in). At this location the fault is bounded on the hanging wall by well-foliated and moderately jointed amphibolite, and on the foot-wall by a quartz vein.

The rock wall above the selected sample site continuously seeped water, thereby keeping the gouge material in a fully saturated condition. The first task before removal was to isolate the sample from this water. The services of the contractor working at the Auburn damsite were employed. An air track drill equipped with a 64-mm (2-1/2-in) bit was moved in to line drill a 3-m (10-ft) long by 2-m (6-ft) deep relief cut downslope of the site. After this relief cut was completed, an area approximately 3-m (10-ft) square was pattern drilled approximately 2 m (6 ft) deep and carefully loaded with explosives. After shooting this rock, a vertical face on the downslope side of the sample site was exposed (fig. 12). The air track then drilled a series of contiguous vertical holes upslope of the sample site, then at a right angle to these holes along the toe of the cut slope. After these holes were completed, the sample was isolated except for approximately 1 to 2 m (3 to 6 ft) of rock overburden. This rock needed to be removed, leaving a uniform thickness of country rock above the fault of approximately 100 mm (4 in). A commercial diamond sawing and core drilling firm was hired to drill a series of 75-mm (3-in) diameter contiguous core holes 100 mm (4 in) above the gouge. This relieved a 1-m (3-ft) square area of overburden rock (fig. 13). The rock overburden was removed exposing a relatively uniform surface from which the drying and impregnation operations could be performed.

The top 100 mm (4 in) of undisturbed rock covering the gouge was moderately jointed. As a precautionary measure to keep this material from being disturbed during subsequent operation, a relatively low viscosity vinyl ester resin system, composed of VE-470 with 1.5 percent MEKP initiator, 0.5 percent CoN promoter and 0.125 percent DMpT promoter, was prepared and spread generously over the entire exposed areas. After this system was applied, there remained larger cracks which the low viscosity system would not seal. A second vinyl ester resin system of higher viscosity, RVE with 4 percent MEKP initiator, 3 percent CoN promoter, and 0.5 percent DMpT promoter, was prepared and applied to the entire surface area to fill the large joints and bond the rock together.

Prior to setting up the gas-fired infrared heater for drying, thirty-four 25-mm (1-in) diameter core holes were drilled through the top 100 mm (4 in) of rock and into the underlying gouge (fig. 14). These holes were necessary to allow the moisture to escape from the gouge during the drying procedure, and later, would provide a means of supplying monomer to the dried gouge material.

A thermocouple temperature sensor was placed in each of six 25-mm (1-in) diameter holes to the depth of the gouge. These holes were then filled with a slurry of pozzolan. Wet pozzolan was used to fill the holes containing the thermocouples to simulate the same wet condition of the gouge. Two thermocouples were also placed in the gouge by driving a 3-mm (1/8-in) diameter rod into the exposed gouge face and placing the thermocouple wire into the holes. Two additional sensors were placed in the gouge near two of the sensors which had been placed in the drill holes and filled with the pozzolan slurry. The purpose of this was to determine if the gouge between the drill holes was attaining the same temperature as the pozzolan material. Temperature data, received from the sensors and recorded by a strip chart recorder (fig. 15), indicated that the gouge did heat and dry uniformly. The gas-fired infrared radiant heater was suspended over the sample area from a tripod such that its distance above the nonlevel surface was fairly uniform and could be varied.

High surface temperatures were not critical to the rock; therefore, the rock surface was allowed to reach temperatures in excess of 240 °C (460 °F). After 4 hours of heating temperatures in the gouge ranged from 60 to 96 °C (140 to 205 °F); the next 13 hours of heating resulted in temperatures of approximately 95 °C (203 °F) uniformly distributed throughout the gouge. The heater was then lowered closer to the surface to bring the gouge temperature to above 100 °C (212 °F). An additional 8 hours of heating gradually increased temperatures to between 95 and 135 °C (203 to 275 °F). These temperatures were maintained for 10 hours. The period the temperature was maintained above 100 °C (212 °F) was probably in excess of that required for drying. As discussed previously, we feel that 4 hours at or above 100 °C (212 °F) is sufficient for drying. Here, however, the 4-hour period ended during the night, and it was not feasible to begin the next procedure until daylight. After the heater was removed it took about 5-½ hours for the gouge to cool to 65 °C (150 °F). Meanwhile, 25-mm (1-in) diameter PVC pipes were installed in

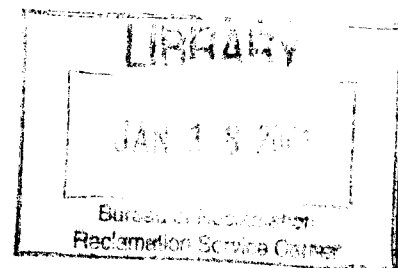
28 of the 25-mm (1-in) holes (fig. 16). The thermocouples were left in the remaining six holes and were sealed with the RVE resin system so the subsequent polymerization of the impregnating monomer system (95 percent MMA, 5 percent TMPTMA, and 1 percent AMVN) could be monitored. The pipe was cut to various lengths as necessary to assure a minimum pressure head of 250-mm (10-in) at the highest elevation of the gouge beneath the rock overburden. After the pipes were installed, a coating of RVE was painted around the joint to prevent leakage and secure the pipes in place.

The gouge was then impregnated with the monomer system. An 11-liter (3-gal) bucket, with a plastic hose attached to the bottom, was suspended from a tripod (fig. 17). The bucket and hose were used to fill each individual pipe with monomer, beginning at the lower end and working toward the highest point. Monomer leaks developed at the lower end where excavation had undercut the gouge material. The high viscosity RVE resin system was used, without success, to penetrate and seal these leaking joints. A mixture of RVE and portland cement was then prepared to a paste consistency, and forced into the joints. This cured rapidly enough to successfully seal against leakage. A total of 21 kg (47 lb) of the MMA monomer system was used for the impregnation; however, a conservative estimate is that approximately half of this monomer leaked out before the cracks and joints were sealed. The rate of absorption of the monomer to volume of gouge material probably did not exceed 400 kg/m³ (0.23 oz/in³).

Soon after the leaks were sealed the MMA monomer system began to polymerize. The gouge was at approximately 65 °C (150 °F) and the monomer was at ambient temperature when the monomer application was begun. This cooled the gouge to approximately 58 °C (136 °F). The exothermic polymerization of the monomer system began and complete polymerization occurred within an hour.

The samples were removed and prepared by removing the PVC stand pipes, relieving the sample at the bottom by core drilling, diamond sawing the samples into 50-mm (2-in) thick slabs, removing the slabs from the site, and applying a resin coating to the slab surfaces for additional protection.

The first procedure used in the technique to remove the 600-, by 300-, by 50-mm (24-, by 12-, by



2-in) samples was to relieve the bottom of the sample zone. This was done by mounting an air-powered core drill on the vertical face of the downslope wall and line drilling eight 75-mm (3-in) diameter holes approximately 1 m (3 ft) deep into the rock (fig. 18). This line of holes was drilled approximately 150 mm (6 in) below the polymerized gouge. After the bottom relief holes were drilled, an air-powered 914-mm (36-in) diameter diamond-tip blade saw was used to cut the sample into 50-mm (2-in) thick slabs to the depth of the relief holes (fig. 19). A total of nine cuts were made. When these cuts were completed, two end cuts, 600 mm (24 in) apart were made, thereby freeing the samples for removal (fig. 20).

These samples were of significant geologic interest to be sent for thin-section petrographic analysis. Care and protection, therefore, were critical in their removal and subsequent handling. To protect the samples, a 6-mm (1/4-in) thick clear acrylic plastic sheet was bonded to the exposed faces. This was done by applying a coat of RVE resin system onto the face of the sample and onto the bonding side of the precut plastic sheet. A bead of silicon rubber caulking was also placed around the side and bottom perimeters of the plastic sheet to prevent the RVE from escaping before it cured. The plastic sheet was then pressed against the sample face and held there until the RVE cured.

The rock between the relief core holes (fig. 21) had been deliberately left to support the samples prior to removal. This material was gently removed with a chisel and the samples were rotated 90° to a horizontal position and removed. After the samples were removed from the site, the opposite face was cleaned and a coat of VE-470 resin system applied. This application served two purposes: First, it penetrated any cracks in the gouge and sheared rock that did not receive full impregnation of the monomer and added additional bonding to the material; and second, it improved visibility of the features of the sample (fig. 22 and 23). Figure 22 shows the sample before the coating of VE-470 was applied and figure 23 shows the sample after coating.

FIELD AND LABORATORY SAFETY PROCEDURES

The monomers, resins, initiators, and promoters described in this report can be hazardous to personnel and equipment unless adequate safety

precautions are taken. These hazards can be separated into three general areas as follows:

- Flammability
- Toxicity
- Uncontrolled or accidental bulk polymerization

The manufacturers of these materials have excellent literature available, describing these hazards and the required safety precautions. A detailed study of this literature is required before using the materials. The discussion that follows is intended as a general summary of the three hazard areas listed above, not as a replacement for the manufacturers' literature.

Flammability

The monomers MMA and styrene, which are a part of the vinyl ester resin systems, are flammable and can evaporate to create explosive vapor concentrations in air. Thus, these monomers and resins must be protected from excessive heat, sparks, and other sources of ignition. Storage and use facilities must be properly ventilated, cooled, shaded, and kept away from open flames and sparks. Obviously, smoking and welding must not be permitted in and around storage or use areas. Special attention should be given to unsuspected sources of ignition such as gasoline or electric motors, light switches, extension cords, or engine exhausts. The use of these materials indoors requires an adequate forced ventilation system. Natural ventilation will normally suffice outdoors. Deep, narrow trenches or unusually calm or humid conditions, however, may require forced ventilation outdoors to prevent the buildup of hazardous vapor concentrations. As a practical rule with respect to flammability, the precautions required for the safe use of gasoline will result in the safe use of the monomers and resins.

The initiators MEKP and AMVN are flammable and heat sensitive. They should be stored in their original containers at temperatures between 2 and 13 °C (35 and 55 °F). Storage at subfreezing temperatures is not required and may be harmful to the materials. These initiators are also sensitive to long-term exposure to sunlight and must be kept in the shade. At elevated temperatures, the initiators can decompose violently.

Toxicity

The monomers and resins, if taken internally, are mildly toxic and the manufacturers warn that skin

exposed to these materials may develop mild cases of dermatitis. Eyes, however, are particularly sensitive to these materials and, as a minimum protection, personnel should wear glasses or goggles. In some instances, full face shields may be justified. Impervious gloves, aprons, or coveralls and boots will protect personnel from skin exposure to the monomers and resins. Skin exposed to these materials should be promptly washed with soap and water. The vapors of MMA and styrene may be irritating to the respiratory membranes, but the ventilating precautions necessary to prevent flammability hazards generally are adequate to eliminate respiratory hazards. Due to the strong irritating odor of these materials, user personnel will not voluntarily stay in hazardous vapor concentrations under normal conditions.

The initiators MEKP and AMVN and the promoter DMpT are very toxic and should not be allowed to come in contact with the skin. Lasting or permanent damage to the eyes can result from direct contact with MEKP. Care should be taken to insure that the initiators and promoter do not contaminate food, water, or tobacco.

Uncontrolled or Accidental Bulk Polymerization

The monomers and resins contain polymerization inhibitors that protect these materials from accidental polymerization under normal conditions. Long storage or elevated temperatures may, however, deplete the inhibitors and result in bulk polymerization within the storage drums. This polymerization reaction generates heat which can cause the material to boil and ultimately destroy its containers in a pressure-type explosion. Hazardous quantities of vapor and hot polymerizing material are released in these instances.

To prevent these types of problems, the manufacturers recommend that the monomers and resins be stored only in well-ventilated, shaded locations at temperatures below 32°C (90°F). The monomers MMA and TMPTMA can be safely stored under these conditions for more than 1 year. The vinyl ester resins, however, should not be stored longer than 3 months.

Adding polymerization initiators to monomer or resin results in very rapid depletion of the inhibitor. For this reason, initiator should be added only to quantities of monomer or resin planned for immediate use. Leftover quantities of initiated monomer or resin that are not used within 4 to 6 hours, should

be discarded. In no event should such material be returned to storage.

The initiators, MEKP and AMVN, and the promoters CoN and DMpT can be safely stored in accordance with the previous recommendations. The promoters do not require refrigeration. It is poor practice, however, to store promoters and initiators in the same location. If, as a result of an accidental spill, these two are mixed, a violent reaction, fire or explosion, can occur. Accordingly, *initiators must never be mixed directly with promoters for use in monomer or resin*. The only acceptable procedure is to thoroughly mix the promoter with the monomer or resin after which the initiator can be added just prior to use.

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Figure 1.— General view of site ST-68. The eroded shear zone is apparent on the right, or south, wall.
Photo P801-D-79248

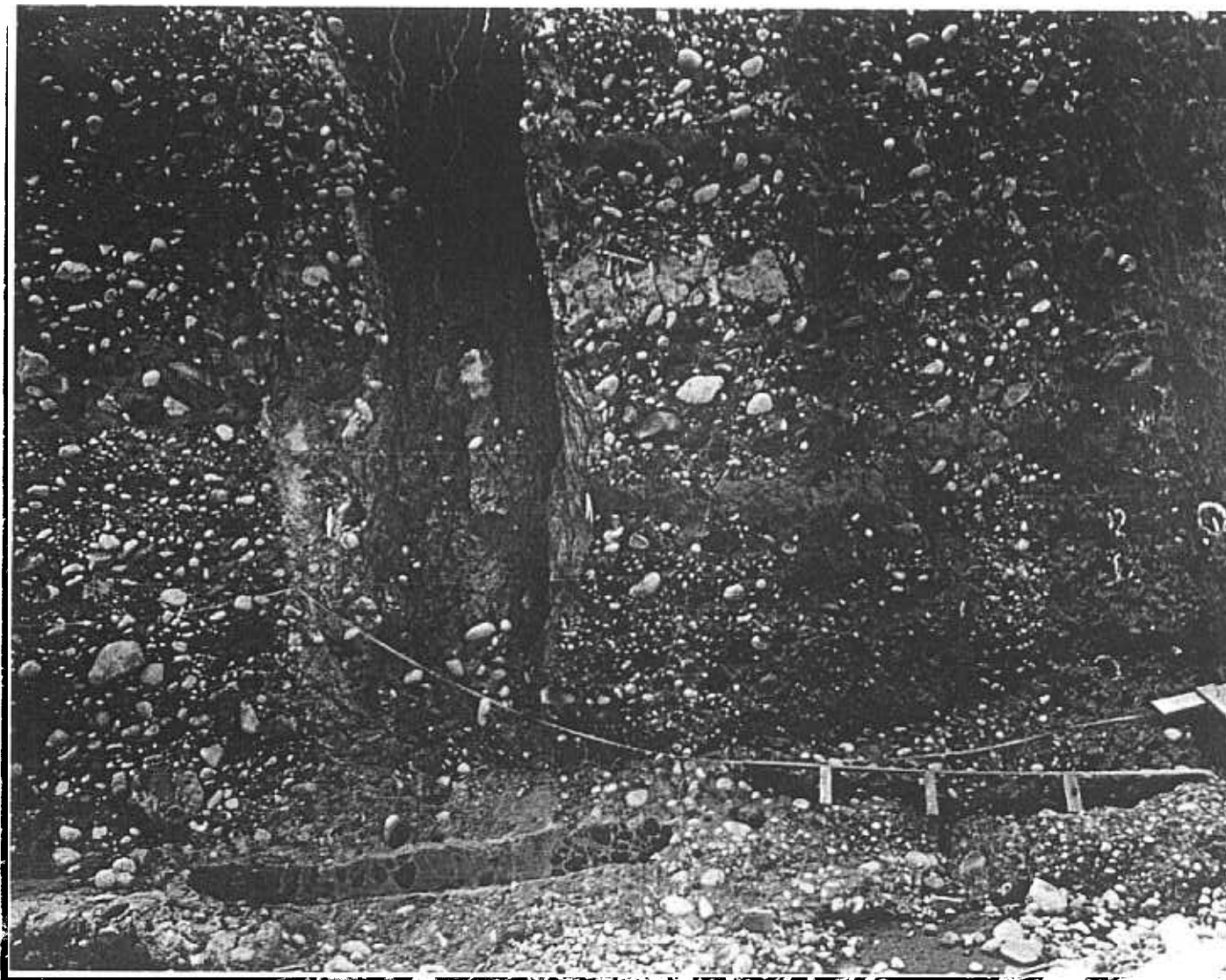


Figure 2.—Detailed view of the south wall of ST-68. (Note, the shear zone is more apparent in this view).
Photo P801-D-79249

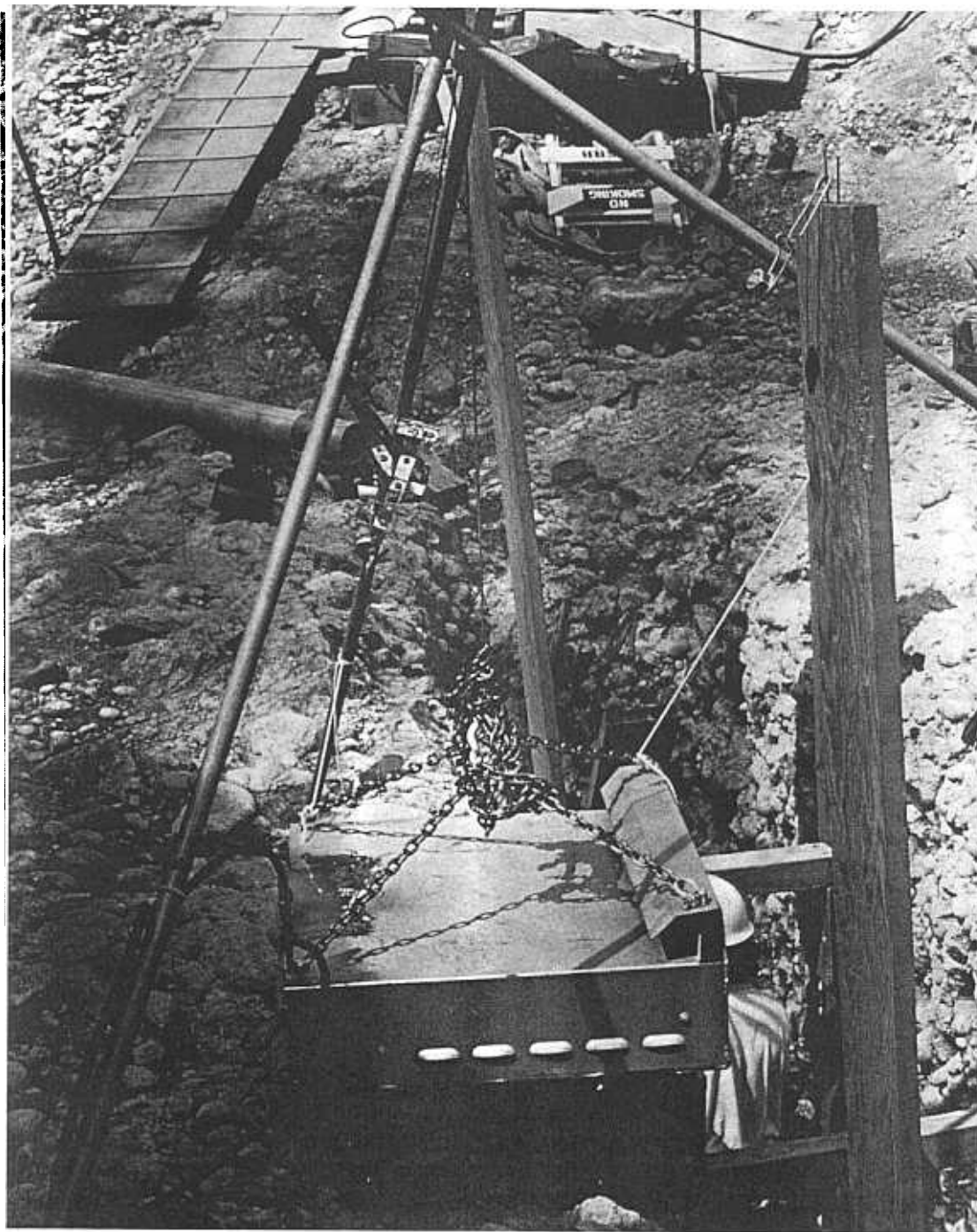


Figure 3.— Gas infrared heater used to provide heat for drying. Photo P801-D-79250

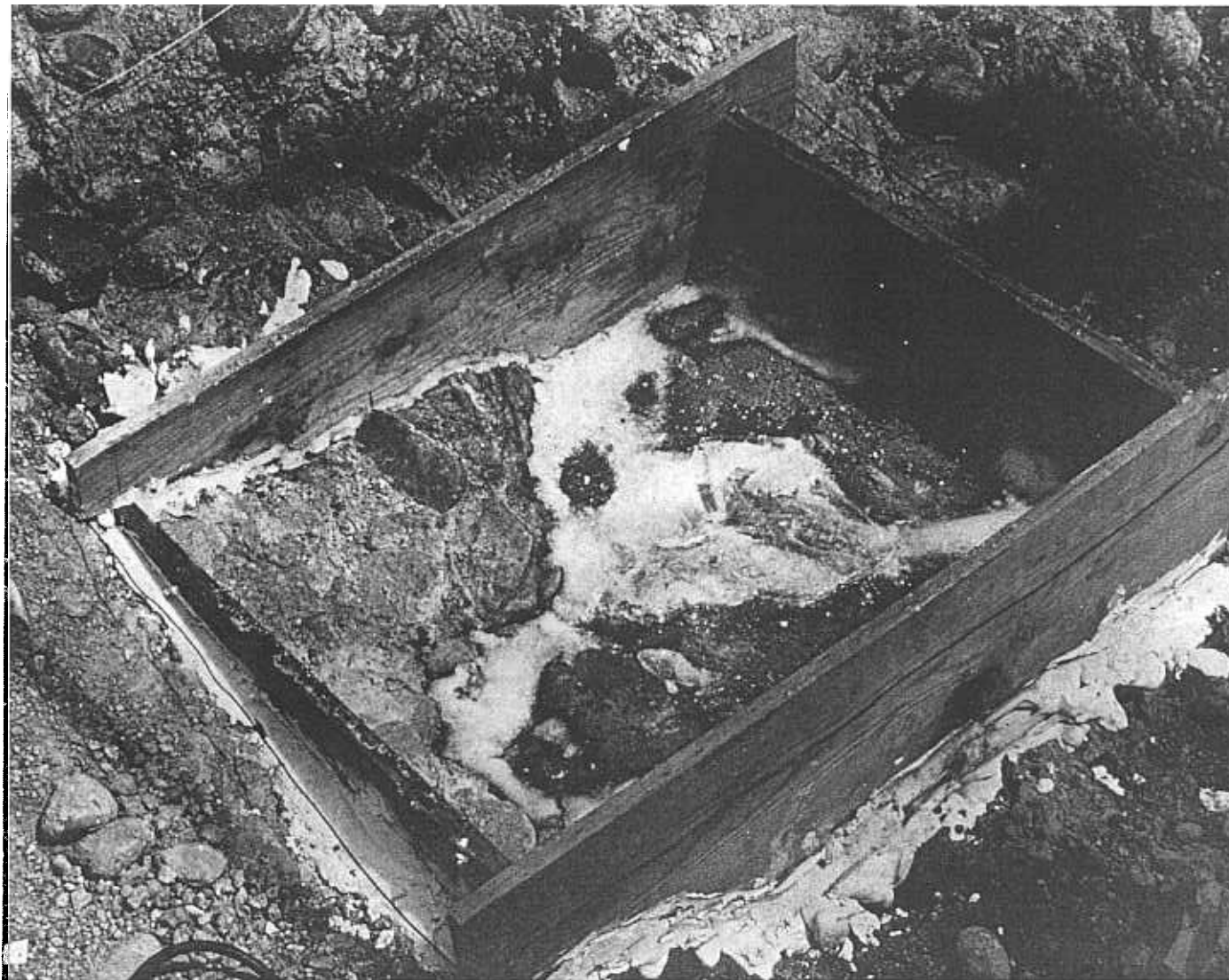


Figure 4. — Monomer reservoir placed over a sample site. Polymerization has been completed and the site is ready for sample removal operations. Photo P801-D-79251



Figure 5.— Sample site located on an irregular, sloped surface. Photo P801-D-79252

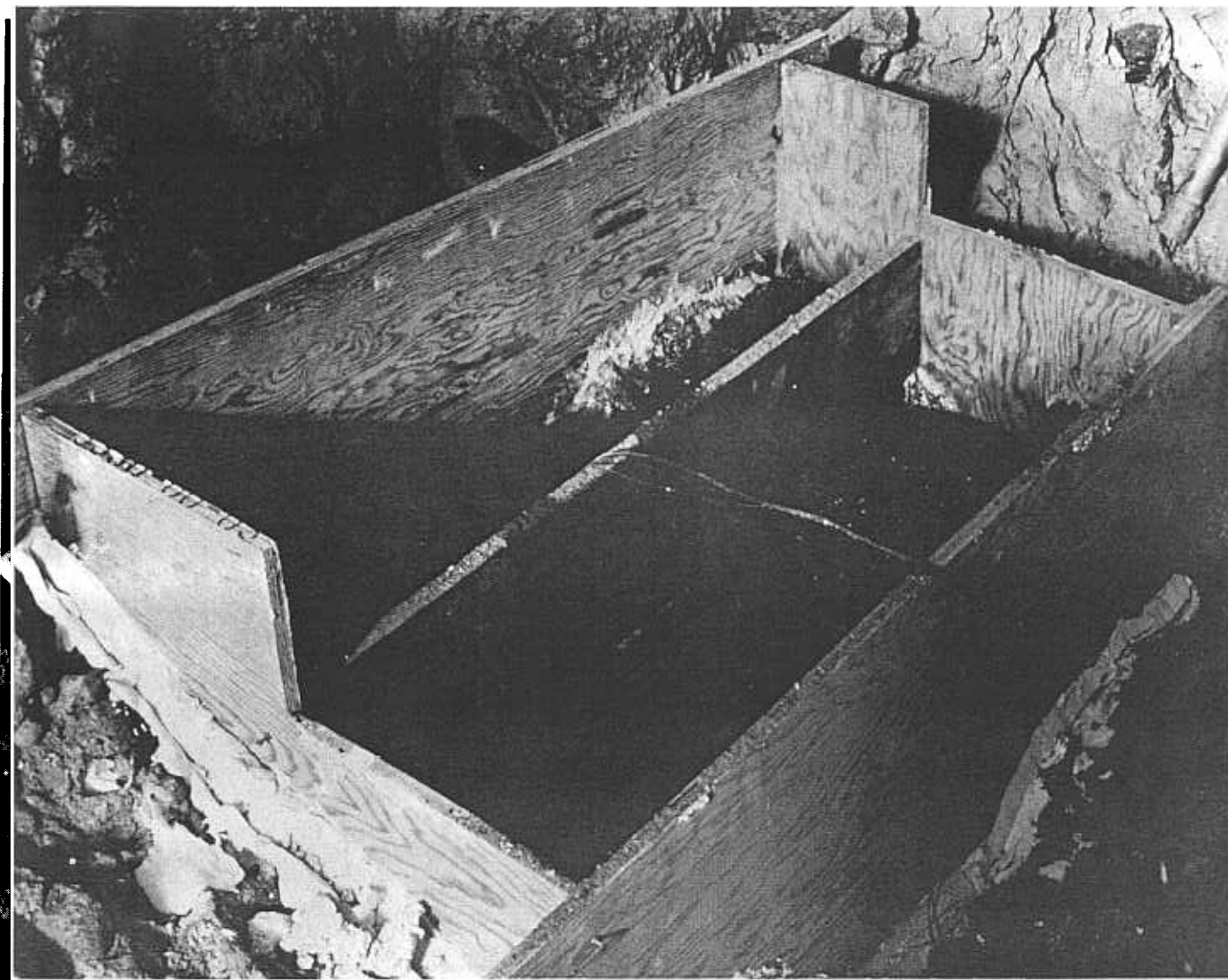


Figure 6. — Partitioned monomer reservoir used to retain monomer on the steeply sloped surface. Photo P801-D-79253



Figure 7. — The low viscosity monomer system is poured into the reservoir to begin impregnation. Photo P801-D-79254



Figure 8. — A diamond-tip blade saw was used to make vertical cuts into the sample site. These cuts divided the site into slabs for removal and further study. Close observation also reveals several transverse cuts. Photo P801-D-79255



Figure 9.—Slab sample showing shear zone in the center. Photo P801-D-79256

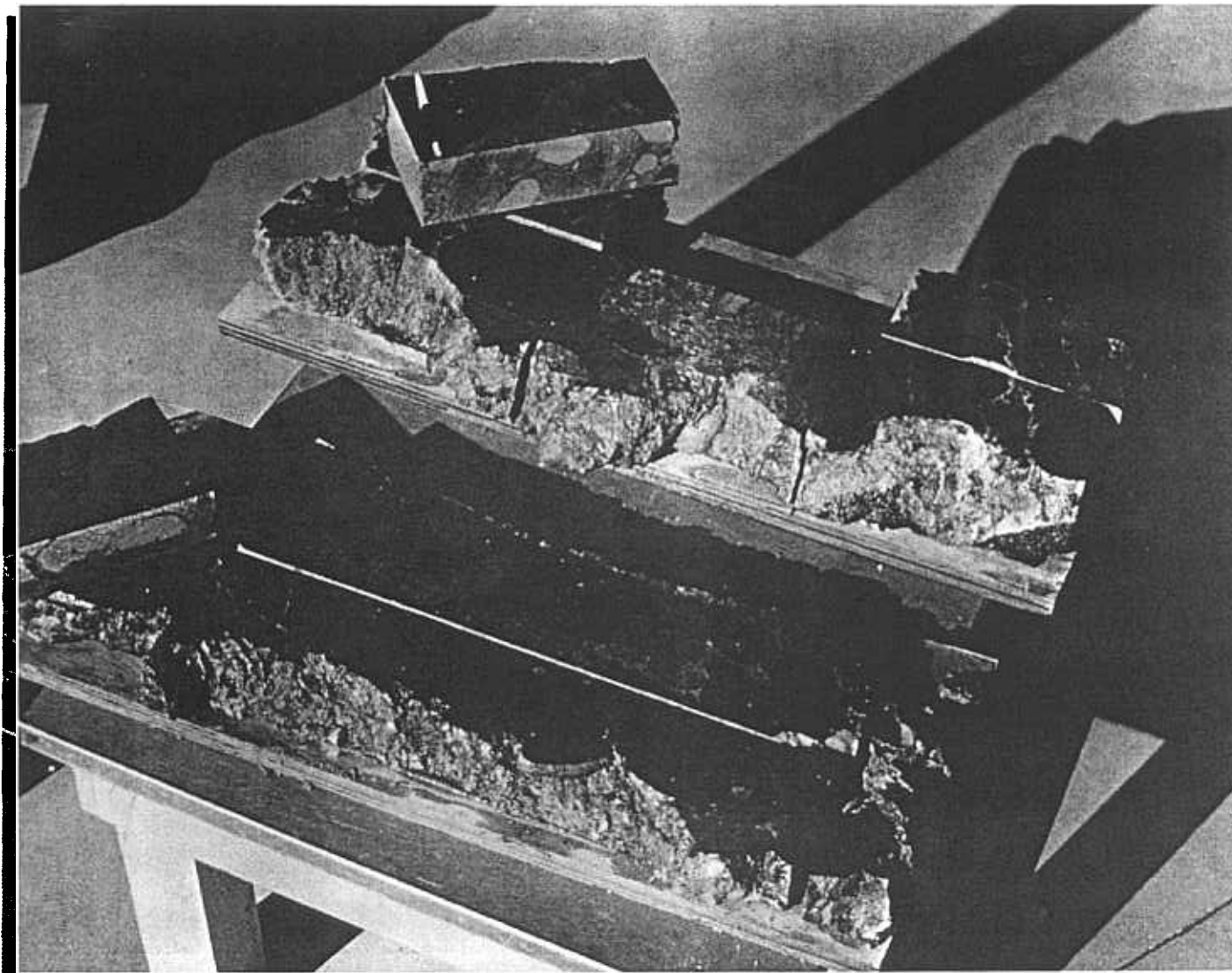


Figure 10. — Slabs which have been coated with resin and sawed into smaller sections for shipment. Photo P801-D-79257



Figure 11.— Left abutment foundation excavation looking toward the river channel. The fault (F-1) occurs along the toe of the 30-m (100-ft) high cut slope. Photo P801-D-79258



Figure 12.— Exposed vertical wall after controlled excavation in preparation for sampling. Photo P801-D-79259



Figure 13.— Air-powered, 75-mm (3-in) diameter core drill mounted on the downslope vertical face. Operator is core drilling a continuous line of holes so that the overburden can be removed without disturbing the fault. Photo P801-D-79260



Figure 14. — Air-powered, 25-mm (1-in) diameter core drill used to drill holes into the gouge. There were 34 holes drilled through 100 mm (4 in) of amphibolite. Photo P801-D-79261



Figure 15. — Gas-fired, infrared radiant heater mounted over test site, and recorder monitoring temperatures. Temperature was sensed by eight thermocouples buried within the gouge. Photo P801-D-79262

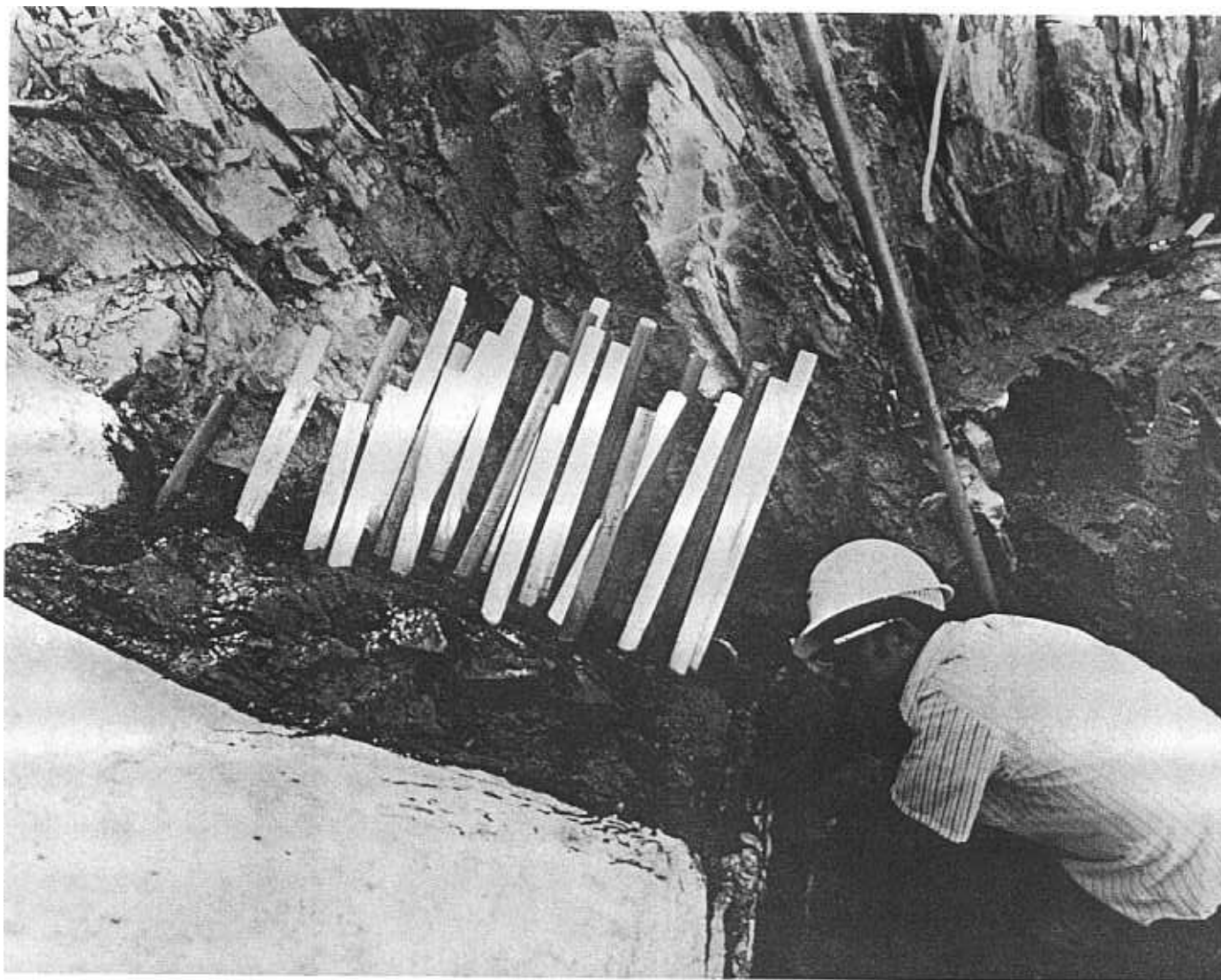


Figure 16. — The 25-mm (1-in) diameter PVC pipes installed in the previously drilled holes. These served as the reservoir for the monomer system (MMA) during impregnation. The amphibolite rock displaying the dark shining color has been coated with RVE resin system to seal cracks and joints. Photo P801-D-79263

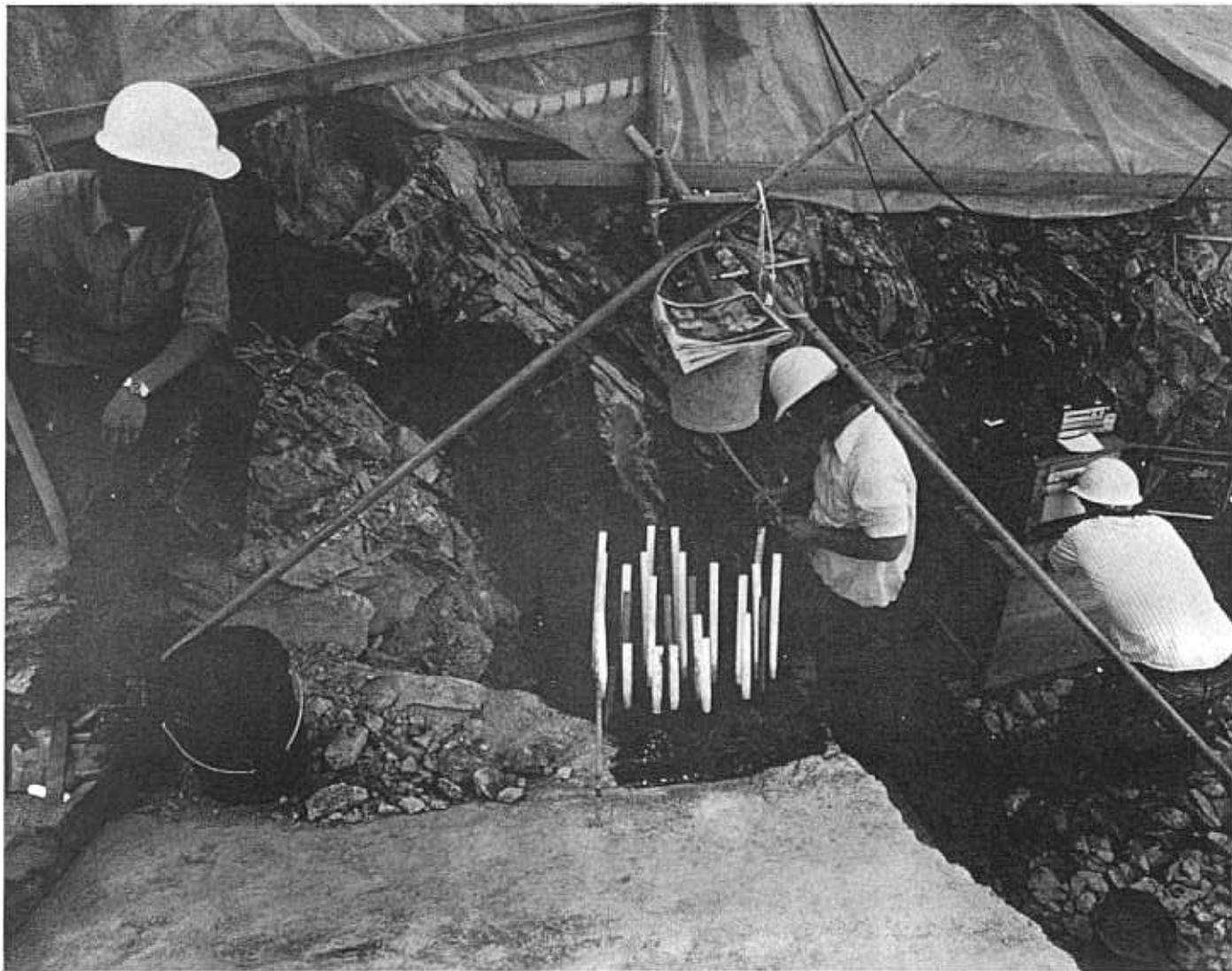


Figure 17.— Monomer system (MMA) admitted to the dry gouge through the 25-mm (1-in) PVC pipes.
Photo P801-D-79264



Figure 18.—The air-powered core drill line being used to drill eight 75-mm (3-in) diameter holes to relieve the bottom of the test site. Photo P801-D-79265

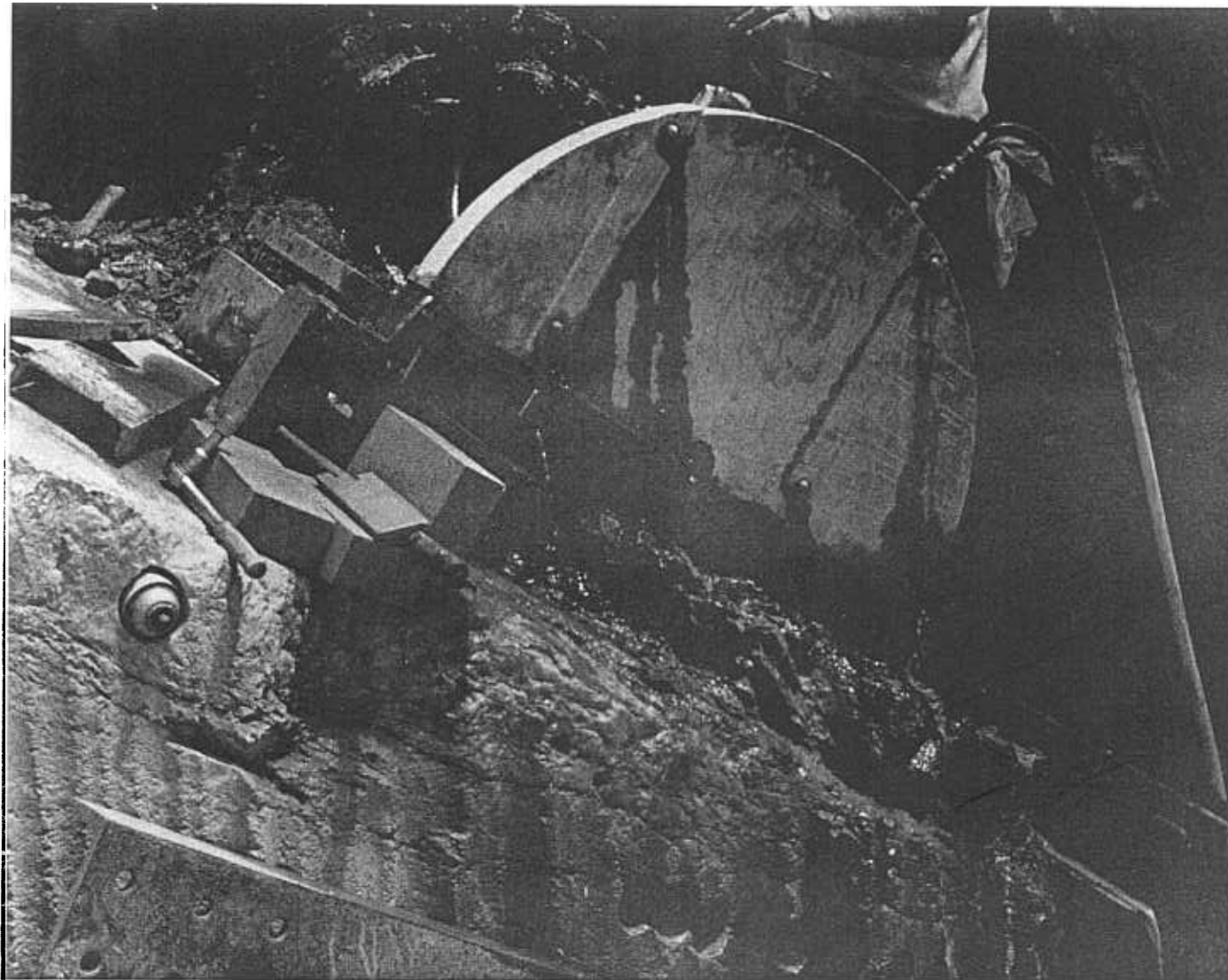


Figure 19. — Air-powered 914-mm (36-in) diameter diamond-tip blade saw cutting the test site into 50-mm (2-in) thick slabs. Photo P801-D-79266



Figure 20. — Mounting the air-powered saw driver onto the track preparing to make the second cut. (This relieved the slabs for removal.) Photo P801-D-79267

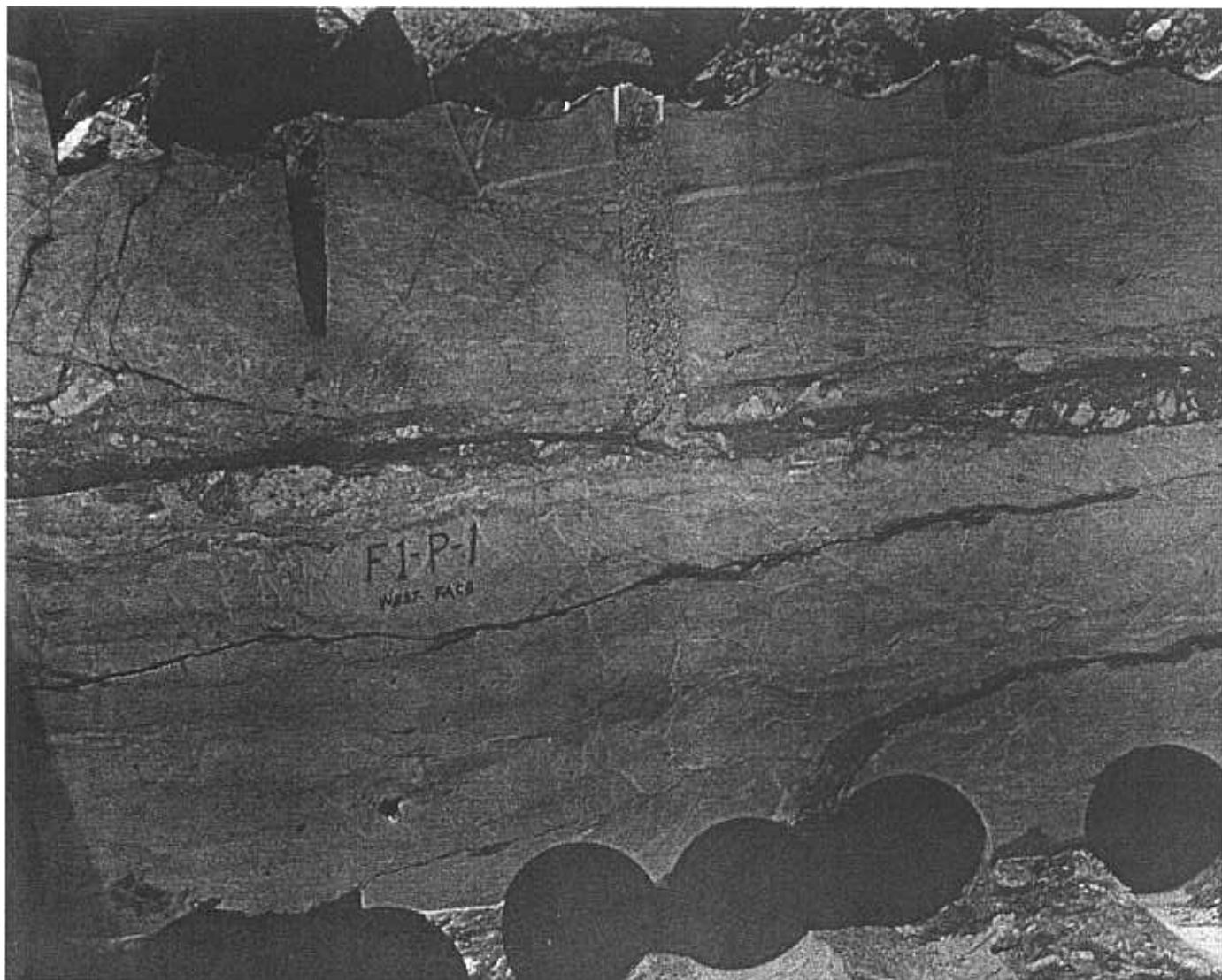


Figure 21. — Exposed face of the first slab before removal. Note that the line of drill holes was interrupted at two locations to provide support for the slabs prior to removal. Photo P801-D-79268

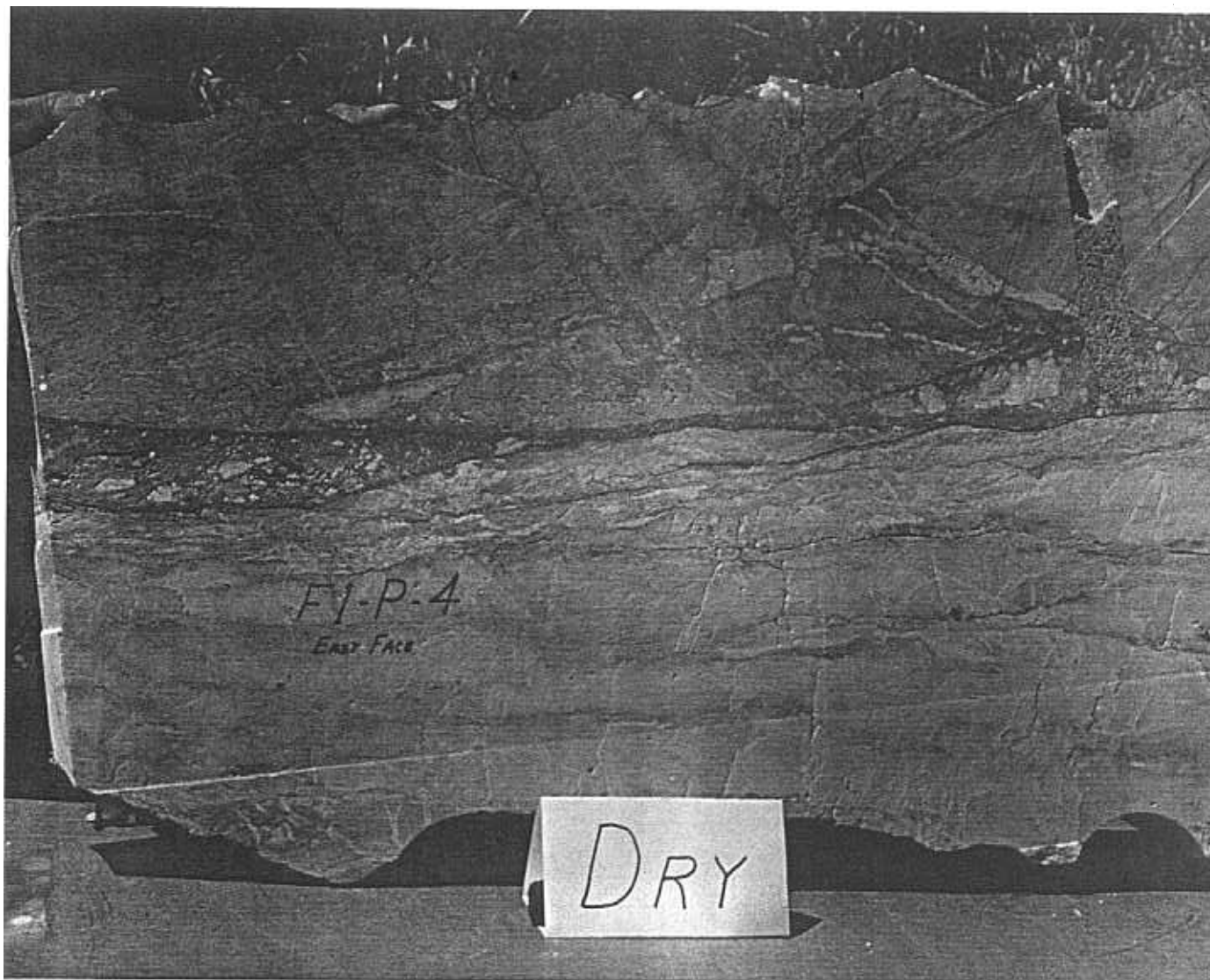


Figure 22. — Typical slab showing the gouge bounded by amphibolite on top and quartz on bottom. Gouge material is approximately 25 mm (1 in) thick at either end and approximately 6 mm (1/4 in) thick through the center of the sample. Photo P801-D-79269

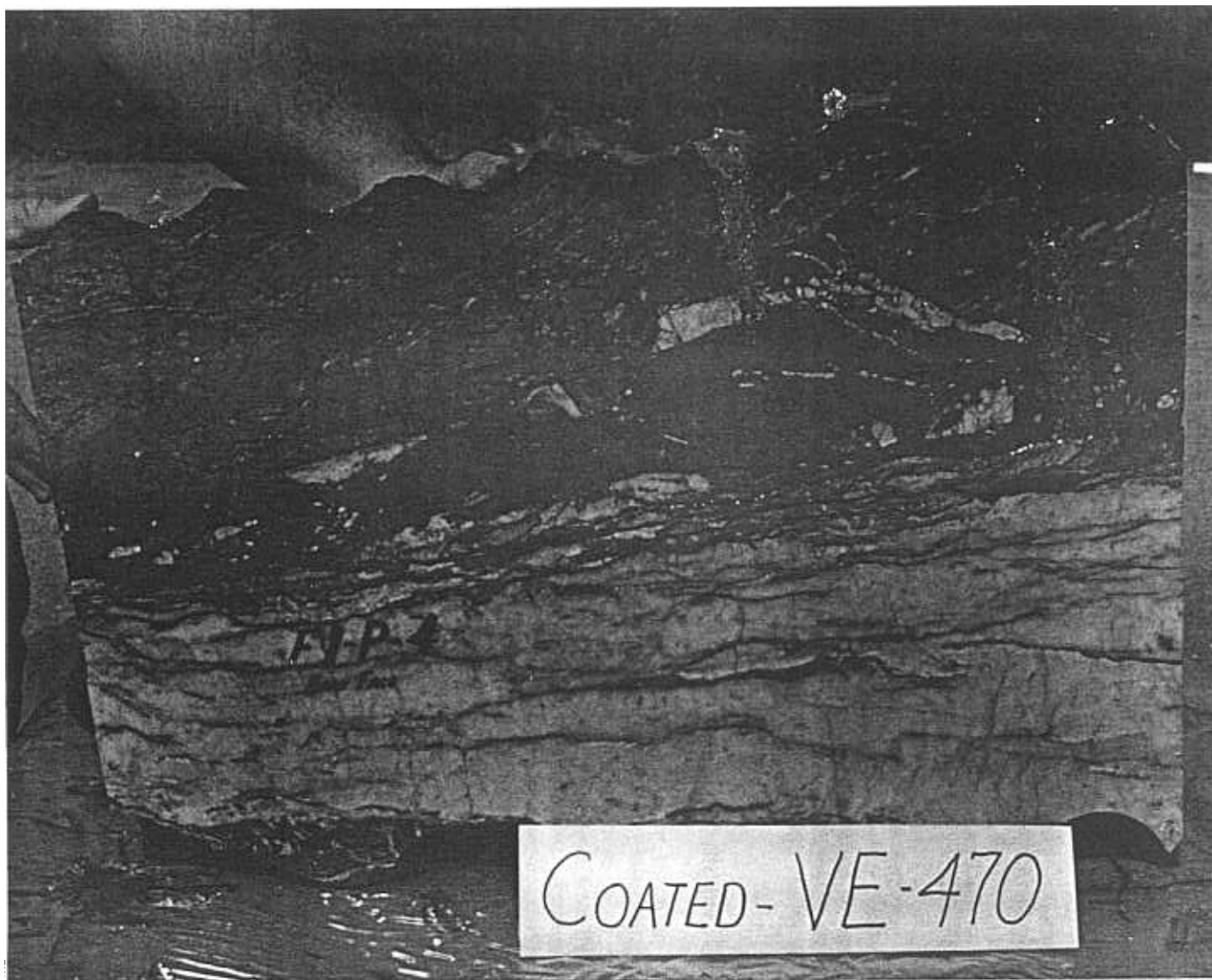


Figure 23.— The same slab (as fig. 22) coated with the VE-470 vinyl ester resin system. Note how the coating accentuates the various features of the sample. Photo P801-D-79270

APPENDIX A TRIALS AND TREATMENT TECHNIQUES TESTED DURING DEVELOPMENT OF THE RECOMMENDED TREATMENT PROCEDURES

The first impregnation trial area at the Maidu East trench was selected near the longitudinal centerline of the trench bottom. This area, designated ST-68-27, included the main shear but was considered of secondary importance because the zone was relatively wide at this location and a narrower portion of this shear was available nearer the north trench wall.

The gas infrared heater was suspended over the test area on a "come-along" attached to a pipe tripod. The "come-along" was used to adjust the height of the heater above the ground surface to control drying temperature. Additional temperature control was provided by an adjustable gas pressure regulator in the supply pipe between the gas supply tank and the heater.

Thermocouple temperature sensors were located on the surface and at depths of 25, 75, and 125 mm (1, 3, and 5 in) at the center of the treated area. The input from these sensors was continually recorded on a strip chart recorder and used to monitor temperatures throughout the treatment.

This trial area was heated at a surface temperature of about 150 °C (302 °F) for about 24 hours, after which the surface temperature was gradually increased to about 200 °C (372 °F) during the next 24 hours. After 48 hours of heat application, the heater was turned off to terminate the drying cycle. At this time, the temperature at the 25- and 75-mm (1- and 3-in) depths was 95 to 100 °C (203 to 212 °F) and was 75 to 80 °C (167 to 176 °F) at the 125-mm (5-in) depth. While this area was cooling, the drying heater was moved to the second treatment area, ST-68-26, to begin its drying cycle. During the cooling cycle a plywood form approximately 100 mm (4 in) high was constructed around the perimeter of the dried area (fig. A-1). Silicon caulking and plaster of paris were used to seal this form to the ground surface to provide a relatively tight reservoir for monomer during impregnation.

Twenty-two hours after the heater had been turned off, the 95-5 MMA-TMPTMA monomer system containing 1 percent AMVN polymerization initiator was applied. The area readily accepted the monomer with only minor leakage from immediately beneath the form or reservoir. This area, however, was immediately adjacent to a 3-m (9-ft) deep trench in the bottom of the larger investigation trench; shortly after soaking was started, monomer began to leak from the impregnation area into the trench from a point about 150 mm (6 in) down the adjacent trench wall. During an impregnation period of about 2 hours, 41 kg (90 lb) of monomer was added to the reservoir. A 75-mm (3-in) thick layer of dry soil density test sand was added to the reservoir during the last 30 minutes of the soak cycle. During the polymerization cycle, the excess monomer polymerized in the sand and formed a strong protective shell bonded to the treated area. Polymerization was accomplished by using the infrared heater to heat the impregnated area to a surface temperature of 85 °C (185 °F) for a period of about 5 hours.

The ST-68-26 area (figs. A-2) had been drying at a temperature of about 200 °C (390 °F) on the surface for only 22 hours when the heater was removed for use in polymerizing area ST-68-27. The effects of a shorter drying time on impregnation depth were evaluated at this location. Cooling was allowed to continue for about 10 hours until the 125-mm (5-in) deep temperature reached about 65 °C (150 °F), the approximate polymerization temperature of the monomer. A monomer reservoir similar to that used for ST-68-27 was constructed during cooling. This site was not as fractured and jointed as ST-68-27 and only minor leakage of monomer occurred. Approximately 32 kg (70 lb) of monomer was applied to the reservoir along with a 75-mm (3-in) thick layer of dry local pit run sand. After about 1 hour, a temperature increase became apparent at the 125-mm (5-in) level, indicating that the exothermic polymerization reaction had begun. The heat generated by polymerization at the lower level progressed upward into the cooler upper levels and caused polymerization of the entire impregnated zone. Peak temperatures of over 100 °C (212 °F) were measured in the impregnated zone during the polymerization period.

This temperature probably assured complete polymerization of the monomer, but additional heat was applied for 2 hours with the infrared heater for a safety factor. This was found to be unnecessary and was discontinued on all following tests.

After the first two areas were treated, a concrete sawing company was hired to remove the test samples. They used a portable, air-powered, water-cooled, diamond-tip blade saw with a 915-mm (36-in) diameter blade to make two longitudinal and numerous transverse vertical cuts into the treated area. The longitudinal cuts were made at the boundary of the treated area and the transverse cuts provided slab-like samples normally 50 mm (2 in) thick. Hand tools were then used to carefully remove untreated material from one transverse boundary of the impregnated area to fully expose a cut face. Polymer impregnation depth at ST-68-27 was 125 mm (5 in) and at ST-68-26 was 50 to 65 mm (2 to 2-1/2 in). Shear zone visibility was excellent on the smooth sawed faces.

Two techniques were used to remove the test slabs and provide additional protection during transportation. After the vertical faces were gently washed with water to remove the sawing mud, they were surface dried with a small electric heater. A sheet of 6-mm (1/4-in) thick clear acrylic plastic was bonded to the face of slabs designated for thin-section analysis. The bonding medium was a high viscosity RVE resin containing 4 percent MEKP, 1.3 percent CoN promoter, and 0.5 percent DMpT promoter. This system had a pot life of about 10 minutes and developed an excellent bond between the sample and the acrylic plastic. Visibility through the acrylic was very good. A horizontal relief cut was then made with a knife or screwdriver at the bottom of the sample and the test slab was rotated 90° to a horizontal position and removed from the trench.

The slabs not destined for thin-section analysis were cleaned, dried, and coated with a thick layer of the RVE monomer system. This clear, amber-colored coating provided improved visibility of the features of the slab, and strengthened it for removal. A horizontal relief cut was made at the bottom of the slab which was then rolled over onto a 25-mm (1-in) thick plywood panel.

After the slabs were removed, the newly exposed top faces were cleaned, surface dried, and coated with several coats of a low-viscosity VE-470 resin system that penetrated the cracks, fractures, and joints of the shear, and further strengthened the slab. This monomer system was prepared with 1.5 percent MEKP, 0.5 percent CoN, and 0.125 percent DMpT. Pot life of this system was about 10 minutes and the coating achieved a tack-free cure in 1 to 2 hours.

Eight test slabs, ST-68-27-A through -H, were removed from the first trial and four, ST-68-26-A

through -D, were removed from the second. All slabs were 50 mm (2 in) thick, except slab ST-68-26-D which was 100 mm (4 in) thick.

The third area selected for impregnation, ST-68-19, shown previously in figure 5, was a continuation of the main shear previously treated in ST-68-27. At the ST-68-19 site, the shear was narrower and better defined. The geologists expressed concern that the relatively high temperatures used to dry the previous areas might damage the minerals and structure of the zone and they suggested that this area be dried at lower temperatures. Accordingly, surface temperatures of 120 to 130 °C (248 to 266 °F) were maintained during the drying cycle. Because of the lower drying temperatures and also because of laboratory work that was being performed to evaluate the use of an ambient temperature polymerizing monomer system intended for use in impregnating this area, the drying time was increased to 80 hours.

Prior to constructing the impregnation reservoir, the ground surface immediately beneath the walls of the reservoir was coated with the VE-470 monomer system to seal any cracks and prevent monomer loss. This area was also adjacent to the trench that caused problems at location ST-68-27, and an excess of the VE-470 monomer system was poured over the ground surface between the area to be treated and the trench. After the VE-470 monomer system had cured, the reservoir was placed and caulked, as with previous treatments. An exceptionally tight seal resulted.

Laboratory tests discussed below, indicated that the ambient temperature polymerizing monomer system was not suitable for impregnating the soil in the Auburn area, so the 95-5 MMA-TMPTMA monomer system was used on this area as on ST-68-26. Approximately 27 kg (60 lb) of monomer was added to the reservoir. Polymerization was accomplished by the heat retained in the ground. The temperature at 125-mm (5-in) depth was 65 °C (149 °F) at the time of impregnation. The recorder showed a temperature increase after 20 minutes, at the 125-mm (5-in) level, and after 1 hour at the 75-mm (3-in), 25-mm (1-in), surface levels. Test samples from this area were cut, cleaned, removed, and treated in the laboratory as previously described. Polymer impregnation depth varied from 50 mm (2 in) to over 75 mm (3 in). The shallower penetration depths achieved in this treatment were the result of lower drying temperatures. Seven slabs, ST-68-19-A through -G, were removed from this site.

The fourth area treated with polymer impregnation, ST-68-6, was a narrow shear bounded on both sides by relatively dense, jointed rock. The clay material in the shear contained about 40 percent moisture by mass. [Drying was accomplished by heating the area to a 125-mm (5-in) depth temperature of 77 °C (171 °F) over a period of 72 hours.] Cooling, impregnation, and polymerization were accomplished as previously described. The rock bounding this shear, however, retained heat longer than the clay, and only about 10 to 15 minutes soak was accomplished during the impregnation cycle before polymerization began. Figure A-3 shows the site following polymerization. Polymer penetration was 50 to 64 mm (2 to 2-1/2 in). Six test slabs, ST-68-6-A through -F, were removed.

Treatment area No. 5, ST-68-20, unlike the four previous areas, contained a very thin clay zone of approximately 25-mm (1-in) width. This zone was bounded by dense, jointed rock. Drying was accomplished by heating the area to a 125-mm (5-in) deep temperature of approximately 97 °C (207 °F) over a period of 33 hours. The 125-mm (5-in) deep temperature exceeded 90 ° (194 °F) for 3 hours during this period. Monomer impregnation was begun after 11-1/2 hours of cooling and at a 125-mm (5-in) depth temperature of 68 °C (154 °F). It took about 80 minutes for the polymerization exotherm to occur at this depth and 3-1/2 hours before peak exotherm was reached at the surface of the sample. A polymer penetration of 150 to 175 mm (6 to 7 in) was visible upon sample removal. Six test slabs, ST-68-20-A through -F, were removed from this site.

Laboratory Tests

Laboratory tests were performed at the Auburn Materials Laboratory to develop a technique of providing additional impregnation to field-treated samples after they had been removed from the field sites, and to provide the samples with polymer coatings to give additional protection and to improve the visibility of the features of the shears.

Several MMA monomer systems containing BP initiator and DMpT or DMA promoters were used to impregnate portions of field samples. It was found during these tests that DMA reacted with the soil from ST-68 causing the soil to change color to a dark purple or greenish black as shown in figure A-4. The nature of this reaction was not defined.

Similarly, MMA-BP-DMpT monomer systems were also found to cause a color change in the soil, although this reaction occurred much slower than with the DMA promoter. Laboratory impregnation was attempted using the same 95-5 MMA-TMPTMA-AMVN monomer system used for field impregnation. The sample was oven-dried to constant weight at 100 °C (212 °F), cooled, and soaked in a monomer bath for 3 hours. The excess monomer was drained and the impregnated sample polymerized in the laboratory oven under a layer of hot water separated from the sample by a polyethylene sheet. This sample turned a dark greenish-black color during polymerization. It was not determined why this reaction occurred in the laboratory but not in the field. All of the samples impregnated in the laboratory swelled and cracked considerably during treatment. This obviously defeated the purpose of additional impregnation, and further attempts with the MMA monomer system were abandoned.

The vinyl ester resin systems described previously were found to be compatible with the soil, and a penetrating coating was developed to strengthen the field samples after removal from the trench. A low viscosity vinyl ester, VE-470, penetrated surface-dried samples to a depth of approximately 1.5 mm (1/16 in) or more, depending upon the moisture content of the sample. Full oven-drying which, if successful, would have permitted deeper impregnation, created excessive shrinkage cracking, and was not attempted on field samples that were to be retained.

This low-viscosity resin system also flowed into the various natural cracks in the test slabs and ultimately filled and sealed them. As the low-viscosity resin soaked into the clay and polymerized, however, the polished or wet surface appearance decreased. A final coat was thus applied using the high-viscosity RVE system. The higher viscosity reduced penetration and resulted in a polished appearance on the surface. The amber color of the vinyl ester systems enhanced the visibility features of the slabs somewhat as stain brings out the grain in wood.

These vinyl ester systems were also applied to the surfaces of the treated areas after all desired samples were removed to preserve them for future observation. Included in the areas treated in this manner was a 3.7-m (12-ft) long cut across the entire shear zone on the south wall of trench ST-68 and the in-place face of fault F-1. Table A-1 lists the results of pot life tests with various resin systems.

Table A-1. — *Vinyl ester pot life tests*

Resin system	Initiator (percent by mass)	Promoter (percent by mass)	Pot life (min)
VE-470	1.5 MEKP	0.5 DMA 0.125 DMpT	90 (at 52 °C (126 °F) in oven)
VE-470	1.5 MEKP	1.0 DMA 0.125 DMpT	Did not cure at ambient temperature
VE-470	1.5 MEKP	0.4 DMA 0.05 CoN	19
VE-470	2.0 MEKP	0.40 DMpT 0.05 CoN	7
VE-470	1.5 MEKP	0.125 DMpT 0.50 CoN	10
RVE	4.0 MEKP	0.5 DMpT 1.3 CoN	10
85 percent VE-470 15 percent MMA	1.0 MEKP	0.25 DMpT 0.50 CoN	7-8

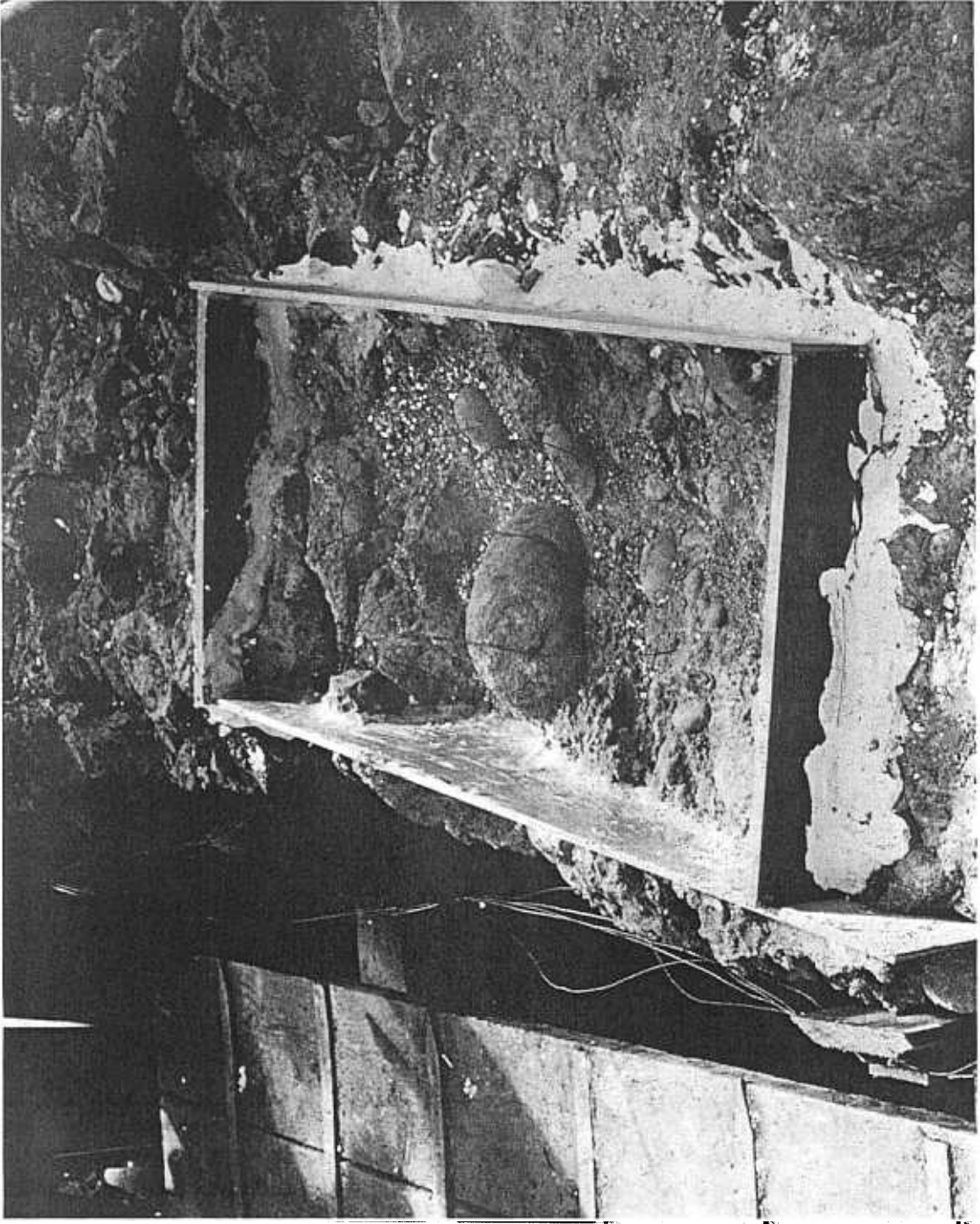


Figure A-1. — Trial area S T-68-27 with its monomer reservoir sealed to the ground surface. Photo P801-D-79271

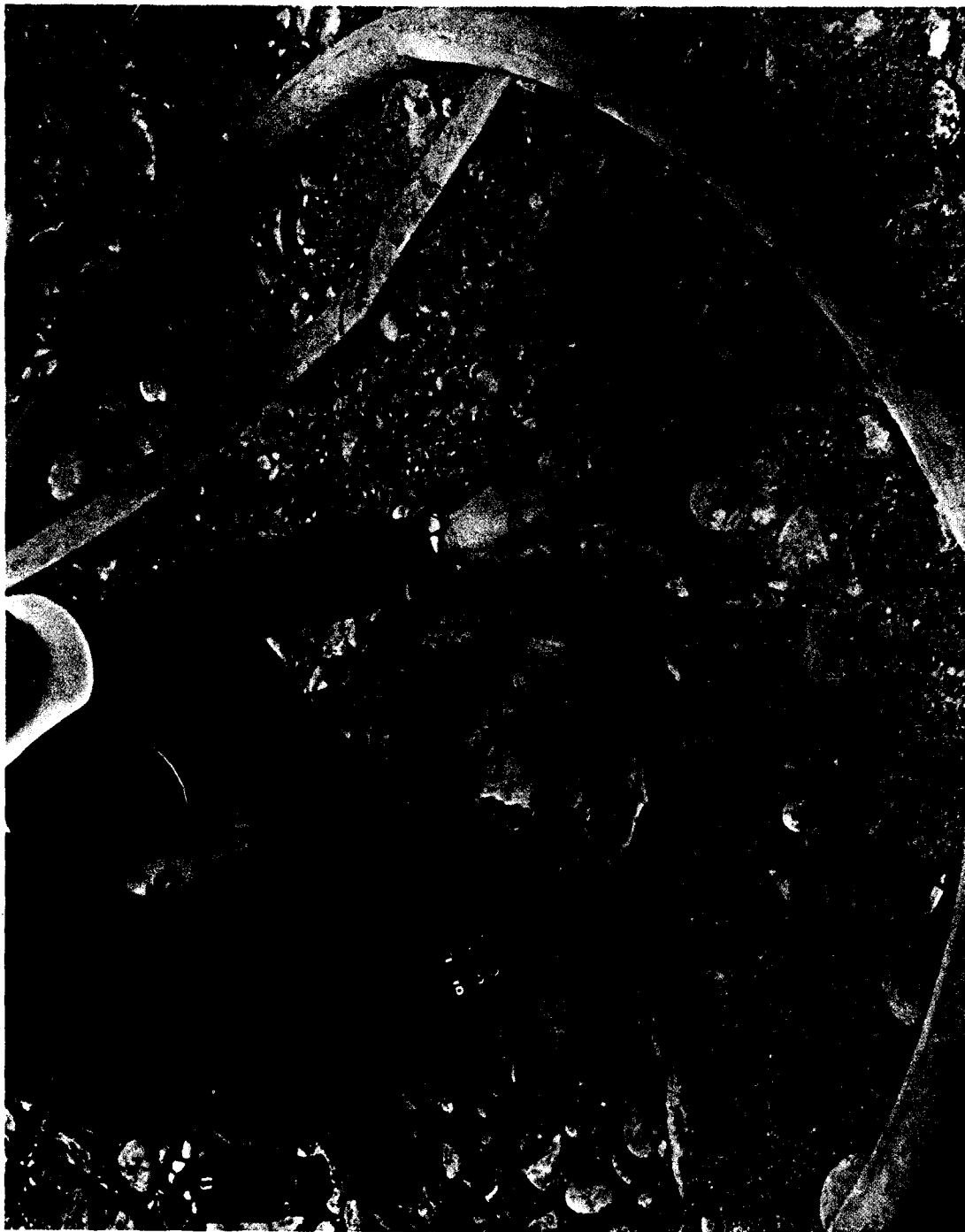


Figure A-2. — Sample area ST-68-26 included a relatively narrow zone of material. Photo P801-D-79272



Figure A-3. — Site ST-68-6 was located near the base of the north trench wall. Resin was applied to the surface below the site to prevent excessive monomer leakage. Photo P801-D-79273



Figure A-4. — The dark purple or greenish black color change occurred when monomer containing DMA was added to the soil. Here the monomer was being used to anchor a saw track bolt to the site. Photo P801-D-79274

APPENDIX B

PARTIAL LIST OF SUPPLIERS

(Numbers in brackets match those in the "Abbreviations" list, page v, and designate suppliers of that product.)

- | | |
|---|--|
| [1] Westville Chemical Corporation
66 Old Farms Road
Woodcliff, New Jersey 07675 | [4] Aldrich Chemical Company
940 West Saint Paul Avenue
Milwaukee, Wisconsin 53233 |
| [1] Polysciences, Inc.
Paul Valley Industrial Park
Warrington, Pennsylvania 18976 | [4] Polysciences, Inc.
Paul Valley Industrial Park
Warrington, Pennsylvania 18976 |
| [2] Lucidol Division, Pennwalt Corporation
1740 Military Road
Buffalo, New York 14240 | [5] Rohm and Haas Company
Independence Mall West
Philadelphia, Pennsylvania 19105 |
| [2] Polysciences, Inc.
Paul Valley Industrial Park
Warrington, Pennsylvania 18976 | [5] E. E. duPont de Nemours
Wilmington, Delaware |
| [3] Service Supply Company
2650 South Zuni
Englewood, Colorado 80219 | [6] Dow Chemical Company
Midland, Michigan 48640 |
| [3] Eastman Organic Chemicals
Rochester, New York 14650 | [7] Celanese Plastics Company
26 Main Street
Chatham, New Jersey 07923 |
| | [7] Rohm and Haas Company
Independence Mall West
Philadelphia, Pennsylvania 19105 |