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Observations of Nuclear Explosive Melt Glass Textures and Surface Areas

A. B. Kersting, D. K. Smith

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Observations of Nuclear Explosive Melt Glass Textures and Surface Areas

Annie B. Kersting and David K. Smith
Lawrence Livermore National Laboratory
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Introduction

This memo report summarizes our current knowledge of the appearance of melt glass formed and subsequently deposited in the subsurface after an underground nuclear test. We have collected archived pictures and melt glass samples from a variety of underground nuclear tests that were conducted at the Nevada Test Site (NTS) during the U.S. nuclear testing program.

The purpose of our work is to better determine the actual variation in texture and surface area of the melt glass material. This study is motivated by our need to better determine the rate at which the radionuclides incorporated in the melt glass are released into the subsurface under saturated and partially saturated conditions. The rate at which radionuclides are released from the glass is controlled by the dissolution rate of the glass. Glass dissolution, in turn, is a strong function of surface area, glass composition, water temperature and water chemistry (Bourcier, 1994).

This work feeds into an ongoing experimental effort to measure the change in surface area of analog glasses as a function of dissolution rate. The conclusions drawn from this study help bound the variation in the textures of analog glass samples needed for the experimental studies. The experimental work is a collaboration between Desert Research Institute (DRI) and Earth and Environmental Sciences-Lawrence Livermore National Laboratory (EES-LLNL).

On March 4, 1999 we hosted a meeting at LLNL to present and discuss our findings. The names of the attendees appear at the end of this memo. This memo report further serves to outline and summarize the conclusions drawn from our meeting.

The United States detonated over 800 underground nuclear tests at the NTS between 1951 and 1992. In an effort to evaluate the performance of the nuclear tests, drill-back operations were carried out to retrieve samples of rock in the vicinity of the nuclear test. Drill-back samples were sent to Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) and analyzed for diagnostic purposes. As a result of these activities, a body of knowledge consisting of personal accounts, photos, reports and archived solid samples was gained regarding the physical nature of the melt glass that formed during an underground nuclear test.

In this memo report, we summarize previously published reports, compile archived photos, document and describe melt glass samples and summarized discussions from former field engineers and radiochemists who had direct knowledge of drill-back samples. All the information presented in the report was gathered from unclassified sources. We have included as wide a variation of samples as we could document. Unfortunately, as part of the drill-back and diagnostic efforts, it was not common practice to photograph or physically describe the material returned to the surface.

Production and Distribution of Melt Glass

To help orient the reader, a brief discussion is provided regarding the production of nuclear explosive melt glass. At zero time during the detonation, temperatures may exceed 10 x 10^6 K and pressures may exceed more than several Mbar. The device and adjoining medium adjacent to the explosion are vaporized and a cavity forms due to the gas pressure and explosive energy imparted to the surrounding rock. Shock melting causes the rock around the expanding cavity to be melted; the cavity continues to expand adiabatically until the gas pressure inside the cavity falls to below lithostatic pressure. The cavity is lined by molten rock that is formed from three sources: 1) condensate from the high temperature plasma formed by the explosion, 2) melt produced by shock melting of the adjacent formation, and 3) melted host rock which has fused during contact with molten cavity lining. Approximately 700 metric tons of glass are produced per kiloton of nuclear yield (Olsen, 1967). For a contained explosion, the melt flows down the walls of the standing cavity and begins to coalesce on the cavity floor forming a glass puddle. After several seconds the melt begins to solidify. Condensable gases liquify and the cavity pressure drops. Within seconds to days the gas pressure in the cavity falls to a point where it can no longer support he weight of the overlying rock. The cavity collapses in on itself with blocks of overlying rubblized rock chaotically incorporated in the partially molten puddle glass. As blocks of rock fill the cavity void a collapse chimney forms which projects upwards to the surface. Because the post shot radiochemical diagnostics rely on samples of glass which volumetrically incorporate the refractory bomb fraction, most of the glass examined in this study was collected within or adjacent to the puddle region at the bottom of the cavity. Figure 1 illustrates the formation of the cavity and collapse chimney following an underground nuclear detonation (Schwartz, 1984). Because of the extreme energy associated with an underground nuclear explosion, the production of glass involves rapid shock melting in the presence of steam and other noncondensable gases followed by quenching due to loss of heat to the formation and contact of the glass with rubblized host rock. For these reasons, the glass is typically quite heterogeneous.

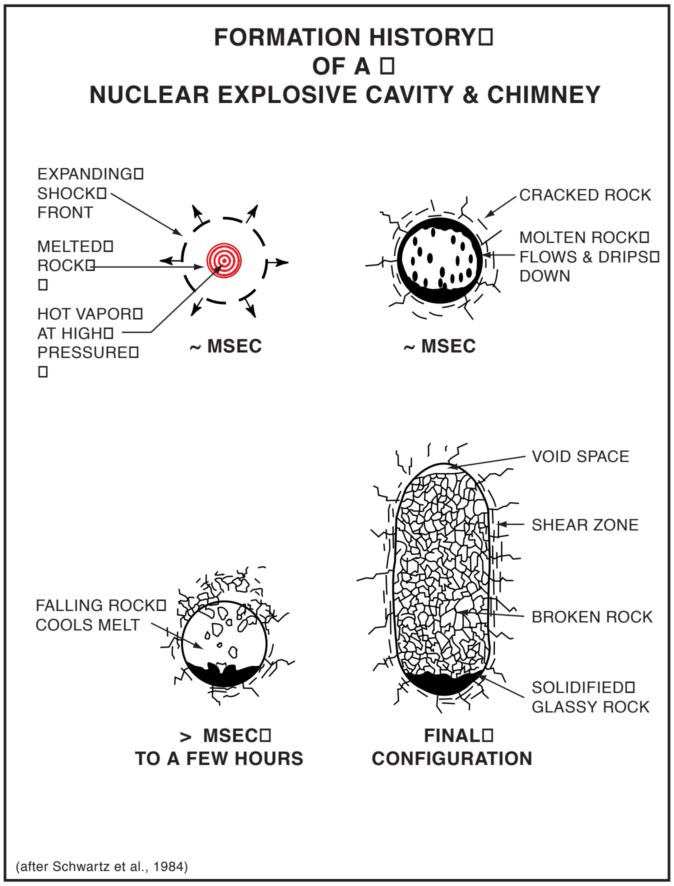

Figure 1. Illustration of the formation of a nuclear test cavity and collapse chimney. Molten glass accumulates in a puddle at the bottom of the cavity immediately following the detonation. Collapse rubble mixes with the still partially molten puddle glass.

Sources Researched

Listed below are the source locations and people accessed for this report.

- Nevada Test Site Post-shot Core Library, Area 12
- Los Alamos National Laboratory Post-shot Core Library, TA-48
- Lawrence Livermore National Laboratory Post-shot Core Library, Building 151
- LLNL and LANL radiochemists and field personnel (Ronald W. Lougheed - LLNL, John F. Wild - LLNL, Dee Donithan - LLNL and DRI, and D. Wes Efurd- LANL) who had experience with the post-shot field operations and the samples collected during the nuclear the test program.

Summary of Results

Table 1 is a compliation of the nuclear tests where we were able to obtain either photographs or solid samples of nuclear melt glass.

Table 1. Nuclear Tests with Archived Melt Glass Information

Test name	Test date	Announced yield (Kt*)	Rock type at WP**	Type of test
Rainier	9/19/57	1.7	volcanic tuff	tunnel
Logan	10/16/58	5	volcanic tuff	tunnel
Hard Hat	2/15/62	5.7	granite	shaft
Bilby	9/13/63	249	tuff/ carbonate	shaft
Scaup	5/14/65	< 20	volcanic tuff	tunnel
Cambric	5/14/65	0.75	alluvium	shaft
Pile Driver	6/2/66	62	granite	tunnel
Camembert	6/26/75	200-1000	volanic tuff	shaft
Cheshire	2/14/76	200-500	volcanic tuff	shaft
Bullion	6/13/90	20-150	volcanc tuff	shaft

* Kt = nuclear yield expressed as kilotons of TNT equivalent

** WP= working point, or emplacement depth of the nuclear device. (DOE/NV-209, 1994)

Some of the best reports describing and documenting the post-shot subsurface conditions come from investigations of the Rainier nuclear test. The Rainier test was the first successfully contained underground nuclear test. It was detonated in fractured volcanic rock, in Rainier Mesa in 1957 and had an announced yield of 1.7 kt. The area surrounding the Rainier test was the target of extensive drilling and tunnel re-entry efforts in order to better understand the mechanics of an underground nuclear explosion. In a LLNL report, Wadman and Richards (1961) describe the glass in the cavity region:

> *"After detonation, a spherically shaped cavity was formed which was lined with several inches of molten tuff containing radioactive material. This radioactive melt was retained by a 3 ft to 4 ft zone of plastically deformed rock. The cavity stood long enough for the molten rock to collect at the bottom as a pool. …The resulting lens shaped puddle is about 20 ft thick at the maximum and is a mixture of collapsed rock blocks and fragments in a matrix of frothy glass. Approximately ninety-five percent of the radioactive material is now concentrated between this 20 ft level and the bottom of the cavity (page 1)."*

Several photographs from the Wadman and Richards (1961) report are reproduced in Figure 2. These photographs show the contact between the melt glass and the host rhyolitic rock located approximately 20 m below the working point (WP) or device location. It was estimated that 95-98% of the total fused material had coalesced in a puddle at the bottom of the cavity. The majority of this material is black, vesicular and continuous. Several types of glass were observed in the puddle region, but the bulk of the fused material was very frothy and vesicular. Figures 2B and C show extensive flow structure in the melt glass. A thin layer of dark melt glass in immediate contact with the wall rock was found to be less vesicular than the massive melt glass material. Blocks of host rock were incorporated in the melt zone and are thought to have fallen into the still molten melt during the collapse of the cavity (Figs. 2A-C).

In addition to the puddle of glassy material formed at the bottom of the cavity, glass droplets, seams and stringers of fused material were found baked on surfaces of collapsed blocks and injected into cracks within the cavity region. Fused material located above the puddle region was usually dense and sometimes red or green.

The photos shown in Figure 3 were taken in 1967 of a tunnel excavation asociated with an unknown nuclear test. The host rock appears to be a rhyolitic tuff. These photos provide further evidence that the formation of an extensive zone of melt that is heterogeneous in nature.

The Rainier test shown in Figure 2 and the unknown 1967 test shown in Figure 3 are the only documented examples of excavated melt glass zones area found during this investigation. The majority of the drill-back operations were not tunnel operations, but consisted of drilling a vertical or slant-drilled hole with 2 7/8 inch casing. The extensive excavation of the tunnel drill-backs afford an extraordinary opportunity to observe, in-situ, the geologic conditions existing after a nuclear test. Both the photos in Figures 2 and 3 document the heterogeneous nature of the melt zone and the sharpness of the contact between the melt material and the host rock. Samples obtained at the Rainier Mesa drill-back operation and the unknown 1967 test support the conceptual model of a melt zone forming at the bottom of a cavity that is overlain by a rubble or chimney area.

Photos of melt glass samples collected from drill-back samples from the Cheshire, Bilby and Cambric nuclear tests are shown in Figures 4, 5 and 6, respectively. The Cheshire test was fired in fractured rhyolitic rock on Pahute Mesa, Bilby in alluvium near the regional carbonate aquifer in Yucca Flat, and Cambric was detonated in alluvium in Frenchman Flat. Samples were collected as sidewall drill-back samples, not as continuous core. The melt glass samples all have light pumiceous and lithic fragments incorporated into the darker, more vitreous glassy matrix. The photos shown in Figures 4B, 5B-D and 6B are all magnified images of the glassy fragments. The photos taken at high magnification consistently show the highly vesicular texture of the melt glass fragments.

Figure 7A-C shows four melt glass rock samples. These samples were the largest melt glass samples we documented. The nuclear tests from which these samples were collected are unknown. The samples are composed of dark massive glass with pockets of highly vesicular glassy material. All four samples have lithic fragments, many of which appear pumiceous. In contrast to the textures shown in Fig 4, 5 and 6, these melt glass samples are more massive and less vesicular.

Figure 8 shows melt glass samples that have been mounted in epoxy plugs. Samples shown in 8A and B are both massive glass fragments void of vesicles. The samples are from unknown drill-back operations. Figure 8C shows glass beads recovered from the 1965 Scaup nuclear test. Glass beads were also found and described during the Rainier drill-back operation.

Representative side-wall core samples archived at the NTS were photographed and are shown in Figure 9. These samples appear as when removed from the side-wall sampler, and the glass has not been separated from the post-shot debris. The core samples consist of heterogeneous mixtures of rock and glass fragments. No large, homogeneous glass fragments were observed in any of the core examined. Both LLNL and LANL field engineers and radiochemists have stated that the shaft drilling operations would return rock core and side-wall samples that were extensively fractured due to the drilling process. Therefore, the disaggregated textures shown in Figure 9 are more likely due to the sampling process and not necessarily the nuclear test. These samples represent a contrast to the continuous massive melt glass found at the bottom of the Rainier and unknown 1967 drill-backs. It is clear that core can also consist of glassy fragments in aa matrix dominated by lithic fragments in the cavity region.

In contrast to the side-wall core samples observed in Figure 9, continuous cores were taken from the Piledriver underground nuclear test, which was fired in granite. The three post-shot cores do not sample the lower cavity, but some masive glassy core was recovered from the cavity/chimney region. The core collected from PS-3 from 263-270 feet appears to be a black and continuous glassy vesicular section of core. Descriptions of the appearance of melt glass found are similar to the textures seen in Figures 1-8.. Borg (1970) describes the melt glass samples as consisting of glassy vesicular debris together with melted and highly fractured granite. Narrow glass seams were also found and thought to fill pre-exisiting fractures.

Two samples of the green and red glass from the Logan underground nuclear test are shown in Figure 10. Red and green glass was also observed in the Rainier drill-back operation (Wadman and Richards, 1961).

Conclusions

The textures observed in the photos and solid samples from the LLNL, LANL and NTS archives supports the original description of the melt glass collected in the Rainier tunnel drill-backs.

Four observations are common to all the samples we examined for this report.

- Individual melt glass fragments have a large range in vesicularity ranging from massive to highly vescicular to pumiceous in texture.

- Although the majority of melt glass occurs in a puddle configuration at the bottom of the test cavity, it is a complex body of glass consisting of both massive and highly vescicular lenses with lithic fragments.
- The nature of the melt glass is independent of the original host rock composition or design of a specific nuclear test.
- The melt glass samples show a range in glass color from white, to dark black, often within a single specimen.

Due to the observation that many of the samples from different nuclear tests showed consistency in the range of textures, we have confidence that the melt glass samples described in this report are representative of the majority of glasses encountered underground at the Nevada Test Site.

List of attendees at the melt glass meeting held at LLNL on April 4, 1999.

William L. Bourcier	LLNL
Carol J. Bruton	LLNL
Jenny Chapman	DRI
Donithan Dee	DRI
Jacqueline M. Kenneally	LLNL
Annie B. Kersting	LLNL
Lambis Papelis	DRI
Gayle A. Pawloski	LLNL
Charles E. Russell	DRI
Dave K. Smith	LLNL
Timothy P. Rose	LLNL
Andrew F.B. Tompson	LLNL
Mavrik Zavarin	LLNL

References

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Bourcier, W.L. (1994) Waste Glass Corrosion Modeling: Comparison with Experimental Results. *Mat. Res. Soc. Symp. Proc*. 333:69-82.

Olsen, C.W. (1967) Time History of Cavity Pressure and Temperature Following a Nuclear Detonation in Alluvium. Lawrence Livermore National Laboratory, UCRL-70379.

Schwartz, L., Piwinskii, A., Ryerson, F., Tewes, H., and Beiriger, W. (1984) Glass Produced by Underground Nuclear Explosions. *J. Non-Crystalline Solids*. 67:559-591.

U.S. Department of Energy (1994). United States Nuclear Tests, July 1945-September 1992). DOE/NV-209 (Rev. 13)

Wadman, R.E. and Richards W.D., (1961). Postshot Geologic Studies of Excavations Below Rainier Ground Zero. *Lawrence Radiation Laboratory*, UCRL 6586 27p.

Figure 2. Photos taken from the exploratory drifts drilled into the Rainier underground nuclear test, Rainier Mesa, NTS (Wadman & Richards, 1961). Photos show the contact between the melt glass (dark material) and the host rhyolite rock (light material) at the bottom of the cavity. 12 inch scale bar is located in Figure A, bottom right.

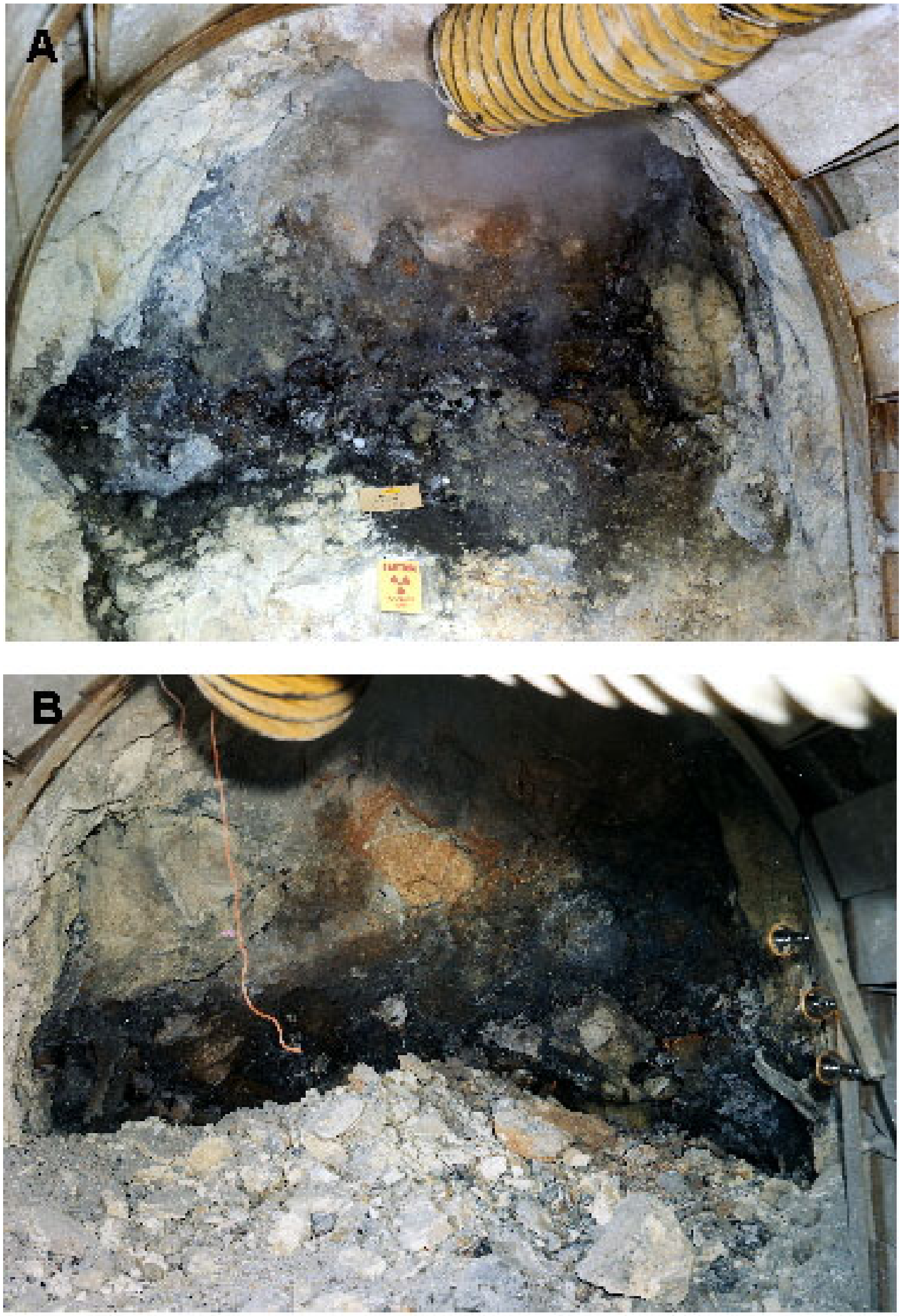

Figure 3. A and B) photos taken from a tunnel drill-back of an unknown nuclear test. Photos were taken in 1967. No scale bar is included, but the rebar framing the tunnel is probably ~4 inches, similar to the rebar shown in Figure 1. Photos are from LLNL.

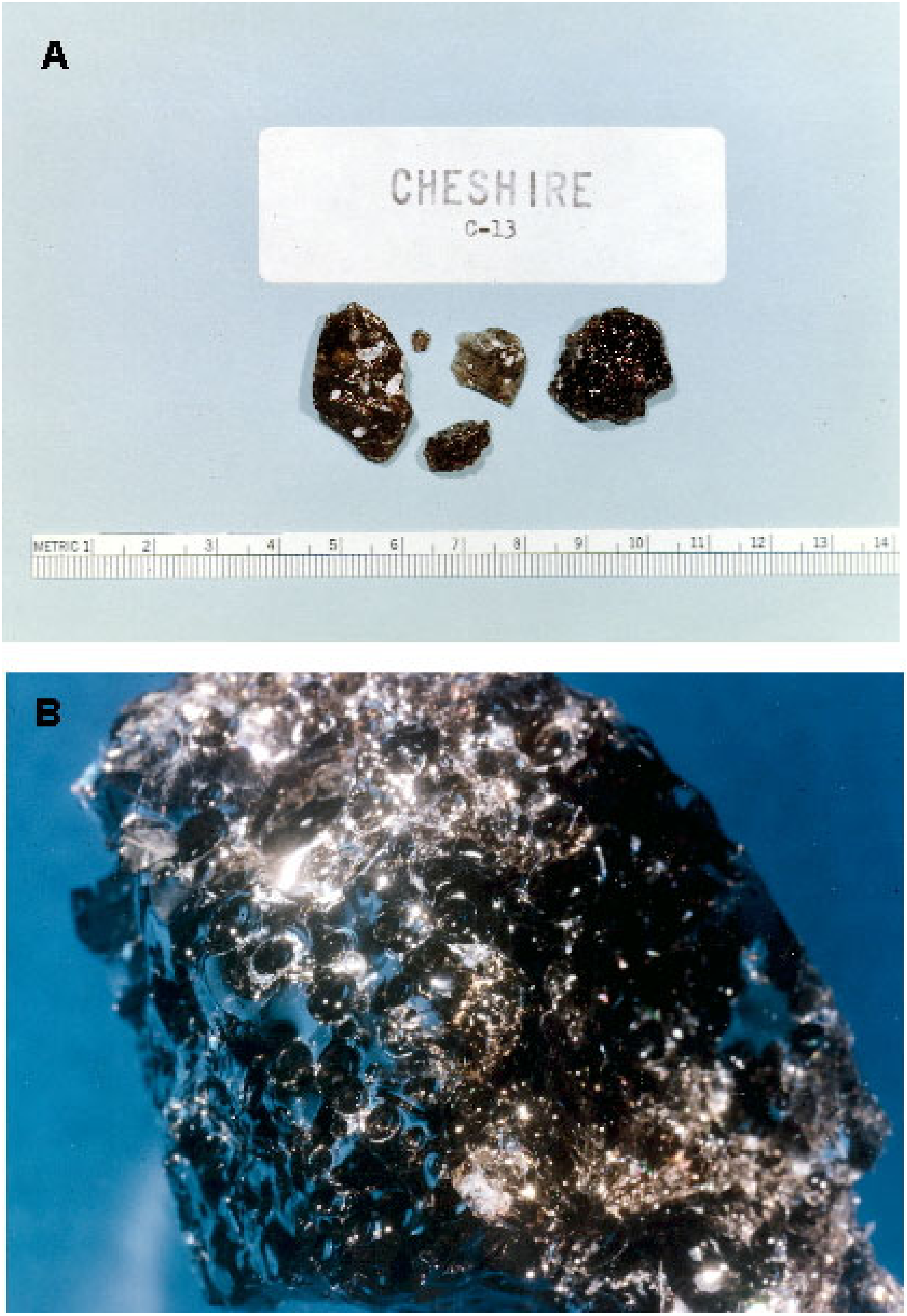

Figure 4. A) melt glass chips collected during the drill-back of the Cheshire underground nuclear test. B) Melt glass chip set in epoxy. Magnification unknown. Photos are from LLNL.

Figure 5. A) Melt glass samples collected during the drill-back of the Bilby underground nuclear test. B-D) Magnification of a melt glass sample from Bilby. Scale unknown. Photos are from LLNL.

Figure 5 continued

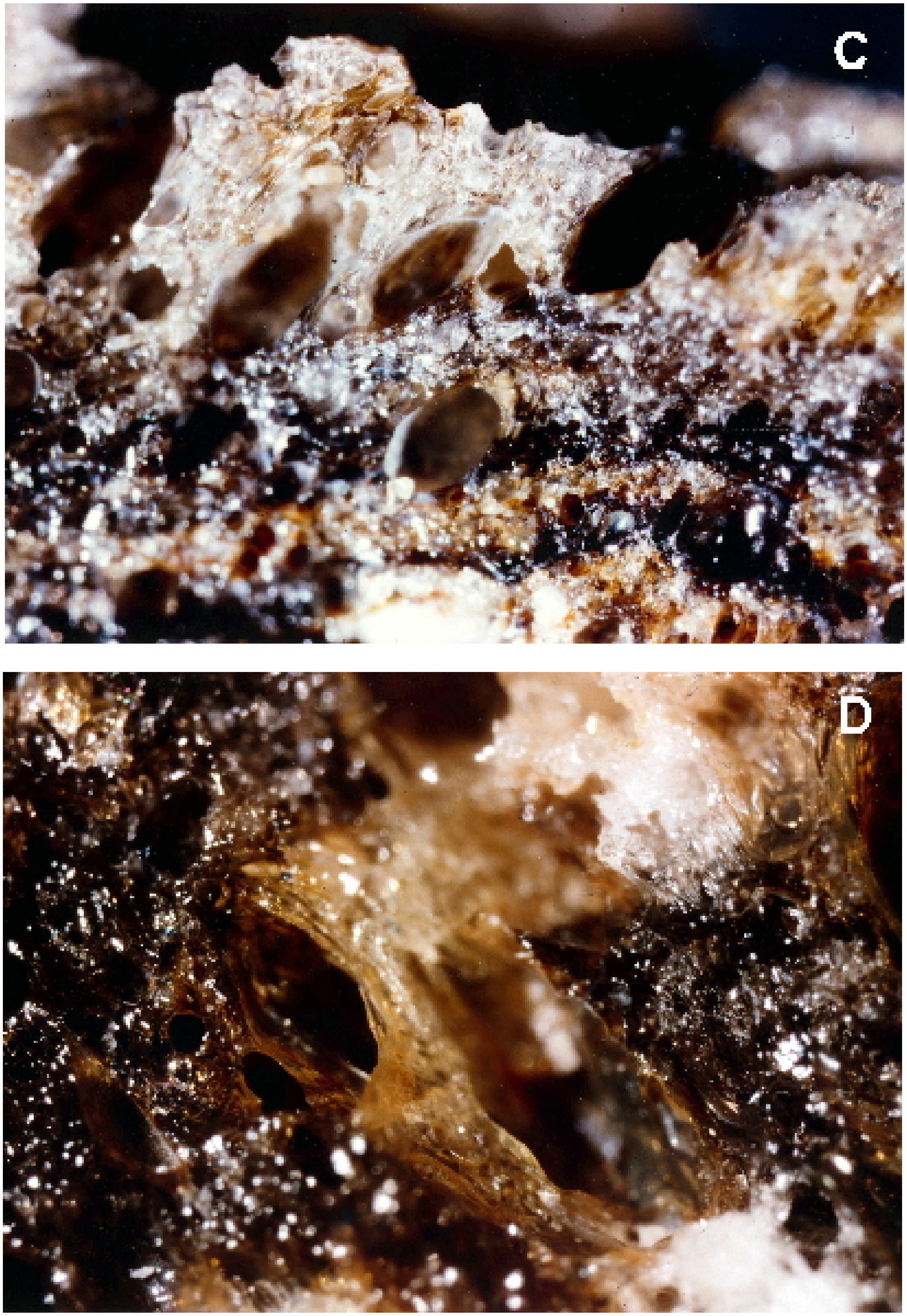

Figure 5. C and D) Magnification of melt glass samples from Bilby.

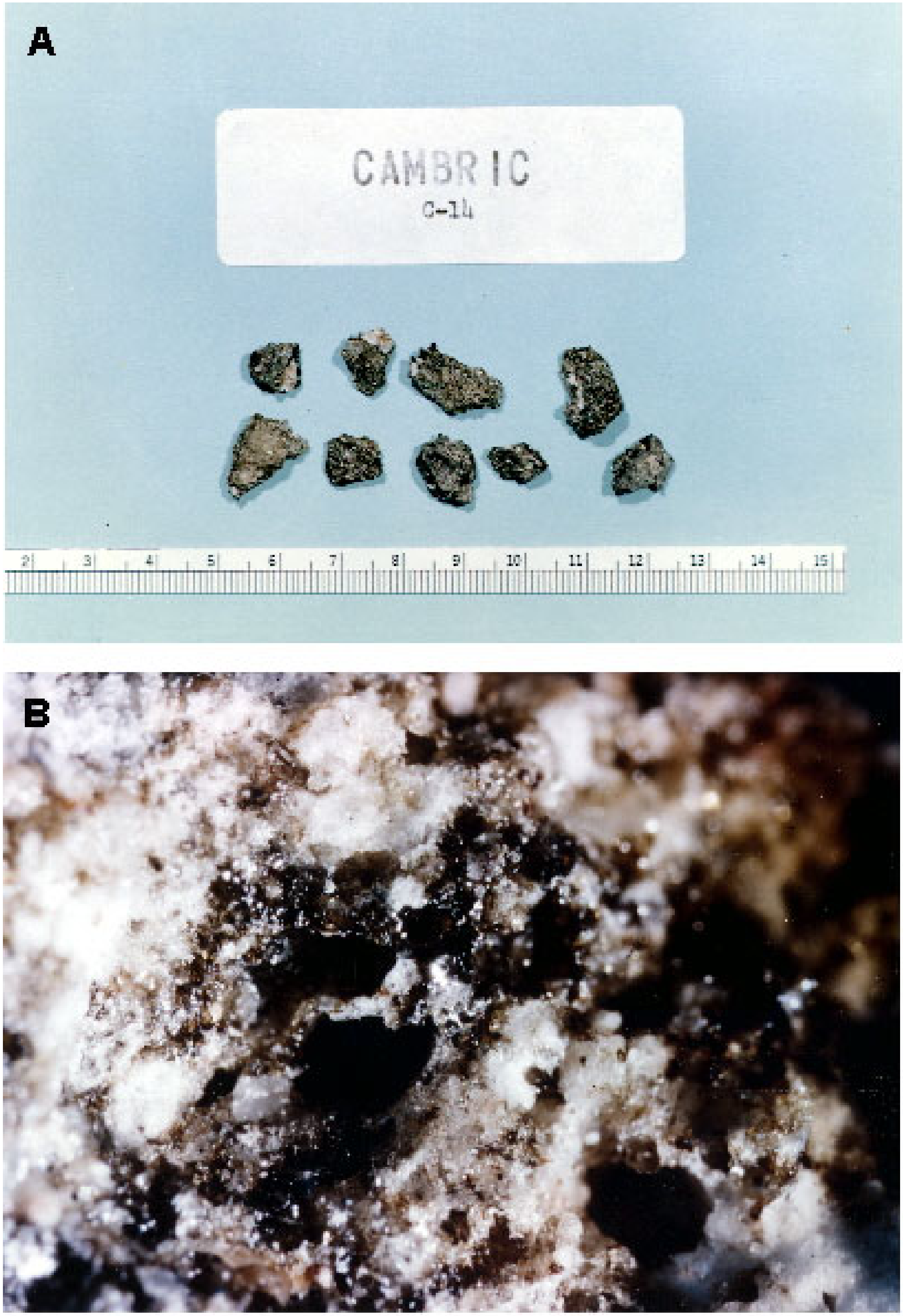

Figure 6. Melt glass samples collected during drill-back operations of the Cambric underground nuclear test. B) Magnification of a melt glass sample from Cambric. Magnification unknown. Photos are from LLNL.

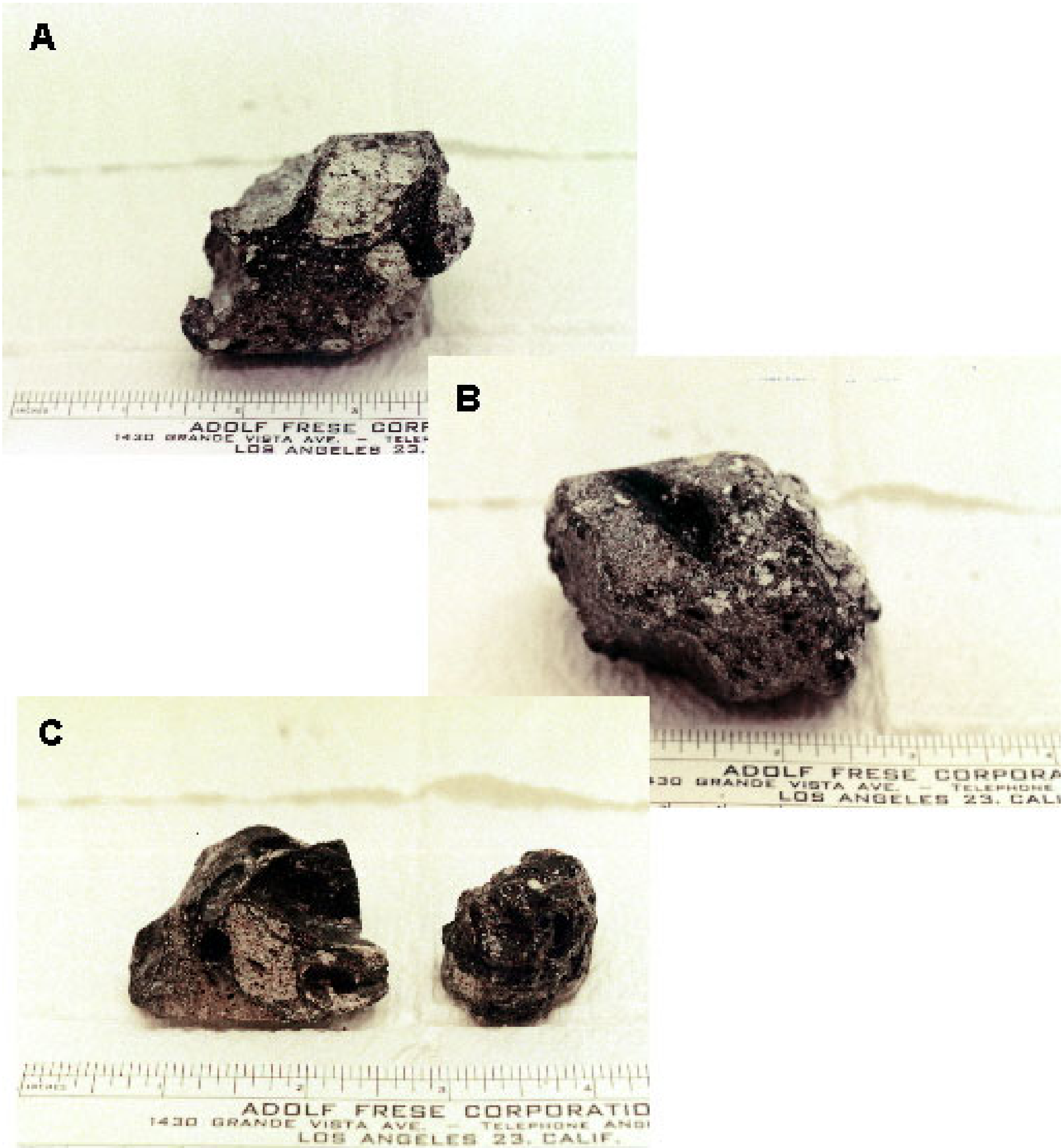

Figure 7. A-C) Representative melt glass samples collected from the NTS are the largest samples observed in our study. These samples are from unknown tests. All the samples contain lithic fragments, lightly colored and pumaceous in texture set in a more massive dark glass. Samples are from LANL.

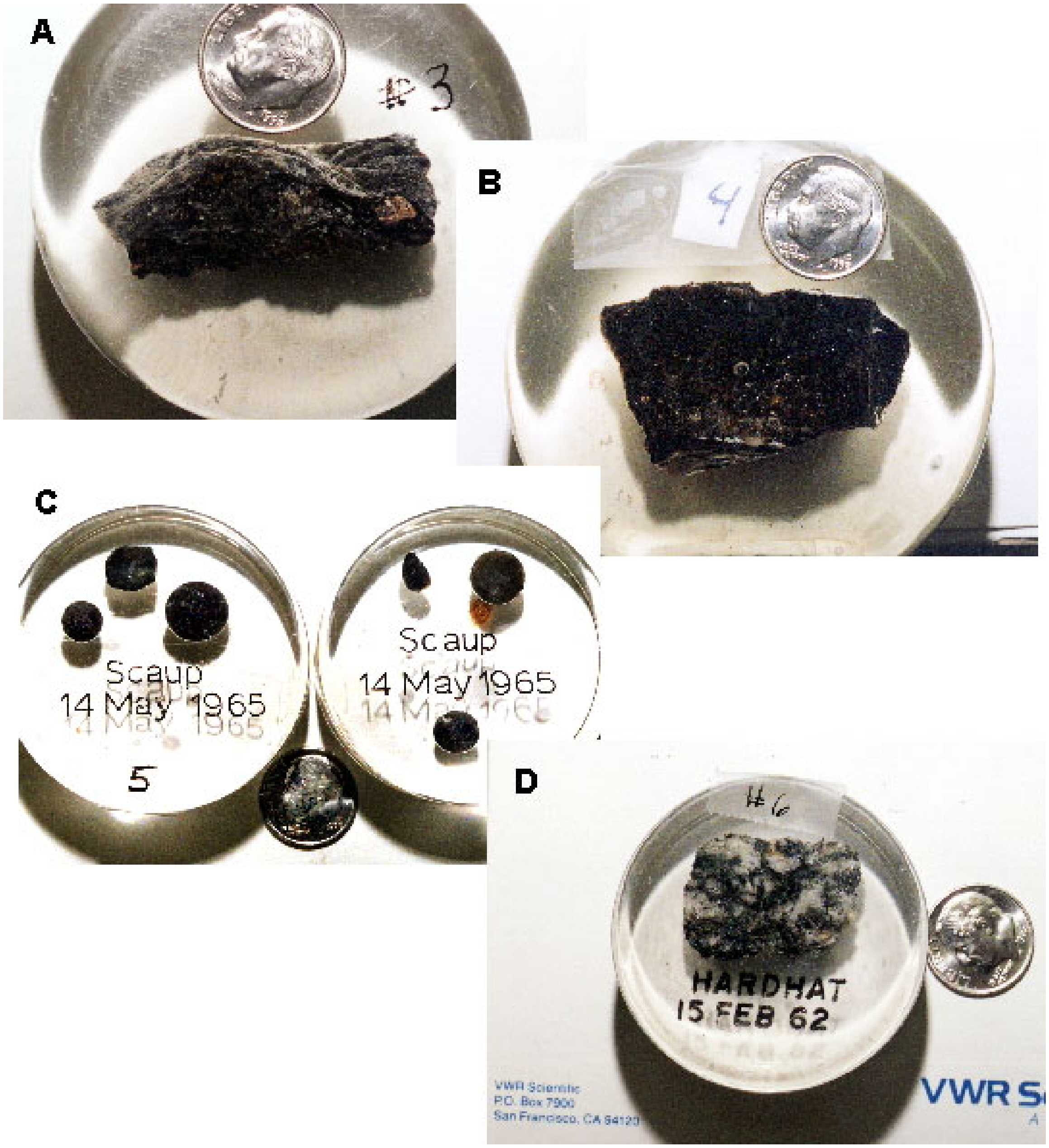

Figure 8. Small melt glass fragments set in epoxy. Samples shown in Figures A and B are massive, non-vesicular glass chips from unknown nuclear tests. The melt glass sample shown in Figure A shows flow banding. Glass droplets from the Scaup nuclear test are shown in Figure C. Figure D shows a glassy granite rock fragment from the Hardhat nuclear test. A dime is shown for scale. Samples from the LANL collection.

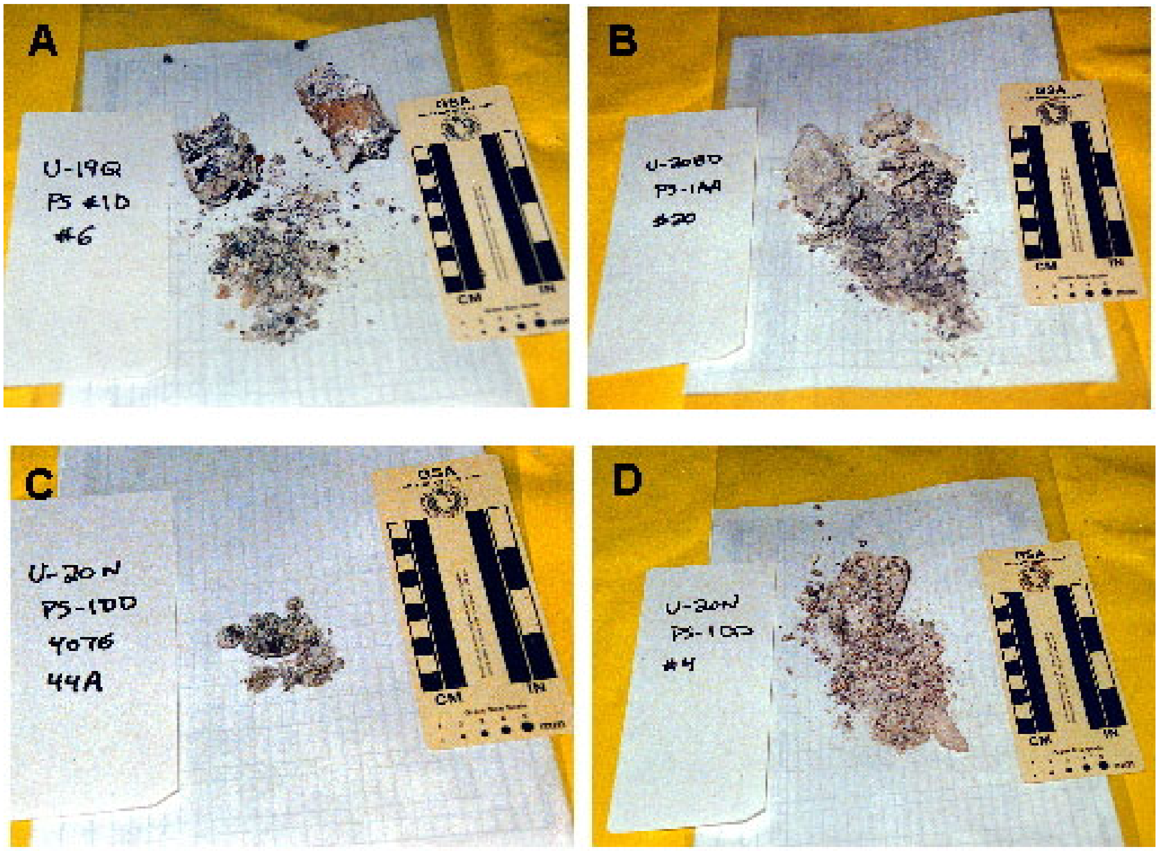

Figure 9. A-D) Representative core samples from the NTS library. A) Core from the Camembert underground nuclear test at 193 feet below working point. B) Core from the Bullion underground nuclear test at 184 feet below the working point. C and D) Core samples from the Cheshire underground nuclear test at 90 feet above and 156 feet below the working point, respectively.


192' FROM G.Z.


160' FROM G.Z.