Scoping Study of the Effects of Aging on Landmines

Presented to

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<th>Full Form</th>
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<tbody>
<tr>
<td>AP</td>
<td>Anti-personnel</td>
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<tr>
<td>AT</td>
<td>Anti-tank</td>
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<tr>
<td>CMAC</td>
<td>Cambodian Mine Action Centre</td>
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<tr>
<td>CKA</td>
<td>C King Associates Ltd</td>
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<tr>
<td>ERW</td>
<td>Explosive remnants of war</td>
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<tr>
<td>EOD</td>
<td>Explosive ordnance disposal</td>
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<tr>
<td>GWHF</td>
<td>Golden West Humanitarian Foundation</td>
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<tr>
<td>JMU</td>
<td>James Madison University (location of the MAIC)</td>
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<td>MAIC</td>
<td>Mine Action Information Center</td>
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<td>MRE</td>
<td>Mine risk education</td>
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<tr>
<td>MAG</td>
<td>Mines Advisory Group</td>
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<tr>
<td>NGO</td>
<td>Nongovernmental organization</td>
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<tr>
<td>NPA</td>
<td>Norwegian People's Aid</td>
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<tr>
<td>RCAF</td>
<td>Royal Cambodian Armed Forces</td>
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<tr>
<td>UXO</td>
<td>Unexploded ordnance</td>
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1. Executive Summary

During the past year, the Mine Action Information Center at James Madison University has partnered with a British EOD consultancy company, C King Associates Ltd, to conduct a preliminary study into the effects of aging on landmines. This project entailed examination and disassembly of several types of anti-personnel mines, a literature review of relevant material and analysis of the initial findings.

The study confirms a fairly obvious assumption: The characteristics of mines change significantly as they grow older. However, while this situation is constantly observed in the field through the recovery of rotted, rusted and damaged mines, it has never been adequately investigated. The literary review found little evidence of any systematic attempt to document the effects of aging, let alone to analyze their implications for mine action.

The traditional assumption is that aging ammunition tends to become “unpredictable,” which is often interpreted as “unstable.” Initial findings from this study indicate that, on the contrary, many aging effects are not only inevitable, but frequently lead to mines becoming inoperative. These findings have far-reaching implications for both the mine-action “industry” and for military operations.

Applications from the findings range from assisting high-level decisions on funding allocation to modifying clearance techniques in the field. Not surprisingly, there are implications for detection and equipment development. Additionally, many of the models and images currently used for recognition training look completely unlike the mines as they appear now, so there are significant implications for improving mine risk education.

It was necessary to severely limit the extent of this initial phase, both technically and geographically; in fact, this important work was delayed for many years because the subject seemed too broad to approach. This effort has highlighted important trends that clearly warrant further investigation; in particular, there is a need to quantify the effects observed and to validate the deductions.

It is recommended that this study serve as a foundation for more analytical work, which expands on the types of mine examined and the regions, or generic conditions, in which they are found. The outcomes from further research on the effects of aging on landmines offer the prospect of allowing substantial savings to program managers through enhanced decision-making and economy of effort; and more importantly, these findings have the real potential to save lives.
2. Introduction

2.1. Background to the problem

Virtually nothing in the way of scientific evidence is known about the effects of aging on landmines. However, observation, anecdotal evidence and case studies give reason to believe that, in affected countries throughout the world, many types of landmines are being neutralized over time due to aging and climate. There is great need for scientific research in order to find any evidence of this phenomenon and to assess the implications for mine action.

A preliminary literature review of information available about the effects of aging on mines suggests that there is little information available in a formal published manner on the subject of the effect of aging on landmines. The closest findings have included some research on deterioration over time of unexploded ordnance (UXO), particularly related to rusting. However, the variety of landmine configurations and materials demands a far more rigorous investigation.

The detailed characteristics of mines affected by aging, and their consequent weaknesses, have largely been overlooked during the development of demining equipment and the evolution of field procedures; these aging characteristics have also had little or no bearing on the prioritization of clearance tasks at the strategic level. It is also important to note that many of the implications for humanitarian mine action are equally relevant to military units operating in post-conflict regions.

In an effort to better understand the effects of aging on landmines, this scoping study observed, recorded and analyzed the characteristics of old mines. The intention was to establish a solid knowledge base and identify recommendations for future scientific research regarding the extent and nature of landmine deterioration.

Cambodia was selected as the region best suited for initial field research because mines that were laid more than 30 years ago are readily available, and many show obvious signs of deterioration. The primary regional clearance organizations, Cambodian Mine Action Center (CMAC), The HALO Trust, Mines Advisory Group (MAG) and Golden West Humanitarian Foundation (GWVF), had all expressed an interest in the project and a willingness to assist.

In order to make best use of resources and achieve worthwhile findings, the scoping study was confined to anti-personnel (AP) mines, focusing in detail on just four pressure-operated blast types. Further observations were made of another seven types of mines in order to highlight additional issues relevant to other mine categories, including bounding fragmentation and electronically fuzed types.

2.2. Funding

This project has been generously funded by United States Department of State, Bureau of Political-Military Affairs/Office of Weapons Removal and Abatement. Other organizations, most notably The HALO Trust, contributed to the study at no cost.

2.3. Project goal

The primary goal of this scoping study was to begin to investigate the causes and effects of aging on landmines in order to identify potential benefits for mine action.
2.4. Project objectives

The objectives of this scoping study were the following:

- **Objective 1**: Determine what information has already been generated regarding the topic(s) of landmine aging, deterioration and neutralization through a literature review and collection of case studies (published and unpublished).

- **Objective 2**: Through empirical field research in Cambodia, study the conditions of previously emplaced landmines to collect observed data and deduce both the state of deterioration of these landmines due to aging and the conditions associated with deterioration.

- **Objective 3**: Based on the results of empirical research in Cambodia, conduct analysis on test findings, produce any evidence of mine deterioration and develop research outcome implications, including those relating to demining techniques and clearance priorities in Cambodia.

- **Objective 4**: Based on the results of empirical research in Cambodia, conduct analysis on the implications to the global landmine problem by hypothesizing about affected regions with similar mine types and environmental conditions.

- **Objective 5**: Based on the results of empirical research in Cambodia and subsequent interviews/site visits, determine future requirements and partners for a follow-up phase. This would involve in-depth scientific research and tests on landmines, to scientifically study the effects of aging, rates of deterioration and possible acceleration of deterioration for potentially enhanced techniques, leading to faster landmine neutralization (and land release).

- **Objective 6**: Disseminate and solicit feedback on final report, to include findings from literature and empirical research and recommendations about the possibility of a future larger-scale study on landmine aging.

The remainder of the report is divided into the following sections:

- Section 3: Methodology
- Section 4: Literature Review
- Section 5: Anecdotal Evidence
- Section 6: Findings
- Section 7: Implications of Findings
- Section 8: Questions Raised by Findings
- Section 9: Conclusions and Recommendations
- Section 10: Bibliography
3. **Methodology**

The assessment took an eclectic approach and consisted of the following components:

- A literature review
- Collection of informal field input and anecdotal evidence
- Field work
- A qualitative assessment
- Data analysis
- Project feedback and comments
- Development of implications and recommendations based on findings

The start point for the assessment was observed and anecdotal evidence of aging in landmines from global survey and clearance operations. The research team documented anecdotal evidence (covered in detail separately). All anecdotal observations are informal and not scientifically proven. Anecdotal evidence was obtained through discussions with clearance and field personnel based on their professional or personal experiences.

This evidence prompted the two major components of the program: a literature review and field work to examine live mines. The literature review (see section 4, page 10) involved a broad search to uncover any relevant documentation from research establishments, commercial organizations, and the military related to landmines and aging. The literature review examined both academic and non-refereed sources, and included search terms related to mines, ordnance, degradation and environments.

The program team was aware that very little literature on the aging of mines was readily accessible, this being one of the primary reasons for the study. The formal literature review supported this observation. The primary source of information, therefore, was the field work to examine live mines.

3.1. **Selection of location**

The location for the field work needed to be a mine-affected region representative of the hot, wet environments typifying the majority of the world’s minefields. The location also had to satisfy a number of other requirements, including:

- Accessibility and permissive working environment
- Adequate security (no ongoing conflict)
- The presence of cooperative demining organizations (ideally more than one)
- Availability of suitable target mines, showing aging effects
- Access to a facility suitable for the breakdown of live mines

It was decided that Cambodia fulfilled all of these requirements, with the additional advantage that the major organizations involved in mine action there had pledged support to the study. One disadvantage of Cambodia was that mines were laid over a period of 30 years, making it impossible to confirm how long individual samples had been in the ground.

3.2. **Selection of facility**

The major mine-action organizations, such as HALO Trust, MAG, CMAC and Norwegian People’s Aid (NPA), do not have facilities for the breakdown of ammunition. However, Golden West Humanitarian Foundation has been operating an “explosive harvesting” plant for several years, offering the following advantages:

- Purposefully built explosives-storage and handling facility
- Licensed by regional authorities
- Specialist equipment for ammunition disassembly
- Staff familiar with ammunition
3.3. **Selection of target mines**

The study chose to focus on AP mines rather than anti-tank (AT) types. AT mines are larger and heavier than AP mines, with substantially larger explosive charges; however, the fuzing mechanisms are broadly similar, as are most of the materials used. The study, therefore, concluded that AP mines would provide the necessary insights, without the additional risks and logistical effort required AT mines.

Ten types of AP mines were selected, primarily on the basis of availability, and comprised both pressure-operated blast and bounding fragmentation categories. Of the former, four types were examined in greater detail, since three of these (the Russian PMN, PMN-2 and Chinese Type 72) are common in other mine-affected regions and the fourth (MD-82B) has characteristics of particular relevance.\(^1\) One further mine, the electronically fuzed Chinese Type 72B, was examined because of its special significance.\(^2\)

The selected mines incorporated many of the same casing, fuzing and explosive materials found in other common mine types. Many of the findings regarding the deterioration of these materials should indicate the likely effects on similar components under comparable conditions elsewhere.

3.4. **Procedures**

The testing site was properly constructed for explosive handling, well-administered and run according to strict safety rules. All participants received a safety briefing and were signed into the site, where medics were in attendance throughout the process. Attention to detail was high; for example, work was stopped if there was an imminent danger of thunderstorms.

Mines selected for examination were photographed and their external appearance (including any visible markings) recorded. After safety checks to confirm the absence of detonators or other means of initiation, mines were disassembled to reveal the internal structures and components. Where possible, dismantling was done by reversing the manufacturing sequence. For those mines being examined in detail, a written matrix was composed to note the condition of each major component.

In addition to recording individual effects, procedural trends were followed to establish consistency between samples. For example, where a certain type of deterioration was noticed on a given component, that component would be examined in other mines for traces of the same effect. For each mine examined, an assessment was made of its viability (ability to function as designed).

In the case of the Chinese Type 72, where the primary initiator could be safely separated from any other explosive charge, the fuze was deliberately actuated under controlled conditions to see whether the initiator would be set off. When each initiator failed to function, a heavier striker was used to test the viability of the explosive composition.

Throughout the examination procedures, photographs were taken as necessary to illustrate, compare or contrast particular characteristics. A number of inert material samples were gathered for recovery (possibly for laboratory analysis in a follow-on phase).

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\(^1\) MD-82B has a plastic casing and an internal fuze mechanism made from mild steel.

\(^2\) This mine is designed to act like a booby trap, initiating when tilted. There was, therefore, special interest in its condition, particularly the viability of the batteries.
At the end of each procedure, all energetic material was accounted for and transported to appropriate storage for safe disposal during subsequent demolitions.

3.5. Analysis

The observations from the field examination were analyzed in order to identify implications for various aspects of mine action. Effects were considered under each of the following headings:

- Prioritization
- Field operations
- Detection
- Mine Risk Education (MRE)

Prioritization refers to issues affecting the allocation of resources to potential clearance tasks. For example, if an area is known to contain mines that have deteriorated to the point at which they are non-functional, then (all other factors being equal) that area should be allocated a lower priority than one containing functional mines.

Field operations cover all matters relating to the selection of clearance equipment and techniques; this applies equally to humanitarian demining and military operations such as peacemaking, force protection, counterinsurgency or warfare. An example of an implication for field operations would be awareness of effects that may lead to a short-term increase in fuze sensitivity; others include the potential life-span of tripwires or of batteries in an electronic fuze.

Detection issues are those related to the processes by which mines will be located, including manual, mechanical and electronic techniques. The most obvious example of an implication for detection is one in which the metallic content of a minimum-metal mine is further reduced by corrosion—potentially to the point at which it cannot be located using a metal detector.

MRE covers all matters relevant to awareness training, whether this training is for affected communities, deminers or military personnel. There is a clear implication for MRE, for example, when the appearance of a mine in the field is radically different from the way it is portrayed during training.

3.6. The feedback loop

A key part of the methodology was the ability to identify issues that required further investigation. Many of the effects observed certainly appeared to be significant but lacked the context needed to understand them. This generated additional questions that will require follow-on work to answer.

For example, a typical observation might be that a rubber cover on a mine had hardened and split, leading to corrosion of metallic components, degeneration of the explosive filling and eventual failure of the fuzing mechanism. Analysis establishes the implications for the various components of mine action, but the observation also raises a number of questions, such as:

- What was the original composition of the rubber?
- How has the composition changed as it deteriorates?
- What factors have caused deterioration?
- How consistent or predictable is this effect?
- How long did it take to deteriorate?

Subsequent phases of the aging study must try to address these questions in order to understand and quantify the effects. Unless the characteristics of the effects are understood, the confidence level in the findings will be low and extrapolation unwise.
4. Literature Review

The study team conducted a literature review and found that there is virtually no refereed literature pertaining directly to landmines and aging.

Despite the lack of scientific evidence, there are expert opinions, field observations and examples of anecdotal evidence that support the hypothesis that time and environment can affect landmines in a variety of ways. In an article published in the 11.2 edition of The Journal of Mine Action (2008), EOD consultant Colin King provided examples of landmines deteriorating in certain environments or climates through rusting, disintegrating tripwires, rotting wooden casings and cracking plastic.

While degradation undoubtedly causes some mines to become more hazardous, King and others point to other cases in which it appears landmines may actually become safer or completely non-functional over time in certain environments.

A large quantity of indirectly related research is available, pertaining to the effects of aging and environment on the specific materials of which landmines may be made. Our review of this secondary literature was not exhaustive, largely because the exact composition of landmine materials is not known. Therefore, specific correlations between materials in mines and those researched in other studies for engineering, chemistry and related fields could not be confirmed. This gap points out the critical need for characterization of mine and ordnance materials, because there are scientific studies related to aspects of aging and environmental impacts on specific materials. Short reviews of sample literature for a variety of materials follow.

4.1. Metal and Alloys

Metal is a critical component to the functioning of many landmines and munitions but is at risk of corrosion due to these major factors as noted by Romanoff (1957): aeration of soil, electrolyte composition of soil, electrical differences within the munition, or miscellaneous factors such as soil bacteria. Ostazeski and Saubier (2002), in an attempt to better understand the corrosion of buried mines, noted that to determine corrosion rates, it was necessary to know how long mines had been in the ground, mine design specifications and certain soil properties.

There is literature available on degradation and effects of environment for specific types of metals. For example, Kubota (2005) used supercomputers to determine the effects of age on aluminum, measuring the relationships between age and density, temperature, pressure and dynamic strength. Madsen and Ghonem (1996) studied the effects of environment and age on Titanium alloy 1100 (Ti-1100), observing that aging and temperature affect the tensile and ductile strength of the alloy. Shimojo and Bowen (1998) found environment played an important role in cross-ply fiber degradation with regards to crack resistance and crack growth. An in-depth review was not implemented during this phase of the study, but future work could utilize the research on aging and the types of metals found in mines.

4.2. Plastics

There are a number of studies to understand types of plastics in relation to aging and environment. For example, early research by Kimball (1961) studied the effect of aging on the strength properties of 11 types of different plastic laminate, finding that while the plastics’ strength declined insignificantly when stored for nine years in a normal atmosphere, when these 11 laminates were exposed outdoors for three years, there was a marked effect on their strength properties. Research by the Pain Research Association (1989) observed and detailed the degradation processes of types of plastic pipes in relation to the effects of sunlight, chemicals, stress corrosion, and water.
Nowak (1985) observed the physical state and fatigue limit of certain plastics with specific properties are both positively and negatively impacted by time, heat, and contact with water and oil. Pavlov, et al. (1991) conducted a variety of tests on specimens of thermoplastics by subjecting them to tensile stress while external conditions such as temperature changes, moisture, light and varying cyclic loads were applied, finding that such stimuli led to loss of elongation and decreased gel fractions and mol masses. Tolinski (2008) studied the effects of light, air and microbes on plastics, identifying in the process modern resins that better resist aging effects. While none of the studies look specifically at landmine plastics, they can indicate potential ways forward for research and tests related to plastic degradation found within landmines.

4.3. Rubber

Rubber is a significant component of some landmines. While no specific literature was found that studied aging of rubber in landmines, other literature on rubber material exists. For example, Akhtar, et al. (1985) observed that in certain conditions high rubber blend indicates extremely poor acid and hot air aging resistance.

4.4. Explosive compound

Degradation and environmental effects on explosives have also been researched in a variety of capacities. An overview encompassing a series of reports on nitro-explosives degradation, future outlook and studies done by Agharkan Research Institute in India was compiled by Kanekar, et al. (2003). Hawari, et al. (2005) provide data on TNT biodegradation and possible effects of mineralization on explosives, while Juhasz and Naidu (2007) have studied how explosive compounds TNT, RDX, and HMX decompose over time as a result of heat and gas, potentially undergoing a transformation. Research by Bocksteiner and Whelen (1995) studied the effects of aging on a specific explosive (PBXW-115) used in mine detonation. They found that when exposed to aging conditions, the PBX encountered mass loss, hardness increases and an alteration of tensile properties; the link between these changes seems to be the plasticizer content of the samples.

Much of this research may have possible implications for landmine detection and research and development tasks. For example, Oxley, et al. (2003) conducted experiments in which post-blast TNT and explosive-related compound residue from landmines were left to degrade over time in soil. The post-blast residue was then observed in relation to the effects on chemical detection including comparison of landmine leakage with post-blast residue, to determine how much toxicity is released and how that changes over time.

Data about the impact of explosives on soil has also been studied by such scientists as Conder, et al. (2004), who examined toxicity in soil and studied sediments spiked with three different levels of TNT concentrations to look at the rate of disappearance, concluding that lethal toxicity decreased over time.

4.5. Chemical composition/signatures

More mine-specific research is found for studies on the chemical signatures of mines. For example, Florian Algarin (2005) identified the chemical composition of select mines and conducted research to determine the effect of environmental parameters like temperature, water content, relative humidity, and light radiation on the fate and transport of the signature compounds. The author observed water composition and temperature were the most important variables in TNT degradation. Webb and Phelan (2002) similarly observed that environmental processes play a significant role in the chemical signature available for detection. A host of additional studies related to this topic exist but were not included in this review for the purposes of this project.
5. **Anecdotal Evidence**

The authors are aware of a good deal of anecdotal evidence regarding the aging of mines. Assertions and observations of aging effects from credible sources were an important factor in the decision to propose a study.

The first anecdotal evidence to link the aging process to a significant change in characteristics occurred soon after the first Gulf War. During the post-war clearance of minefields in Kuwait, there were a number of fatalities attributed to the Czech PT Mi-Ba-III AT mine. These deaths may have been due to the deterioration of a brittle plastic collar used to retain the spring-loaded striker within the fuze. The result appears to be that the fuze became extremely sensitive to movement, although this theory was never officially confirmed.

There has also been a significant amount of discussion about the Yugoslav PROM-1 AP bounding mine, which has been responsible for a large number of deminer casualties in the Balkans. Some claim that the PROM-1 fuze has become more sensitive, though to date no one has yet suggested a credible reason. Unlike the PT Mi Ba-III, the fuze of the PROM-1 shows no obvious mechanism for deterioration that would explain a substantial change in sensitivity. The range and lethality of the mine means that there are no first-hand witnesses, and there appears to have been no detailed technical investigation to establish the unusual function or condition of the fuze.

Anecdotes regarding the sensitivity of the Czech PT Mi Ba-III and PROM-1 mines tend to reinforce the widespread assumption that deterioration generally makes ammunition more “unpredictable” or “unstable.” This characterization tends to be interpreted by most deminers and EOD operators as meaning “more dangerous”; however, the generalized perception that ammunition becomes more dangerous with age is contradicted by most other anecdotal evidence regarding landmines.

During military operations in the Balkans, there were many accounts of AT mines that had failed to explode when run over by armored vehicles. There are accounts from civilians in many other mined regions who have discovered unexploded mines, having trodden on them, and from deminers who have found mines that had been actuated but failed to detonate.

The validity of these accounts has been reinforced by the findings of this study; for example, several of the Type 72 AP mines examined in Cambodia showed that the fuze mechanism had been actuated without initiating the explosive charge.

Perhaps the most significant anecdotal evidence surrounds the condition of tripwires in tropical climates. Approximately two years ago, The HALO Trust program manager in Cambodia pointed out that his deminers had not seen any evidence of tripwires for several years. In subsequent discussions, HALO managers agreed that it was highly unlikely that any iron or steel tripwires could have survived for decades in the Cambodian environment.

In an important policy shift, HALO’s clearance drills in Cambodia were relaxed to allow rapid vegetation clearance (using brush cutters, for example) that would have been unacceptable if there were any likelihood of encountering a tripwire. The adoption of new procedures has reportedly increased demining productivity substantially. The degree of rusting seen on exposed ferrous metals during this study entirely supports HALO’s assertion.

In summary, deterioration has been blamed for mines becoming more dangerous in two instances, one of which appears to be credible. The majority of recent anecdotal evidence

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3 Within the era of modern “humanitarian demining”; there are thought to be numerous anecdotes from World War II mine clearance, but these are largely irrelevant to current operations.

4 Including on the “IGEOD” internet EOD and demining forum.

5 Most notably by the Canadian army, which reported several incidents involving Yugoslav TMA-3 and TMA-4 AT mines that had failed to function.
points to aging mines failing to function, suggesting that—in most cases and contrary to popular belief—the aging process has resulted in mines becoming less likely to function.

The majority of available anecdotal evidence on the aging of mines relates to mines becoming non-functional, rather than more dangerous. However, there is still widespread suspicion that aging tends to make mines more sensitive, unpredictable or dangerous. Natural caution within the mine action community means that this view continues to prevail in many quarters.
6. Findings

6.1. General

Only anti-personnel mines were examined for this study, as these were more readily available, easier to handle and provided more variety than anti-tank mines. The mines were recovered from northwest Cambodia and originated from either HALO Trust demining operations or from a Royal Cambodian Armed Forces (RCAF) stockpile in Battambang, Cambodia. Collections of mines from which the examples were selected are shown in Images 001 and 002 below.

Image 001: PMN mines

Image 002: PMN-2 mines

The following types of live mines were dismantled and examined in detail during the visit to Cambodia:

- MD-82B (Vietnam)
- Type 72 (China)
- PMN (Russia)
- PMN-2 (Russia)

Samples of other types of anti-personnel mines that were dismantled included:

- M14 (USA)
- MN-79 (Vietnam)
- M16A1 (USA)
- OZM-3 (Russia)
- OZM-4 (Russia)
- OZM-72 (Russia)
- Type 72B (China)

The status of tripwires was also considered.
6.2. MD-82B

**Number.** Three MD-82B mines were disassembled, and another was examined externally.

**Markings.** None of these mines had visible markings.

**Age.** The ages were unknown but were probably manufactured in the mid-1980s.

**Origin.** The mines appear to have been recovered from the field.

**Casings.** Two of the plastic casings were split—apparently through mechanical damage (see Image 003, below left). One of these had also been partially melted by fire, with the pressure plate (apparently made from a thermoplastic\(^6\) polythene) sagging over the mine body; this state prevented downwards movement, so the melting would have rendered the mine incapable of functioning. The third was largely intact, although the poor quality of manufacture had permitted the ingress of water. In all cases, the plastic still retained some flexibility, as did the rubber seals.

**Fuzes.** The spring-loaded mechanism of the mine with the best casing was badly rusted and could not have functioned, as shown in Image 004, below right. The mechanism of the burned mine was seized with silt and could not be made to function. The remaining mine appeared to be functional.

**Explosive.** In all mines, the main charge and detonator appeared to be in functional condition.

**Summary.** Two of the three mines examined were incapable of functioning. Yet, despite having a damaged casing, the third mine appeared to be operational.

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\(^6\) A thermoplastic is a plastic that becomes softer or more flexible when exposed to heat.
6.3. **Type 72**

**Number.** Six Type 72 anti-personnel mines were disassembled.

**Markings.** All of the mines had visible markings.

**Age.** All mines were manufactured in the mid-1980s.

**Origin.** These mines were apparently recovered from the field.

**Casings.** All of the mines had intact plastic casings, but all of the rubber covers had deteriorated to a large degree, exposing the hard plastic pressure plate beneath (see Image 005, below left). This degradation had allowed the unrestricted ingress of water. In all mines studied, the small helical spring towards the top of the casing had rusted away.

**Fuzes.** In every case, the firing pin in the center of the Belleville spring\(^7\) had rusted, mostly blunting the point of the pin (see Image 006, below center). Two fuzes were completely corroded away, with one detached from the spring.

**Explosive.** While the main charges seemed to be functional, the detonators appeared to have deteriorated. Four of the detonators had puncture marks where the firing pin had struck but failed to cause initiation (an example can be seen in Image 007, below right). On testing the other two detonators, both failed to function with their firing pins, although the detonators were successfully initiated using a larger pin, with far greater force. Of a further two punctured detonators, only one could be made to function by using additional force. All but one of the detonators had substantially reduced power, and could not have initiated the main charge.

**Summary.** In at least two of these mines, the metal detection signature was probably below the detectable threshold; in other words, the mines could not have been located using a standard metal detector. Four of these mines had been actuated but failed to detonate; the other two did not function when tested, although they were theoretically capable of doing so. Because of the rubber deterioration, these mines were barely recognizable compared to the one in original condition.

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\(^7\) A Belleville spring is a dished diaphragm of metal or composite that inverts sharply under pressure.
6.4. PMN

**Number.** Seven PMN mines were disassembled.

**Markings.** Very few markings were visible on these mines.

**Age.** The ages were unknown, but appeared to fall into two age categories, probably the 1960s and 1970s, with different strikers.

**Origin.** Some of the mines apparently came from storage, but some were possibly used and recovered before that; one was recovered from the field by HALO Trust.

**Casings.** The Bakelite\(^8\) casings and plugs were in generally good condition, but most of the rubber covers had deteriorated badly. Many had cracked, allowing water into the mine; see Image 008, below left. In three of the mines, the steel band securing the rubber cover to the mine body had rusted through in at least one place; an example is shown in Image 009, below center.

**Fuzes.** Two types of striker were noted, one made from steel and the other from alloy. Surprisingly, the coil springs around the steel striker were generally in good condition, while those around the alloy strikers were badly rusted, collapsed and broken (see Image 010, below right). Where water had washed silt into the mine body, some of the strikers were seized into their channels and could only be moved using substantial force. Some of the springs below the actuating plunger were also corroded.

**Explosive.** While some of the explosives appeared to have deteriorated, the main charges and detonators appeared to be functional.

**Summary.** Three of the mines had broken or missing bands, which has been shown to substantially reduce the detection signature of the mine. The complete deterioration of the springs used with alloy strikers would prevent those mines from functioning, although the proportion of PMNs incorporating alloy strikers is not known. Those in which the strikers had seized would also be incapable of functioning. Among mines with viable fuze mechanisms, it is possible that deterioration of the plunger springs could result in a lower operating pressure.

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\(^8\) Bakelite is a hard, thermosetting phenolic plastic (cured by heat), made with wood filler, which does not lose its integrity when hot.
6.5. PMN-2

**Number.** Five PMN-2 mines were disassembled, and another was examined externally for comparison.

**Markings.** Most of these mines had clear markings, showing their date and place of manufacture.

**Age.** These mines were manufactured between 1984 and 1987.

**Origin.** These mines are believed to have been recovered from the field (other than the comparison mine, which was unarmed).

**Casings.** Only one of the five casings was in good condition, the remainder being broken, cracked or warped. In every instance (including the undamaged mine), water had entered the casing, causing the deterioration of internal metallic components and, in some cases, the deposition of silt. The casing of one mine had been penetrated by plant roots, which had caused cracking and partial separation of the pressure plate; this result is shown in images 011 and 012 below). The upper surface of one mine was burned such that the pressure actuation mechanism appeared to be inoperative (see Image 013, at left on page 19). The rubber pressure pads and fabric retaining loops on the pressure plate were burned away, while the thermoplastic casing had melted and affected other components.

**Fuzes.** In each of the mines disassembled, the striker was seized. Other components, such as springs and assembly screws, were corroded to varying degrees. In one mine, the slide containing the detonator was also seized.

**Explosive.** Although apparently deteriorated, the main charges and detonators appeared to be in functional condition.

**Summary.** None of the mines examined were capable of functioning (due to the seized strikers). Some mines had multiple defects that would have prevented them from operating. Image 014 (at right on page 19) shows an example in which corrosion had caused the striker to seize and its spring to collapse.

*Image 011:* Roots had grown into this PMN-2 mine, causing the upper surface to split.  
*Image 012:* Disassembly shows how the roots had spread beneath the pressure plate.
6.6. Other Mines

6.6.1. M14

Two US M14 anti-personnel mines were disassembled. Although the casings were intact, water had entered and caused corrosion of the firing pins. In each mine, the steel firing pin was almost rusted away. Considering also the silt that had built up in the void between the Belleville spring and the explosive charge, it is most unlikely that either mine could have operated.

6.6.2. MN-79

This Vietnamese copy of the American M14 was recovered from the field by HALO Trust. Despite damage to the casing, apparently caused by burning, the fuze mechanism and explosive components were in good condition and appeared to be fully functional. It may be that this mine was laid more recently than other examples, but it is also possible that MN-79 is particularly resilient. The mine components are shown in Image 015 below.
6.6.3. **M16**

Two examples of the American M16 bounding mine were examined. Both were so badly corroded (with the outer casing missing completely) that they could only be identified by internal features—see Image 016, below left. The absence of the outer casing and propellant charge means that these mines were incapable of operating. They were then cut in half using remotely-operated band saws, further confirming their deterioration and inability to function. A section of one of the mines is shown in Image 017, below right.

![Image 016: M16 mines were unrecognizable once their outer casings had rusted away.](Image 016)

![Image 017: A section cut through an M16 mine shows further internal deterioration.](Image 017)

6.6.4. **OZM-3, OZM-4 and OZM-72**

In contrast to the M16, these Russian bounding mines (shown in Images 018, 019 and 020 below) were recovered from storage and were in exceptionally good condition. Disassembly showed the hermetically sealed casings had protected the internal components, which were pristine and fully functional. However, the external fuzes used for initiation were not present. It is likely that, once laid in the field, these fuzes would deteriorate faster than the mine bodies.

![Images 018, 019 and 020: Russian OZM-3, OZM-4 and OZM-72 bounding mines were in good condition, both externally and internally.](Images 018, 019 and 020)
6.6.5. Type 72B

The Type 72B is an electronic anti-disturbance/anti-handling variant of the Type 72. Although externally identical once armed, this mine contains a circuit board, tilt switch and two lithium batteries in place of the mechanical fuze of the conventional Type 72 (see Image 021 below). In both cases, the battery voltage was tested: the two batteries provide 6 volts when new. The first mine showed a voltage of 0.1 and the second 0.26, which would not be adequate for firing. The electrical firing squibs/igniters had more or less disintegrated due to water and were also non-functional.

![Batteries](Image 021: The lithium batteries in the Type 72B had a small residual voltage, but not enough to fire. The igniter was also non-functional.)

6.7. Tripwires

Demining NGOs, such as The HALO Trust, report that they have not encountered tripwires for several years during demining operations in Cambodia. The study team was unable to validate this information, but there is no reason to doubt it.

Most tripwire is made from mild steel and, given the degree of corrosion observed on exposed steel surfaces (such as the bands on PMN mines), it is virtually inconceivable that a complete tripwire of the same age, several meters in length, could have survived intact.
7. Implications of Findings

7.1. General

The findings of the initial aging study appear to have implications for several areas of mine action; these can be broken down into the following categories:

- Prioritization: affecting the allocation of resources to potential clearance tasks
- Field operations: relating to the selection of clearance equipment and technique
- Detection: specific to the processes by which mines will be located
- Mine Risk Education: relevant to the conduct of awareness training

7.2. Prioritization

Of the six Type 72 AP mines examined, none were functional. The PMN-2s, M14s and M16s examined were also found to be inoperative. If further work were to confirm that certain types of mine were consistently liable to failure, this might be an important factor in prioritization.

All other factors being equal, clearance of an area known to contain operational mines should be given higher priority than one containing mines that are unlikely to function. An example would be a wet area known to contain M16 bounding mines compared to a similar area known to contain Russian OZMs. Initial findings from the study indicate that the M16 now poses little risk to people, whereas the OZMs may still be lethal. Similarly, an area where mines have been exposed to elements known to cause deterioration should be a lower priority than one where the mines have been protected.

Further work may establish that—under certain conditions—some types of mine will inevitably become non-functional within a given time frame. If so, this raises the possibility that some minefields might be left to “self-neutralize” before applying a cost-effective clearance solution and appropriate quality assurance process.

7.3. Field operations

Field operators should be aware of the implications of aging mines. Some may prove to be major factors in a threat assessment or evaluation of clearance procedures; others are not concrete enough to justify a major departure from existing procedures but should at least be considered.

Examples include the knowledge that tripwires are unlikely to exist and that batteries in the Type 72B are now virtually discharged. Eliminating the threat from tripwires and anti-disturbance devices substantially decreases the threat to manual deminers during vegetation clearance; in this case, the knowledge has allowed the use of motorized weed cutters (“strimmers”), which have enabled far greater productivity.

Deminers should be aware that certain mines are likely to become inoperative when exposed to surface fires while others may be relatively unaffected, but that (so far) there is little evidence to suggest that mines can be sensitized by fire.

They should understand the possibility that mines may become more sensitive (operate at a lower pressure threshold) when springs become weaker. The recognition of mines that have aged is also critical to the training of deminers (see Mine Risk Education on page 23).

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9 Two mines appeared to be technically capable of operating but failed to function when actuated.
10 The HALO Trust made this assumption approximately two years ago and changed its clearance procedures accordingly to accommodate the use of strimmers.
11 The study indicates that MD-82B and PMN-2, which are made from thermoplastics, are likely to be desensitized by surface fires.
12 For instance, the plunger springs in the PMN and PMN-2 become weaker in this way.
7.4. Detection

The study indicates that certain minimum-metal mines, such as the M14 and the Type 72, may become “undetectable” to metal detectors. This shift is due to the small ferrous components rusting away and losing their ability to respond to electromagnetic induction. Clearly, this information is vital for clearance agencies that rely on metal detection.

The significant reduction in signature resulting from a rusted band on a PMN is also important, since experienced operators learn to identify particular types of mines within their working areas. Not only is there a risk of confusion when a mine responds differently, but the depth at which the PMN can be detected is also likely to change. This effect, in turn, has implications for both the clearance procedure and the certification of the task.13

The changes in detection signature have clear implications for the development of new equipment, which should be designed for, and tested on, mines as they are now (not as they were when new).

Some aging effects, such as the breakdown of casings (which may lead to leakage of explosive compounds) and the decomposition of those compounds, may be relevant to research into alternative detection techniques. For example, chemical detection of a particular mine—not possible when the casing was intact and not needed when the metal content was adequate—might be appropriate if those properties have changed.

7.5. Mine Risk Education (MRE)

The most obvious implication for MRE is that many mines look completely different once they have aged. MRE programs routinely show their audiences pictures or models of new mines, some of which may be completely unrecognizable in their current form. Images 022 and 023 below, which show mines “before and after,” illustrate this point.

Image 022: The aged PMN mine looks significantly different from when it was new.

Image 023: Once the color has faded and the rubber cover perished, the Type 72 is virtually unrecognizable.

The rotting of wood not only alters the appearance of wooden-cased mines but also leads to the collapse of fragmentation stake mines. This means the steel bodies, normally pictured mounted above ground on their wooden stakes, will actually be found lying on the surface, looking more like a discarded grenade. This situation is likely to occur with any stake mine more than a few years old, and means that virtually all MRE and deminer training in this area gives a misleading impression.

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13 Clearance certification is normally given to a certain depth, based on the known capabilities of detection.
8. Questions Raised by Findings

The findings from this study are based largely on observational “qualitative” analysis and raise many questions that would need to be addressed in follow-on work. General questions include:

- What were the original compositions of the mine components?
- How do the compositions change as they deteriorate?
- What factors have caused deterioration?
- How localized can these factors be?
- How does deterioration lead to the inability of a mine to function?
- Are the effects relevant to similar materials in different mines?
- How do the environmental factors differ in other regions?
- To what extent can the effects be quantified or predicted?
- Can the effects be influenced (to accelerate failure, for example)?

There are also a number of important specific technical questions, such as:

- What is the predicted lifespan of a tripwire in a given environment?
- Why have springs on alloy strikers deteriorated faster than on steel?
- Can rusted springs lead to lower operating pressures?
- Can a mine that has lost its detection signature still function?
- How does decomposition affect explosives in detonators/initiators?
- What battery voltage is needed for an electronic fuze to remain functional?

Answering many of these questions would require specialist expertise and facilities for detailed “quantitative” analysis.
9. Conclusions and Recommendations

9.1. Conclusions

The study confirms that aging has significant effects on mines and that there are crucial implications for many aspects of mine action.

It reveals that MRE, long known to be the most cost-effective method of reducing casualties in the short term, can be seriously flawed if it portrays unrepresentative models or images of mines. The ability of deminers to recognize and identify mines may also be affected.

In the field, aging effects have serious implications for mine clearance procedures. In some cases, a reduction in threat may permit more efficient ground-preparation techniques; meanwhile, detection may become more difficult and demand new approaches.

In addition to humanitarian demining, many of the field implications have special relevance for military operations. Some aging mines may become harder to detect yet potentially more vulnerable to countermeasures. Meanwhile, mines used by hostile groups may have a higher failure rate than is currently realized but could be rendered operational again by their users with simple modifications or improvisation.

Perhaps of greatest strategic importance are the implications for task prioritization. Consideration of aging effects should be an important component in the assessment of tasks, yet this element appears to be absent from the current assessment protocol.

The aging factor is vital because, in some cases, it may highlight a massive difference in lethality between areas competing for clearance resources. It may be possible to leave low-value land to “self-neutralize,” or to delay clearance in the knowledge that the mines pose little threat. When the area is eventually returned to productivity, a faster, cheaper form of mechanically assisted clearance could be used.

The extent of the findings from this limited study suggest that further work, to quantify the effects observed and to validate the findings, would be valuable. Such work would probably require the support of specialists (in disciplines such as chemistry, geology and physics) and the use of laboratory facilities.

9.2. Recommendations

It is recommended that the study of the effects of aging on mines be continued in order to:

- Analyze the characteristics of key materials used in mines
- Research the causes of deterioration within these materials
- Examine the failure mechanisms within affected mines
- Broaden the range of mines within the study
- Broaden the regional and/or environmental scope of the study
- Investigate, where possible, anecdotal evidence of aging
- Analyze findings to establish the implications for:
  - Program funding
  - Military operations
  - Mine risk education
  - Field procedures
  - Equipment development

It is further recommended that effective means are found to disseminate the findings of the study and update the humanitarian mine action community on progress. In addition to the publication of reports, these means might include briefings at conferences and a dedicated portal on the Mine Action Information Center website.
10. Bibliography


Florian Algarin, V.M. *Effects of Environmental Parameters on the Chemical Signature of Landmines.* University of Puerto Rico: Mayaguez Campus, 2005.


