TECHNICAL REPORT NO. 74-01

FROZEN GROUND IMPLEMENT
TASK NO. 05-M-71

Final Report

By

Benjamin F. Wood
Mobility Branch

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U. S. ARMY LAND WARFARE LABORATORY
Aberdeen Proving Ground, Maryland 21005

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ABSTRACT

This report presents information on an evaluation of commercial-type liquid carbon dioxide cartridges for use in excavation of frozen ground. The purpose was to develop a portable kit to aid in the construction of foxholes in frozen ground without the use of explosives. The kit consisted of an engine-driven hand-held rock drill, and the carbon dioxide cartridges. Tests were conducted in both shallow frozen and deep (perma-frost) frozen ground. The results were good in shallow frozen ground. Good results were not achieved in deep frozen ground, because proper techniques or devices were not used to keep the cartridge from ejecting from the bore hole. The requirement was withdrawn, and additional development/testing were not conducted.

FOREWORD

This task was conducted in response to a requirement stated by the 8th Army in Korea.

The testing was conducted for the USA Land Warfare Laboratory by Dr. M. Mellor, and Messrs. A Kovacs and B. McKelvy of the USA Cold Regions Research and Engineering Laboratory.

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INTRODUCTION

Problem: The requirement for the Frozen Ground Implement was stated by the 2d Infantry Division of the 8th Army in Korea. This unit was constructing concrete foxholes - called "thimbels" - near the DMZ. Excavation of the frozen ground was a problem, and they wished to do it without the use of explosives in order not to attract attention from the other side of the DMZ. Troops operating in cold regions of the world have always experienced difficulty in working frozen ground. The combat and rear echelon soldiers are faced with many tasks that require excavation of frozen ground. Explosives are used, but are not entirely suitable in some situations. E.g. they may reveal defensive and offensive preparations. Also, often work has to be done around fixed installations where use of explosives would endanger property and personnel.

Approach: Since the requirement was a limited and specialized one, the planned approach was to be limited - initially at least - to development of a kit and techniques utilizing commercially available equipment. After initial user evaluation, it was recognized that additional development or modification would be required for development of a general purpose frozen ground excavation kit. However, the 8th Army requirement was withdrawn, and the task was terminated after the initial testing. The approach chosen was the liquid carbon dioxide blasting cartridge. A hand-held engine-driven rock drill was selected to prepare the bore holes.

CONCLUSIONS

1. The liquid carbon dioxide cartridges are effective in loosening shallow frozen ground for subsequent excavation with hand tools. However, to insure effectiveness, a clamping device (which was not tested) is required for some ground conditions to prevent the cartridge from penetrating deeper than the bore hole, where its effectiveness would be lost.

2. The effectiveness of the cartridges was not demonstrated before the task was terminated. It is believed that a clamping device or appropriate techniques could have prevented the ejection of the cartridge from the bore hole.

DESCRIPTION

The Frozen Ground Implement consists of a portable hand-held rock drill, and an "air-blasting" Cardox-type cartridge. The Cardox cartridge is a slender steel shell, approximately 36 inches long and 2 inches in diameter, filled with liquid carbon dioxide under pressure as shown in Figure 1. The pressure is further increased when a chemical heater is fired. A shear disc ruptures, and the gas is discharged through blast ports at the tip of the cartridge. The specifications of the engine-driven rock drill are as follows:

Weight.	.56 lbs.
Over-all Length (w/o drill bit)	.24 inches
Fuel Capacity	.1/2 gal.
Fuel Consumption	.1/2 gal/hr.
Drilling Rate (hard granite), 2 1/2-inch diameter bit . .	.4 inches/min.

A drilling rate of 4 inches/min. in frozen soil was obtained by relatively inexperienced personnel in tests at Aberdeen Proving Ground with a similar type drill. The drill has the feature of blowing out the loose material in the hole with compressed air.

The hand-held type drill was chosen to provide a portable kit capability. The drill has a digging capability in addition to its drilling capability. Digging is accomplished by selecting and inserting the proper tool into the bit holder. Larger vehicle-mounted drills could drill at much higher rates, and could be used where the vehicle had access to the work site.

The Cardox-type cartridge was selected for its low noise signature, safety, and low brisant expansion. Its action may be characterized as a slow heaving action. Usually, there is little or no flyrock. For these reasons it has found extensive use in coal mining.

Theory of Operation.

The kit was intended for use in soils frozen to depths up to 3 feet. A hole is drilled for the Cardox cartridge so that the tip is near or below the bottom of the frozen soil as indicated in Figure 2. The cartridge is inserted and fired, heaving and breaking-up the frozen soil crust. The fractured soil can then be excavated with hand or power tools. Techniques are available to prevent the cartridge either from ejecting from the hole as a missile, or from penetrating further to a depth where it would be ineffective.

Test Program.

Five shots were fired at Hanover, New Hampshire in soil frozen 6-10 inches deep (similar to conditions which would occur in Korea and Europe); and eight shots were fired at Fort Wainwright, Alaska, in soil frozen to great depths (more than ten feet deep - annual thaw layer completely frozen.) The tests were conducted by emplacing the cartridge into a bore hole drilled by the power drill. The cartridge was fired, and the blast effects measured and recorded. Several dynamite shots were made at both locations for comparison.

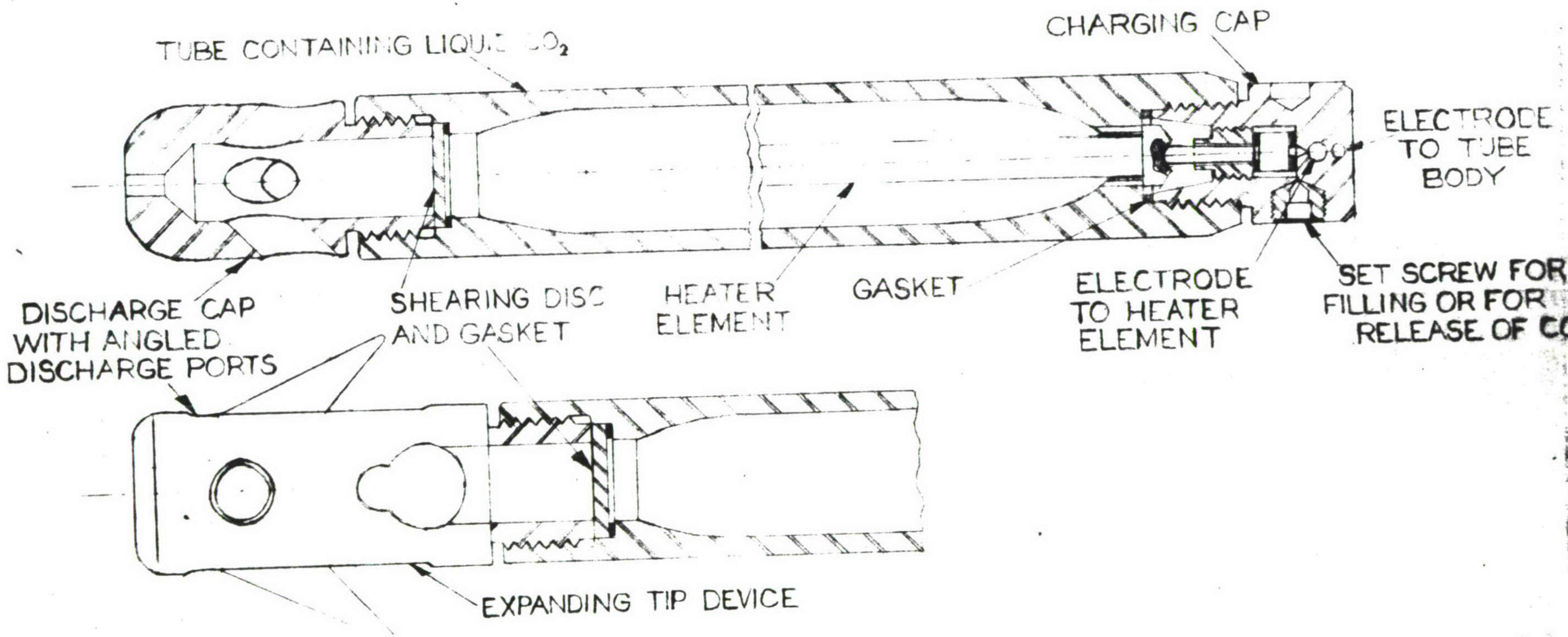

Fig. 1 Cardox Cartridge

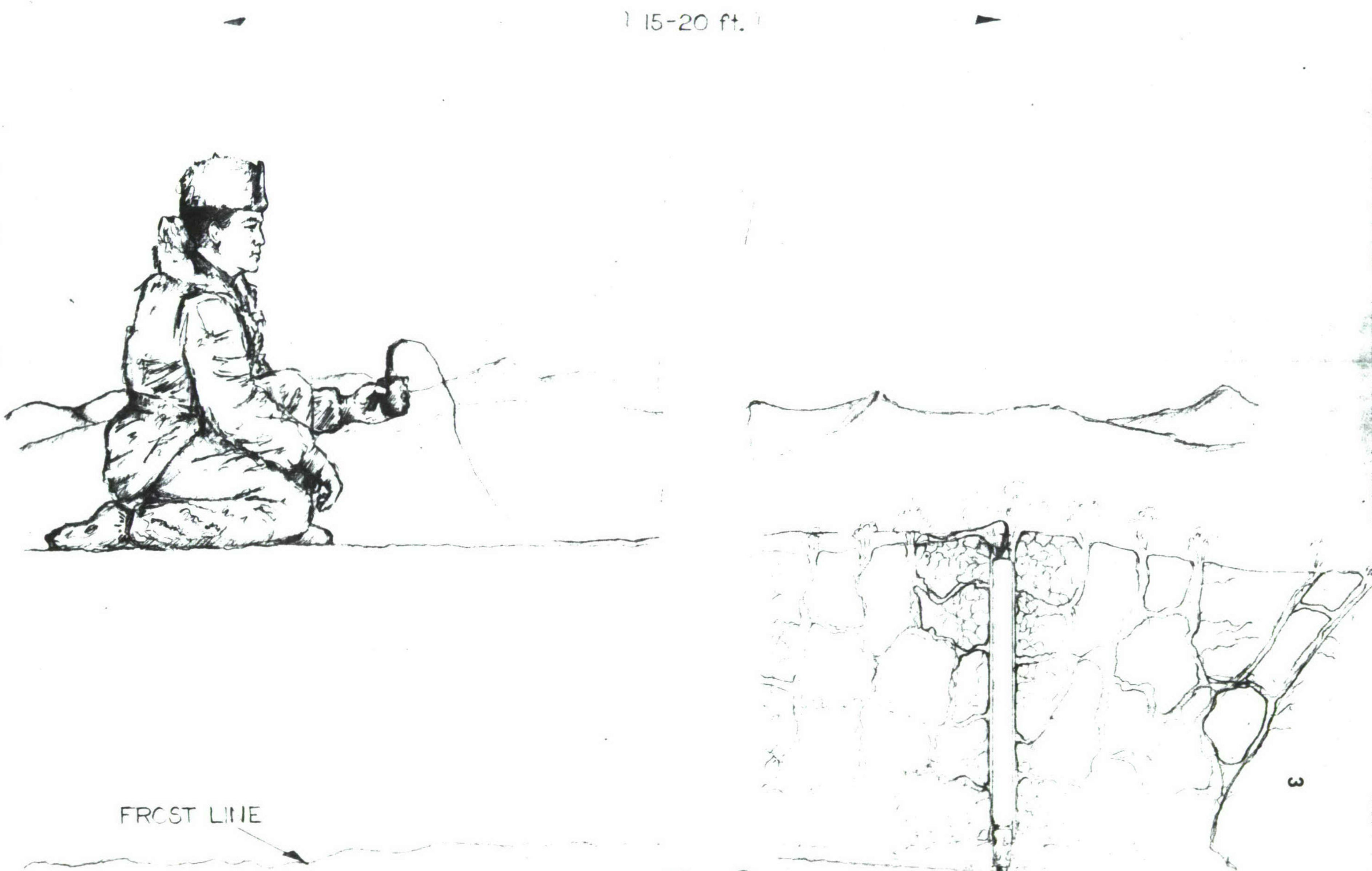

FIG. 2

Test Results.

The test results are reported in the Appendix, and are summarized in the following paragraphs.

At Hanover, one shot was ineffective, because the shell drove downward below the bore hole into the soft soil, where the force of the expansion was absorbed without much surface effect. Four shots were effective to some degree. Two of the shots, which were bored vertically, produced craters 6.0 to 7.2 feet in diameter. The craters were filled with large chunks of fractured debris (frozen soil), which was easy to excavate by hand. The other two bore holes, drilled at a 45° inclination, were less effective.

FIGURE NO. 3: Cardox Breaking Frozen Ground

The shots in Alaska (in deep frozen soil) were not effective. The standard cartridges were used without any kind of device or procedure to hold the shell in the bore hole. Consequently, the cartridges were propelled out of the hole, and their effectiveness was lost.

Discussion.

Good test results and effective soil loosening was achieved in shallow seasonally frozen ground such as would typically occur in Korea or Europe. The results were comparable to that obtained with 1/2 lbs. dynamite. A clamping device is required to insure that the cartridge does not drive deeper into the soil and thereby lose its effectiveness, but was not used for these tests.

Although not used for the tests, procedures may be used to prevent ejection of the cartridge from the bore hole. These have been proven in mining operations. The bore hole may be packed at the bottom with loose material to act as a cushion. This allows the cartridge to travel downward a short distance during the firing cycle (the gas ports are angled to drive the cartridge downwards), and the cartridge will not be ejected. Another expedient method is to place a large stone or object over the bore hole to prevent ejection. Also, there is a special expanding tip available which expands in the bore hole during the firing cycle, and locks the cartridge in the bore hole. Since none of these techniques were used in the tests, the effectiveness in deep frozen ground was not evaluated. The expanding tip device would also be effective in preventing the cartridge from driving too deep in soft soil beneath the frozen crust.

The blasting cartridge technique was not proposed to replace the use of explosives. Properly developed, it is believed that it could be an effective means for excavating frozen soil, particularly where the use of explosives is unacceptable. In situations where explosives are acceptable, there is a need for trimming and shaping the excavation. The drill or concrete breaker will fill this need. See Figure 1 insert.

The cartridges are rechargeable, so that the cost, weight, and volume effectiveness are increased if provisions are made for recharging.

APPENDIX

EXTRACT FROM (Figures Not Included):

FEASIBILITY STUDY OF FOXHOLE EXCAVATION BY COMPRESSED GAS BLASTING

By

Malcolm Mellor and Austin Kovacs

June 1971

Prepared For

U.S. ARMY LAND WARFARE LABORATORY
INTRO-ARMY ORDER NO. 71-31

By

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

PREFACE

This report presents information related to the evaluation of compressed carbon dioxide blasting shells for possible use in the expedient blasting of foxholes in frozen ground.

This work was performed by the U.S. Army Cold Regions Research and Engineering Laboratory, for the U.S. Army Land Warfare Laboratory, under IAO No. 71-31 dated 1 February 1971.

The study was conducted by Dr. Malcolm Mellor, Research Civil Engineer, of the Applied Research Branch and Mr. Austin Kovacs, Research Civil Engineer, of the Foundations and Materials Research Branch, both of the Experimental Engineering Division. The field work was performed by the authors and Mr. Bruce McKelvy, Foundations and Materials Research Branch.

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FEASIBILITY STUDY OF FOXHOLE EXCAVATION BY COMPRESSED GAS BLASTING

by

Malcolm Mellor and Austin Kovacs

Introduction

During past studies of excavation techniques for frozen ground, USA CRREL investigated the performance of airblasting equipment in frozen silt and frozen gravel (Hawkes, 1967; Hawkes et al., 1967; Hawkes and McAnerney, 1968; McAnerney et al., 1969). At the request of the U.S. Army Land Warfare Laboratory, tests were made during the winter of 1971 to investigate the feasibility of blasting foxholes in frozen ground by means of self-contained cartridges of compressed carbon dioxide, which have a blasting action very similar to that of high-pressure compressed air shells.

The object of the tests was to determine whether standard commercial cartridges of compressed carbon dioxide are capable of blasting foxholes, approximately 3 ft deep and 4 ft in diameter at the upper lip, in ground frozen to various depths.

Carbon dioxide cartridges

The cartridges specified by the Land Warfare Laboratory for this project were Long-Airdox Corporation "Cardox" type 2-50. These are cylindrical steel shells, 2 in. in diameter by 35.6 in. long, with nominal weights of 13 lb empty and 14-1/2 lb full. A few type 231-130 Cardox shells, which were being used on another USACRREL project, were also tested. The latter are 2.31 in. in diameter by 59.6 in. long, with nominal weights of 29.75 lb empty and 33.75 lb full. The shells are shown in Figure 1.

The shell (Fig. 2) consists of a slender hollow cylinder filled with liquid carbon dioxide under a pressure of approximately 2000 psi, a discharge head with angled blast ports, and a charging cap fitted with an electrically actuated chemical heater that projects into the carbon dioxide. When the heater is fired electrically (from a battery or a blasting machine) there is a sudden increase in pressure to between 10,000 and 19,000 psi, at which point a shear disc at the discharge head ruptures, and carbon dioxide is released through the blast ports at appreciably lower pressure (Davies and Hawkes, 1964). The blast ports are angled so that the shell tends to drive deeper into the shothole as the gas vents, but if the discharge head is set too deep inside a shothole drilled in strong, impermeable material an unclamped shell (one without a shell-borehole locking device, i.e. clamp) will be ejected violently from the shothole as a projectile.

Test procedure

Tests were made in late February at Hanover, N.H., in silt frozen to a depth of approximately 7 in. Snow cover was removed from the test plot immediately prior to testing. This ground condition was thought to be similar to conditions that might occur in Korea or northern Europe in wintertime. Further tests were made in late March near Fairbanks, Alaska, in silt frozen to great depth, i.e. in excess of 10 ft. Snow at the latter site was cleared one month prior to testing to ensure that the ground was completely frozen down to the permafrost level. For each test a Cardox shell was inserted in a bore-hole and fired. The blast and its effects were photographed by a motorized camera, blast effects were measured and recorded, and attempts were made to dig a foxhole with hand tools.

The standard method of emplacement was to insert the shell to the desired depth in a vertical borehole drilled by a lightweight power auger. The manufacturer's recommendation calls for a 2 1/2-in.-diameter borehole for the type 2-50 shell, and a 3-in.-diameter borehole for the type 231-130 shell. The boreholes actually drilled for the type 2-50 were 2.38 in. in diameter. The type 231-130 was fired in a 4.5-in.-diameter hole with stemming, and in a 2.5-in.-diameter hole.

Comparative tests were made with dynamite placed in stemmed and unstemmed boreholes.

Test results

Hanover tests. Tests were made at Hanover on 23 and 24 February 1971 in sandy silt frozen to a depth averaging 7 in., with variation from 6 to 10 in. depending chiefly on depth of snow cover. The soil beneath the frozen layer was soft and moist sandy silt that was easy to dig with a shovel. A general description of soil properties at this site was made by Crory (1965). Results of the Hanover tests are listed below, and a selection of photographs is presented in Figures 3 - 9. The complete photographic record is on file at USACRREL.

Shot 1: Type 2-50 shell, weight 14 lb 8 oz. Shothole depth 2.25 ft. Ground disturbance very slight. No flyrock. Ground surface cracked and domed up approximately 6 in. around the borehole, with slight disturbance detectable over a diameter of 7.5 ft (Fig. 3a). Shell drove vertically down and out of sight in the soft underlying soil. Shell discharge made very little noise. Three men tried excavating the shot site, to no avail. A layer of soil 1-1/2 in. thick scabbed off, but the main crust could not be broken open with hand shovels (Fig. 3b).

Shot 2: Type 231-130 shell, weight 32 lb 6 oz. Shothole depth 2.25 ft. Shell emplacement is shown in Figures 4a and 4b and flyrock at detonation in Figure 4c. Apparent crater elliptical in plan, 4.1 to 5.3 ft across; almost filled by debris, but debris was easy to dig (Fig. 4d). True crater (limit of surface breakage) 7.2 ft in diameter. Not much noise from shell.

Shot 3: Type 2-50 shell, weight 14 lb 11 oz. Shothole depth 1.65 ft. A view of the test site with shell in place is shown in Figure 5a. Apparent crater 3.0 to 3.6 ft across, with surface debris that could be excavated by hand (Fig. 5b). True crater 6.0 to 6.5 ft across.

Shot 4: Type 2-50 shell, weight 14 lb 10 oz. Shothole inclined at 45° (see shothole drilling, Figure 6a), 2 ft long, i.e. blast ports of shell 1.4 ft below surface. Figures 6b, c and d show views during and after shell detonation. Apparent crater 4.3 to 5.0 ft across, with surface debris that could be excavated by hand.

Shot 5: Repeat of Shot 4 made at site of Shot 1 in order to recover shell #1. Figure 7a shows drilling of inclined shothole. The blast is shown in Figure 7b. Surface crater was approximately 3 ft in diameter and 6 in. deep. Shoveling required to find and excavate shell #1, the top of which was approximately 6 in. below the bottom of the true crater.

Shot 6: Comparison shot with 40% gelatin dynamite. 1/2-lb charge in borehole 1.65 ft deep. Flyrock at detonation is shown in Figure 8a. Apparent crater 3.5 to 4.0 ft across (Fig. 8b), debris easy to dig. True crater 6.5 to 7.2 ft across. Very little noise at detonation.

Shot 7: Comparison shot with 40% gelatin dynamite. 1/2-lb charge in borehole 2.25 ft deep. Stemming of shothole is shown in Figure 9a. Flyrock debris at detonation is shown in Figure 9b. Apparent crater 3.4 to 3.8 ft across (Fig. 9c), debris easy to dig. True crater 5.0 to 5.8 ft across.

Alaska tests. Tests were made in Alaska during the period 18 to 26 March 1971. The test site was located on the Fort Wainwright military reservation. The test material was deeply frozen silt (annual thaw layer completely refrozen). Soil properties at the site are given by Mellor and Sellmann (1970), who identify the site by the name "ESI Silt Site." Results of the Alaska tests are listed below.

Shot 1: Type 231-130 shell in 4 1/2-in.-diameter borehole 3.2 ft deep (blast ports 3 ft below surface). Installed shell is shown in Figure 10. Annular space between shell and hole wall was backfilled with silt cuttings and allowed to refreeze. Shell failed to discharge when firing was attempted, first with a 12-volt battery, later with a 24-volt battery and then with 110-volt A.C. The shell was removed and the CO_2 discharged through the release screw shown in Figure 2.

Shot 2: Repeat of Shot 1. Shell blew stemming from hole, but did no damage to surrounding ground.

Shot 3: Another repeat of Shot 1. Same result as Shot 2.

Shot 4: Type 2-50 shell in 2 3/8-in.-diameter borehole 2 ft deep. Shell ejected from borehole while remaining attached to firing line. Shell rose to height of approximately 60 ft and traveled 130 ft horizontally to land by the firing position. High flyrock (see Figures

11a, b and c). Apparent crater 4.5 ft diameter, 10 to 13 in. deep (Fig. 11d). True crater 5.5 ft diameter, 10 to 13 in. deep. Bottom 14 in. of shothole intact, a portion of which is shown in Figure 11d.

Shot 5: Repeat of Shot 4. Shell flew at least 100 ft into the air (Fig. 12). Apparent (and true) crater 25 to 44 in. across, with 120° segment unbroken. Crater up to 17 in. deep, but bottom part of shothole intact.

Shot 6: Type 2-50 shell in 2 3/8-in.-diameter borehole 2.5 ft deep. Shell blew about 150 ft into the air. Ground surface broken, but no significant flyrock. V-shaped hole excavated by hand, 2 to 3 ft across and 15 in. deep.

Shot 7: Repeat of Shot 6. Shell flew high. Ground surface cracked, but only slightly displaced, over area some 3-1/2 ft in diameter.

Shot 8: Type 2-50 shell in 2 3/8-in.-diameter borehole 3 ft deep. Shell flew very high - one eyewitness estimated 300 ft. Shell was airborne more than 5 sec. Ground cracked over area 2 ft in diameter. Depth of cracking 10 in.

Shot 9: Repeat of Shot 8. Similar result.

Shot 10: Comparison shot with military dynamite. 1-lb charge in 4 1/2-in.-diameter borehole 2.8 ft deep (forward initiation). Apparent crater 2.8 ft diameter by 1.8 ft deep. True crater 4 ft diameter. Flyrock to height of approximately 50 ft.

Shot 11: Comparison shot with military dynamite. 1-lb charge in 4 1/2-in.-diameter borehole 2.2 ft deep (reverse initiation). Apparent crater 5 ft diameter, true crater 6.5 ft diameter. Flyrock to 50 ft vertically and 50 ft horizontally.

Shot 12: Comparison shot with military dynamite. 1-lb charge in 4 1/2-in.-diameter borehole 3.2 ft deep (reverse initiation). True crater 6.5 ft diameter. No significant flyrock. Blocks of debris up to 2 ft across.

Additional tests were made with military dynamite and a special liquid explosive as part of a cooperative program between Picatinny Arsenal and USACRREL. The results of experimental foxhole shots made during this work are summarized in Table I.

Discussion

On the basis of the present tests, standard unclamped Cardox shells emplaced by simple means do not appear to be either safe or effective for foxhole blasting in frozen ground.

When inserted beneath a thin (6- to 10-in.) layer of seasonally frozen soil the type 2-50 Cardox shell is capable of breaking the frozen soil

Table I. Foxhole blasts made during Picatinny/CRREL project.

Site Material: Frozen Fairbanks Silt — *Date:* 22-26 Mar 71

Explosives: Picatinny liquid formulation with M-6 caps and Military dynamite — *Stemming:* None

Shothole Diam. (in.)	Shothole Depth (ft)	Charge	Crater diam. (ft) True crater	Crater diam. (ft) Apparent crater	Remarks
2-1/4	3	3 lb liquid (poured)	8.5	6	High flyrock. Open hole 6 ft diam., 1 ft deep
2-1/4	3	3 lb liquid (poured)	7	5.5	Great amount of flyrock. Open hole 5-1/2 ft diam., 1-1/2 ft deep. After digging, hole 2.8 ft deep with bottom diam. 2.7 ft
2-1/4	3	3 lb liquid (poured)	7	6.25	High flyrock. Open hole 6 ft diam., 1-1/2 ft deep
4-1/2	3	3 lb liquid (poured)	8	6.5	Debris fell back into crater
2-1/4	3	1 lb dynamite	6.5	4	Ground domed around open hole
2-1/4	3	2 lb dynamite		3	Open hole 3 ft diam., 6 in. deep. Small fragments
2-1/4	3	3 lb dynamite (hand-tamped)		4	Open hole 4 ft diam., 1 ft deep. After digging, 2-1/2 ft deep with bottom diam. 1.6 ft
2-1/4	3	3 lb dynamite (hand-tamped)		4.6	Open hole 4.6 ft diam., 1.4 ft deep. After digging, 2.7 ft deep with bottom diam. 2 ft (0.8 ft diam. at base of shothole)
2-1/4	3	3 lb dynamite (hand-tamped)		4.0	Open hole 4 ft diam., 0.9 ft deep. After digging 2.9 ft deep with 2.5 ft bottom diam. and 0.8 ft diam. at base of shothole
4-1/2	3	3 lb dynamite		5	Open hole 5 ft diam., 1 ft deep. Large fragments. Hard to dig

so that a foxhole can be dug, provided that the discharge ports are not set too deep. However, there is a strong possibility that an unclamped shell will drive itself deeper into the soft underlying material, smothering the blast and rendering the shot ineffective (as well as losing the empty shell).

When unclamped type 2-50 shells are inserted 2 ft or more into deeply frozen impermeable soil and fired they become airborne missiles that could be lethal to anyone within 200 ft of the shothole. They are incapable of providing useful foxholes in deeply frozen ground. The larger type 231-130 shell also failed to adequately break the frozen soil for foxhole purposes when fired as they were in oversize shotholes. It seems probable that this larger shell would also become a missile if fired unclamped in a snug shothole.

The blasting effectiveness of the type 2-50 Cardox shell is approximately equivalent to 0.5 lb of typical high explosive, such as dynamite. The type 231-130 Cardox shell has a blasting effectiveness approximately equivalent to 1 lb of high explosive. This has been demonstrated in recent USACRREL tests in which Cardox shells, Airdox shells, and dynamite were used to break lake ice (unpublished USACRREL data).

Compressed gas blasting shells have a different action than high explosives by virtue of their relatively low discharge pressure. In some applications the heaving action of the expanding gas discharge, with virtually no shock wave shattering, is advantageous. However, for foxhole preparation there is much to be said for the shattering action of a brisant explosive, as it tends to produce debris that is easier to dig with hand tools. There does not seem to be very much difference in the noise produced by Cardox shells and equivalent charges of high explosive.

All Cardox shells require clean, snug shotholes. If the hole is too big the discharging gas vents through the annulus between shell and hole wall, and the shot becomes ineffective. If the hole is too tight, or if the hole walls are rough, the shell is difficult to insert. By contrast, dynamite can be placed in unstemmed shotholes ranging in diameter from 1.5 to 4.5 in. without serious loss of performance. In this connection it should be kept in mind that, while shotholes are easy to drill in frozen silt, drilling in frozen gravel may call for hard rock equipment.

In tests with the type 2-50 Cardox shell all shells discharged, although there were several instances in which firing line contacts had to be improved before the shell would fire (good connecting pins would solve this problem). In tests with the type 231-130 shell (including work on another USACRREL project) there have been several misfires - equivalent to about 20% of the total batch. In addition, the body of one shell split during discharge (Fig. 13).

Economic and logistic considerations seem highly unfavorable towards the Cardox shells when a comparison is made with dynamite. Cardox shells weigh about 30 times as much as an equivalent package of high explosive, and their volumes are about 12 times as great as equivalent dynamite cartridges. If Cardox shells are regarded as expendable, they will probably be about 3 orders of magnitude more expensive than dynamite. If the shells are retrieved and refilled, they will still be about 2 orders of magnitude more expensive than dynamite.

While it may be possible to overcome some of the present objections to Cardox shells by further development work (e.g. by developing *completely* reliable shell clamps), the authors are unable to find an adequate justification for such a program.

The following points seem worthy of consideration in the design of a foxhole blasting kit for frozen ground.

1. The original ideal of an "instant foxhole" may be unrealistic. Violent ejection of shells, shrapnel, or flyrock fragments greater than about 1 in. in size seems highly undesirable, since normal blasting precautions will not always be possible under battlefield conditions.

2. Any device for making one-man foxholes ought to be light, compact and cheap. Devices like the rocket-driven foxhole digger that was once under development seem absurd.

3. Emplacement of an explosive charge beneath the ground surface is the most difficult part of the problem. Existing shaped charges are far from ideal, and there is no lightweight drill that is capable of driving shotholes in all types of frozen ground.

4. If shotholes can be provided, a small two-element delay decking charge ought to be sufficient to prepare a foxhole. This would minimize overbreak and limit flyrock travel in cases where there is only a thin layer of frozen ground. Such a charge could be pre-wired and packaged for easy operation.

5. If shotholes are punched by shaped charges, liquid explosive may be preferable to solid explosive for the cratering charge.

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Figure 1. Cardox shells. Left, type 2-50; right, type 231-130.

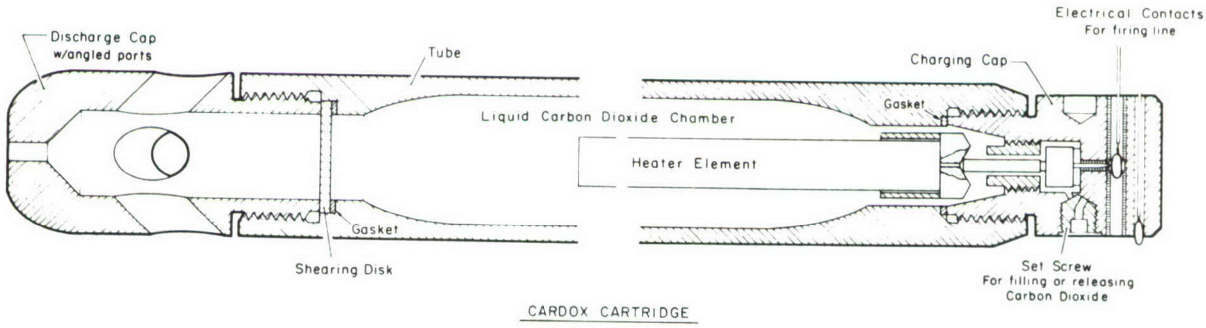


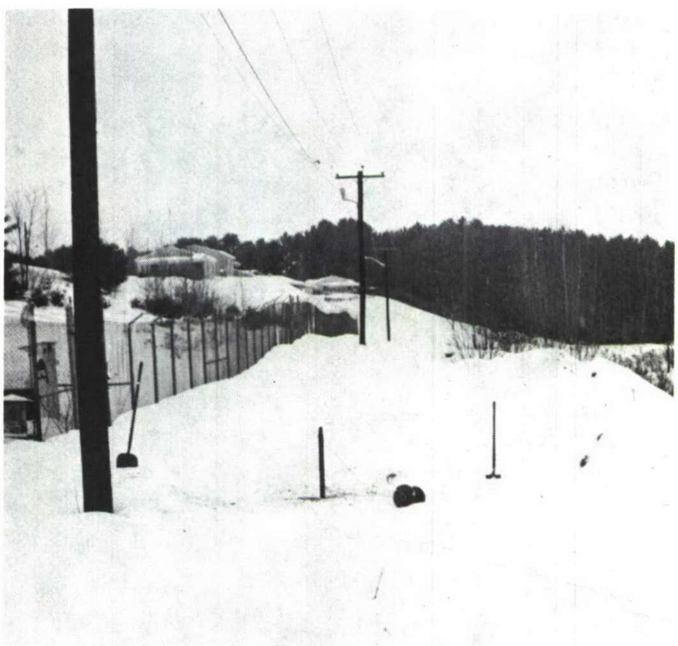
Figure 2. Diagram of the Cardox shell.

a.

b.

Figure 3. Hanover test site (Shot 1).

a.



b.

Figure 4. Hanover test site (Shot 2).

c.

d.

Figure 4 (cont'd). Hanover test site (Shot 2).

a.

b.

Figure 5. Hanover test site (Shot 3).

a.

b.

Figure 6. Hanover test site (Shot 4).

c.

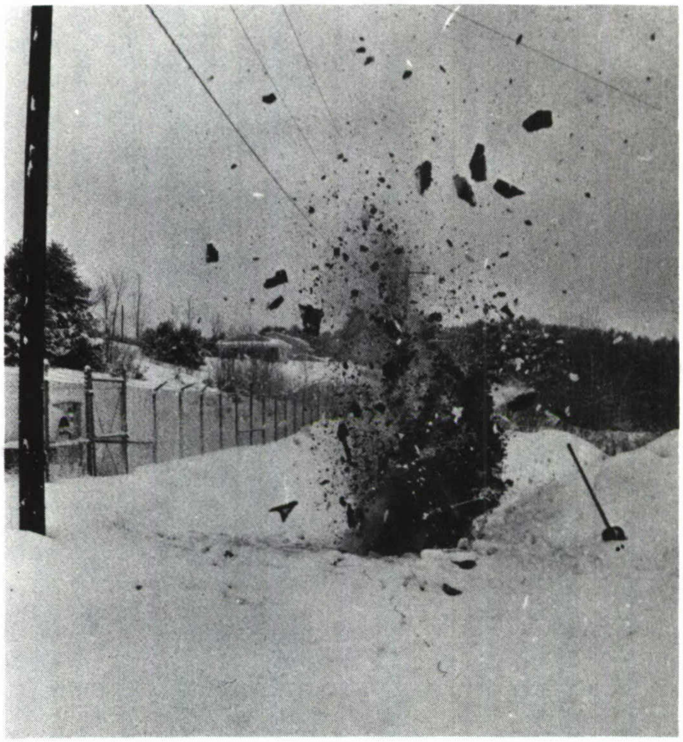
d.

Figure 6 (cont'd). Hanover test site (Shot 4).

a.

b.

Figure 7. Hanover test site (Shot 5).



a.

b.

Figure 8. Hanover test site (Shot 6).

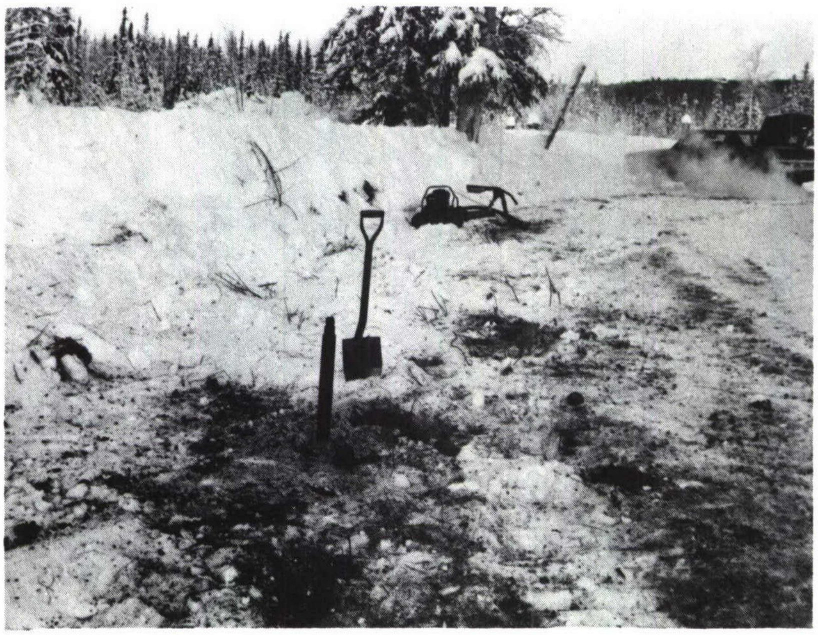
a.

b.

Figure 9. Hanover test site (Shot 7).

c.

Figure 9 (cont'd). Hanover test site (Shot 7).



d.

Figure 10. Alaska test site (Shot 1).

a.

b.

Figure 11. Alaska test site (Shot 4).

c.

d.

Figure 11 (cont'd). Alaska test site (Shot 4).

a.

Figure 12. Alaska test site (Shot 5).

b.

Figure 13. Fractured shell casing.

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US Army CDC Intelligence & Control Systems Group
Fort Belvoir, VA 22060 1

USACDC Liaison Officer
Aberdeen Proving Ground, MD 21005 1

Commander
US Army Test and Evaluation Command
Aberdeen Proving Ground, MD 21005 1

Commander
US Army John F. Kennedy Center for Military Assistance
Fort Bragg, NC 28307 1

Commander-In-Chief
US Army Pacific
ATTN: GPOP-FD
APO San Francisco 96558 1

Commander
Eighth US Army
ATTN: EAGO-P
APO San Francisco 96301 1

Commander
US Army Europe
ATTN: AEAGC-ND
APO New York 09403 1

Commander
US Army Alaska
ATTN: ARACD
APO Seattle 98749 1

Commander
MASSTER
ATTN: Materiel Test Directorate
Fort Hood, TX 76544 1

Commander
US MAC-T & JUSMAG-T
ATTN: MACTRD
APO San Francisco 96346 2

Senior Standardization Representative 1
US Army Standardization Group, Australia
c/o American Embassy
APO San Francisco 96404

Senior Standardization Representative 1
US Army Standardization Group, UK
Box 65
FPO New York 09510

Senior Standardization Representative 1
US Army Standardization Group, Canada
Canadian Forces Headquarters
Ottawa, Canada KIAOK2

Director 1
Air University Library
ATTN: AUL3T-64-572
Maxwell Air Force Base, AL 36112

Battelle Memorial Institute 1
Tactical Technical Center
Columbus Laboratories
505 King Avenue
Columbus, OH 43201

Defense Documentation Center (ASTIA) 12
Cameron Station
Alexandria, VA 22314

Commander 2
Aberdeen Proving Ground
ATTN: STEAP-TL
Aberdeen Proving Ground, MD 21005

Commander 1
US Army Edgewood Arsenal
ATTN: SMUEA-TS-L
Edgewood Arsenal, MD 21010

US Marine Corps Liaison Officer 1
Aberdeen Proving Ground, MD 21005