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MINERALOGY OF SELECTED WORLD SOIL SAMPLES, WITH IMPLICATIONS REGARDING THE ABRASION/CORROSION POTENTIAL OF ENVIRONMENTAL DUST ON MILITARY ORDNANCE AND A HYPOTHESIS FOR THE SOUTHEAST ASIA PROBLEM

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Monterey, California

March 1973

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Mineralogy of Selected World Soil Samples, with Implications Regarding the Abrasion/Corrosion Potential of Environmental Dust on Military Ordnance and a Hypothesis for the Southeast Asia Problem

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; March 1973

5. AUTHOR(S) (First name, middle initial, last name)

Edwin Willis Shaar, Jr.

6. REPORT DATE March 1973	7a. TOTAL NO. OF PAGES ~~66~~ 65	7b. NO. OF REFS 27

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

Fifty-four representative soil samples from all over the world were selected for heavy mineral analysis from those provided by the Naval Weapons Center, China Lake, California.

Data thus obtained, in conjunction with mineralogical, chemical, and abrasion investigation data from the literature, is presented in support of a discussion of the relationship between the mineralogical and chemical content to abrasion/corrosion potential of environmental dust.

Crushed quartz is the most representative material for dust abrasion testing, but not for total dust damage potential prediction. It is quartz (not laterite), together with the phenomena of "Differential Aeration Cell" corrosion/erosion-corrosion and possible thermochemical contributions, that is believed to be responsible for the extensive damage to military ordnance due to dust contamination experienced in Southeast Asia.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
soil mineralogy						
damage potential of soil						
world-wide soil dust damage potential						
soil dust damage potential						
soil dust abrasion potential						
soil dust induced corrosion potential						
dust erosion problem in Vietnam						
dust erosion problem in Southeast Asia						

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by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL

March 1973

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Milton U. Clauser
Academic Dean

To my wife, Linda, and children, Trey, Betsy, and Tony, whose faithful encouragement and undying patience, understanding, and love made this work possible.

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ACKNOWLEDGEMENTS

To the numerous people who have contributed generously of their valuable knowledge, experience, and time, I express my sincere appreciation.

I am especially grateful to my advisor, Dr. Robert S. Andrews, who has been a constant source of stimulation and guidance along the long, sometimes arduous, but richly rewarding road of scientific endeavor.

Special recognition is also due Dr. C. F. Rowell and Dr. J. R. Clark, whom I have plagued with what no doubt seemed like an endless shower of questions.

My thanks go also to Miss Lyke and the Naval Postgraduate School Library Staff for their invaluable assistance.

Finally, I would like to thank my parents and Parker Small, my chemistry teacher at Massapequa High School, Massapequa, L. I., New York, for the motivational and inspirational endowment that ultimately paved the way toward this achievement.

Funding for this project and soil samples were made available by the Naval Weapons Center, China Lake, California.

I. INTRODUCTION

A. GENERAL

During the last decade, overhaul and replacement costs of both military and commercial machinery due to dust erosion (a form of mechanical abrasion caused by solid air-borne particles), possibly accelerated by dust induced corrosion, have been extreme. The service life of helicopter gas turbine engines has been reduced in some cases to 10% of the norm during dusty terrain operation. As a result of military operations in Southeast Asia alone, such costs are well over $100,000,000.00 a year [Smeltzer, et al., 1970].

This failure of machinery to withstand the severe environments of some operational areas after having survived current test specifications is sufficient indication that a more thorough knowledge of the actual sand and dirt environments and of dust abrasion/corrosion phenomena is essential to the development of representative test criteria and adequate methods of minimizing the problem.

Consequently, the Naval Weapons Center, China Lake, California, launched a world-wide soil collection and analysis program in 1966 in an effort to acquire an accurate understanding of the Earth's soils (a soil being the complex residue of the physical, chemical, and biological weathering of rocks as a function of rock type, climate, topography, biologics, and time) [Kuletz and Schafer, 1971].

B. PURPOSE AND SCOPE

Although it is generally accepted that quartz is the most common mineral found in the epipedons (surface horizons) of world soils, concentration of heavy minerals (those with specific gravity greater than that of Bromoform, 2.85) [Table I], which contain most of the species which are harder than quartz (MOH hardness 7), does occur under dynamic conditions in nature such as on beaches and in stream beds. This process of concentration could occur in windy, dusty areas of the world, such as deserts or freshly cleared, unprepared, lateritic areas such as experienced in Southeast Asia.

In light of this consideration, the fact that mineralogical constituents of soil become prominent in the fine sand fraction [Jeffries, 1937], and that chemical analyses of soils can be misleading in regard to the mineral species actually present (considering polymorphism), the initial purpose of this study was to investigate the heavy mineralogy of the sand fraction of 54 selected world soil samples in order to augment present knowledge of environmental dust, particularly in the vicinity of military operating areas. The initial hypothesis was that anomalous surficial concentrations of heavy minerals harder than quartz (possibly corundum, with MOH hardness 9; diamond, the hardest mineral on the MOH scale, having a hardness value of 10) could possibly be the cause of this excessive dust erosion experienced in Vietnam, and also other areas could possess the same potential. The specific samples studied were selected from those sent by the Naval Weapons Center (NWC), China Lake, California, on the basis of the chemical analyses performed at NWC (e.g., those high in Al_2O_3 and Fe_2O_3 were of most interest), known dust potential of the area (deserts, Vietnam and the lateritic belt in general, etc.), and common occurrence of minerals harder than quartz, as outlined by Dana [1958].

The remaining purpose was three-fold:

TABLE I

MINERALS WITH MOH HARDNESS GREATER THAN 7

	MINERAL	FORMULA	SPECIFIC GRAVITY	MOH HARDNESS
1.	ANADALUSITE	Al_2SiO_5	3.2	7.5
2.	BERYL	$Be_3Al_2(Si_6O_{18})$	2.8	7.5-8
3.	CHRYSOBERYL	$BeAl_2O_4$	3.8	8.5
4.	CORDIERITE	$Mg_2Al_3(AlSi_5O_{18})$	2.6	7-7.5
5.	CORUNDUM*	Al_2O_3	4.0	9
6.	DIAMOND	C	3.5	10
7.	GAHNITE	$ZnAl_2O_4$	4.5	7.5-8
8.	GALAXITE	$MnAl_2O_4$	4.0	7.5-8
9.	GARNET	$(X,Y)(SiO_4)_3$	4.0	6.5-7.5
10.	SPINEL	$MgAl_2O_4$	4.0	8
11.	LAWSONITE	$CaAl_2(Si_2O_7)(OH)_2H_2O$	3.1	8
12.	PHENACITE	$Be_2(SiO_4)$	3.0	7.5-8
13.	STAUROLITE	$Fe_2Al_9O_7(SiO_4)_4(OH)$	3.7	7-7.5
14.	TOPAZ	$Al_2(SiO_4)(F,OH)_2$	3.5	8
15.	TOURMALINE	$XY_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$	3.2	7-7.5
16.	ZIRCON*	$ZrSiO_4$	4.7	7.5

* COMMON STABLE ACCESSORY MINERALS OF IGNEOUS ROCKS

1. To define the abrasion/corrosion potential of world dust;
2. To analyse the highly erosive situation encountered in Vietnam as opposed to desert regions in the United States and to establish a hypothesis as to the probable cause(s) or at least to eliminate those parameters that definitely do not contribute;
3. Finally, to address the applicability of current dust test specifications and the warranty of establishing a more pedologically representative world-wide "Standard Dirt" for such tests.

II. BACKGROUND

Mechanical abrasion has been an area of extensive interest and investigation over the past few years, most recently with regard to the dust erosion phenomenon. Holding specific variables constant (positions of vulnerable surfaces relative to the ground or dust), the abrasion process is believed to be governed by three parameters: particle and surface (target) characteristics and the environment, both contact and ambient [Compton and Steward, 1968; Finnie, 1971].

Since the extent of dust erosion is highly dependent on the nature of the abrasive dust (particle size, hardness, angularity, and concentration) [Tilly, 1969], which is variable depending upon the physiographic region of occurrence, an accurate understanding of the actual dust environment is basic to further investigation.

The literature, including available pedological sources, indicates that quartz is both the most common and most erosive mineral species occurring naturally in dust [Goodwin, Sage, and Tilly, 1970]. This is intuitively reasonable and satisfying since only 15% of the minerals exposed to weathering at the earth's surface (3% of igneous rocks) are heavy minerals and that weathering processes concentrate quartz in and leach heavy minerals out of the "A" soil horizon and concentrate heavy minerals in the "B" soil horizon [Ollier, 1969]. Thus, crushed quartz (0-150μ diameter) is the primary abrasive used to simulate natural dust for both abrasion mechanism investigation and Military Standard Test Specifications (MIL-STD-810B/510, MIL-E-5007C, etc.).

However, there are inconsistencies contained in the literature. Most references indicate that the extent of damage of all forms of abrasion is directly proportional to particle hardness and angularity, but Nathan and Jones [1966] found an unsystematic variation in this relationship and Ridgeway, Ballard, and Bailey [1933] found that when the hardness of the abrasive was very much greater than the contact surface, increase in abrasive hardness was insignificant. Some investigators [Smeltzer, et al., 1970] believe that rather than concentration, it is the total amount of abrasive ingested that is an important parameter in dust erosion.

In general, a good correlation has been observed between laboratory testing and the damage resulting from operational usage [Tilly, 1969]. However, H. Schafer [NWC, China Lake, personal communication] indicated that the extensive damage to ordnance material resulting from the dusty environment of Southeast Asia was not predicted by current military test criteria. A study conducted by Solar, a division of International Harvester, found that the so-called highly erosive, ubiquitous, red-brown, lateritic dust of Vietnam is low in quartz (less than 10% by weight) and is not only non-erosive, but the strong adhesive properties of the soil (due to the 80-90% kaolinite/hydrous sesquioxide mixture) might possibly serve as a protective coating against erosion [Smeltzer, et al., 1970].

Further, although the factors influencing corrosion (gradual physiochemical destruction of materials by the environment) [Tomashov, 1967] are well documented in the literature, its effects have been given little consideration in the present context. (In the classical sense, erosion is a physical process, the word originating from the Latin <u>erodere</u> - to gnaw out, while corrosion is a chemical/electrochemical process, coming from the Latin <u>corrodere</u> - to gnaw away). The fact of the matter is that it is sometimes extremely difficult (if not totally impossible) to differentiate between the two phenomena. Often, both types of deterioration alternate, depending on climatic conditions, or occur simultaneously, a process known as erosion-corrosion.

A great deal remains to be learned about abrasion/corrosion and associated environmental relationships.

III. METHODOLOGY

A. SAMPLE COLLECTION

Over 240 soil samples were collected by NWC with the help of personnel stationed around the world [Kuletz and Schafer, 1971]. Top priority was given to the Southeast Asia area because of the United States involvement in Vietnam and the highly erosive problem commensurate with the region. Desert soils were given high priority as well due to the associated high dust potential. In general, assuming the samples to be representative of the region from which they were taken, a good statistically random world-wide sampling was carried out, since most areas have dry periods and thus some dust potential. The sampling locations of the samples analyzed in this study are presented in Fig. 1 and Table II.

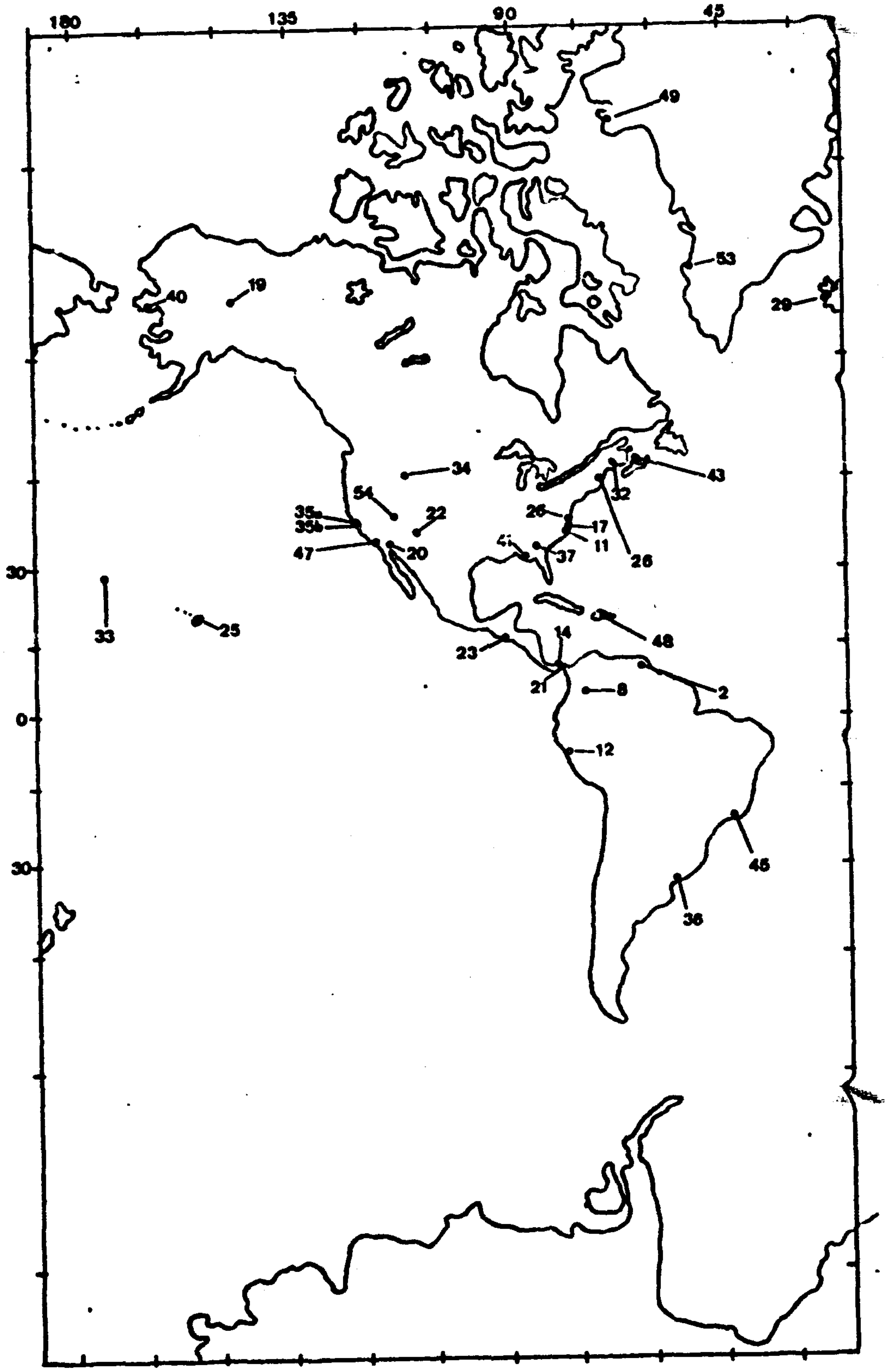


Fig. 1. Soil Sample Sites

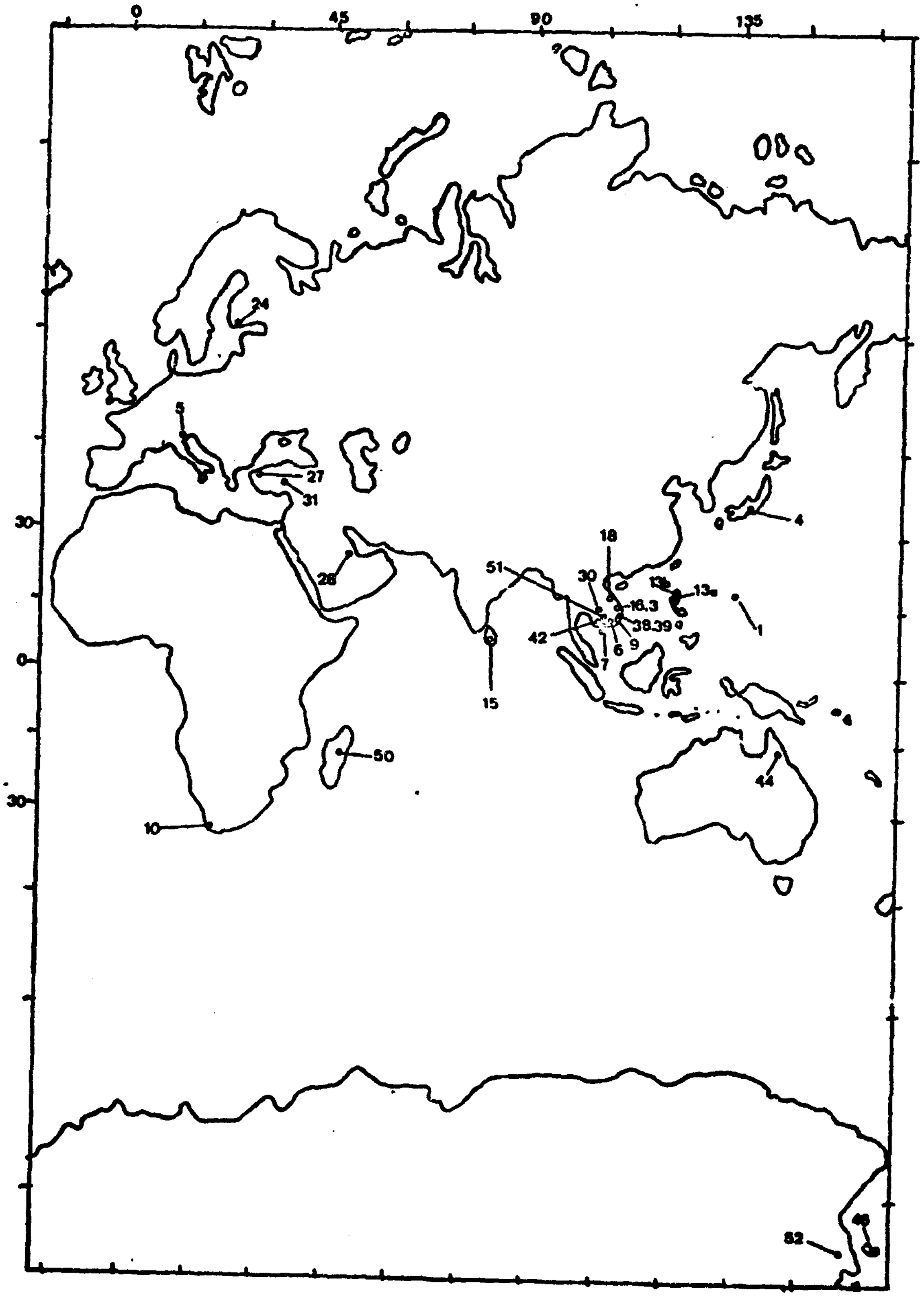


Fig. 1. (Continued)

TABLE II

SOIL SAMPLE SITES

1. Agana, Guam
2. Anaco, Venezuela
3. AT-955-805, Vietnam (V.N.)
4. Atsugi, Japan
5. Aviano, Italy
6. Bien Hoa A.B., V.N.
7. Binh Thuy, V.N.
8. Bogota, Columbia
9. Cam Rahn Bay, V.N.
10. Cape Town, S. Africa
11. Cherry Point, N.C.
12. Chimbote, Peru

13a. Clark A.F.B., Philippines

13b. Cubi Pt., Philippines

14. Coco Solo, Panama
15. Colombo, Ceylon
16. Da Nang A.B., V.N.
17. Dam Neck, Va.
18. Dong Ha, V.N.
19. Eielson A.F.B., Fairbanks, Alaska
20. El Centro, California
21. Fort Clayton, Panama
22. Four Corners, U.S.A.
23. Guatemala City, Guatemala

24. Helsinki, Finland
25. Hickam, A.F.B., Hawaii
26. Indian Head, Maryland
27. Istanbul, Turkey
28. Jidda A.F., Saudi Arabia
29. Keflavik, Iceland
30. Korat, Thailand
31. Malaya, Turkey
32. Marble Mt., Maine
33. Midway
34. Missoula, Montana
35a. Monterey, California
35b. Carmel Beach, California
36. Montevideo, Uruguay
37. N.A.S. Albany, Georgia
38. Nha Trang, V.N.
39. N. of the Khe Sanh
40. Nome, Alaska
41. Pensacola, Florida
42. Phnom Phen, Cambodia
43. Prince Edward Island, Canada
44. Queensland, Australia
45. Rio, Brazil
46. Ross Island, Antarctica
47. San Diego, California
48. Santo Domingo, D.R.
49. Sonrustrom, Greenland
50. Tananarive, Madagascar
51. Tan Son Nhut, V.N.
52. Taylor Valley, Antarctica
53. Thule A.F.B., Greenland
54. Yuma, Arizona

A quart size paint can with a polyethylene bag inner liner was used as the sample container. Personnel were instructed simply to scoop some soil into the bag, seal with the accompanying wire, secure the top of the can with the fiberglass tape provided, and send to NWC, China Lake, California [Fig. 2].

Since there was no control over the sampling technique, are the samples truly representative? Soils are heterogeneous (irregular and patchy) and it is quite possible to sample an anomalous patch vice an area characteristic of an isopedological region. It is most important that the samples be representative, not merely for accurate mineralogical data, but to determine the source (parent rocks) and, through a knowledge of drainage basins (plus geological heuristics), to extrapolate to broader geographic regions.

B. SAMPLE PREPARATION

Prior to opening in the United States, the samples were subjected to a rigorous sterilization treatment in order to eliminate any possibility of bacteriological contamination. Since 170-180°C (338-356°F) for not less than two hours is the recommended sterilization environment, the temperature within the ovens was maintained between 350-400°F and the samples were cooked overnight as a safety precaution. This dry heat treatment method was employed because it was convenient, economical, and effective [Kuletz and Schafer, 1971]. So effective, as a matter of fact, that a few of the samples exhibited what can accurately be described as hastened laterization and hardening and no longer appeared as they had in situ. Thus, upon receipt from NWC, mechanical dispersion (breaking-up of the samples) was often necessary using a mortar and pestle before proceeding with the preparation technique.

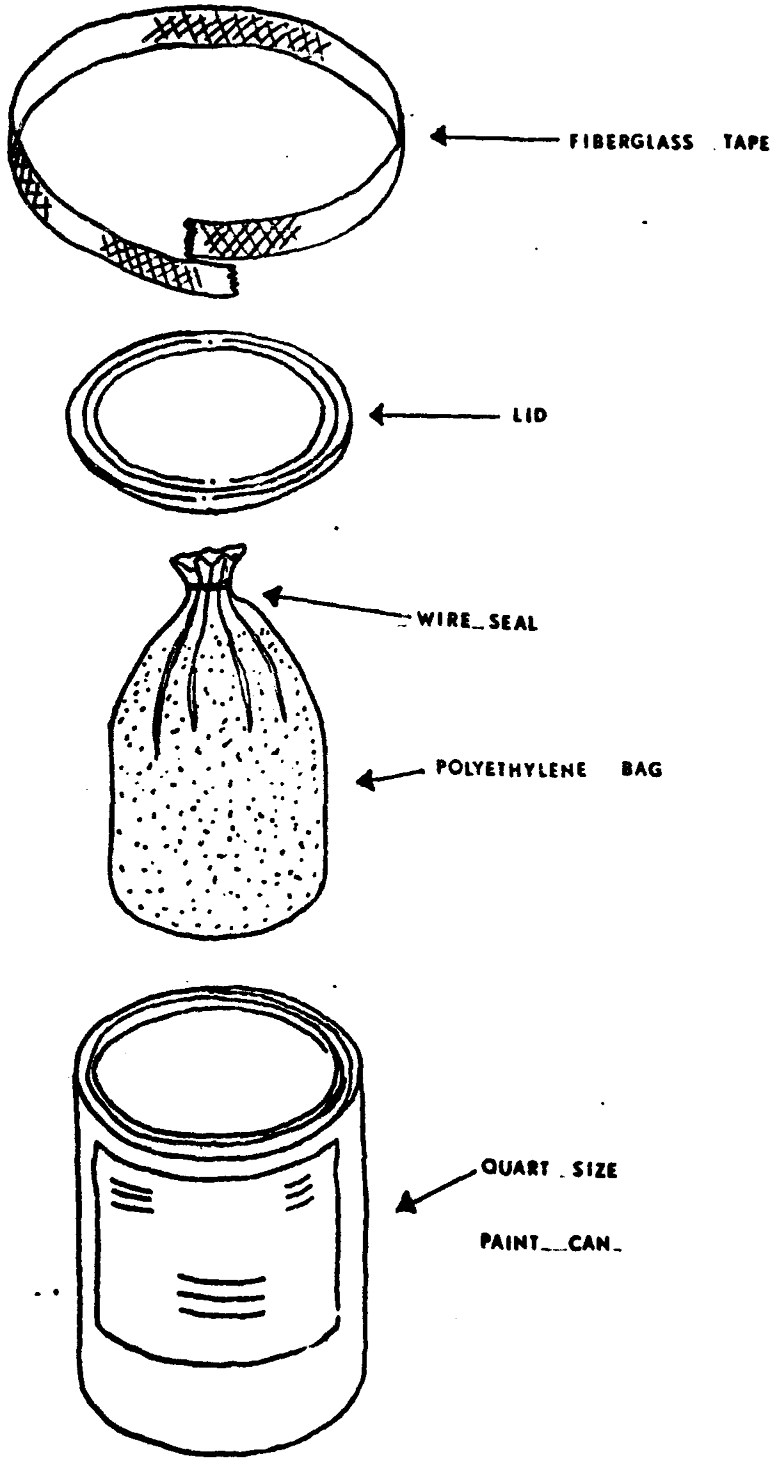
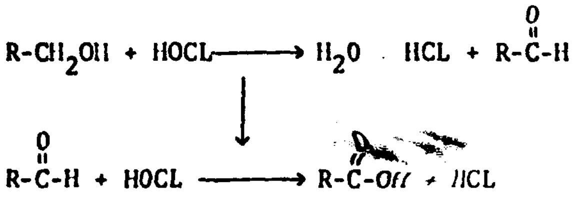


Fig. 2. Soil Sample Container

Each sample (100 g) was then given a preliminary separation using a U.S. Standard #18 mesh screen (1000 μ openings) to remove pieces of thermally altered polyethylene, pebbles, roots, twigs, and the like, which were not considered soil material.

Next, since many soil materials have constituents, such as organic matter, carbonates and sulfates of calcium and magnesium, and the hydrous oxides and hydroxides of iron and aluminum, which militate against their breakdown into individual mineral grains, a rather thorough washing procedure was employed.

The organics were removed first (oxidized to water soluble species) using "Hypochlorite" (Chlorox). A typical reaction series illustrating the chemistry involved is the oxidation of an alcohol to an aldehyde to carboxylic acid:



$$R\text{-}CH_2OH + HOCL \longrightarrow H_2O \quad HCL + R\text{-}\overset{\overset{O}{\|}}{C}\text{-}H$$

$$R\text{-}\overset{\overset{O}{\|}}{C}\text{-}H + HOCL \longrightarrow R\text{-}\overset{\overset{O}{\|}}{C}\text{-}OH + HCL$$

The standard peroxide method for removing organics was not used so as to avoid damage to the primary minerals.

After washing by sedimentation and decantation, the sesquioxides were rendered soluble by the "Dithionite" treatment. The chemistry of this treatment is illustrated by the following step-wise reactions:

step 1. $Fe_2O_3 + 4C_6H_5O_7^{-3} + 3H_2O \longrightarrow 2Fe(C_6H_5O_7)_2^{-3} + 6OH^-$

CITRATE

step 2. $Fe_2O_3 + 12S_2O_3^{-2} + 3H_2O \longrightarrow 2Fe(SSO_3)_6^{-9} + 6OH^-$

THIOSULFATE

The "Oxalic Acid/Magnesium Ribbon" treatment was also employed, with the following illustrative (step-wise) reaction series:

$$\text{step 1.}\quad Fe_2O_3 + \underset{\text{OXALATE}}{6C_2O_4^{-2}} + 6H^+ \longrightarrow 2\,Fe(C_2O_4)_3^{-3} + 3H_2O$$

$$\text{step 2.}\quad Fe_2O_3 + Mg + H_2O \longrightarrow \underset{\hookrightarrow\ \text{acid washing}}{Mg(OH)_2} + 2Fe^{+2} + 2O^{-2}$$

Hematite (MOH hardness 5.5-6.5) was removed with the hydrous species because prime interest was in regard to those minerals that are harder than quartz. Corundum, on the other hand, even though a sesquioxide, is highly resistant to hydration and acid attack [Cotton and Wilkinson, 1962]. Therefore, the species was preserved.

After a final washing, heavy mineral separations were conducted [Krumbein and Petijohn, 1938] on the remaining sand size separates (the silt and clay sizes having been washed out, since particle sizes finer than 60 μ are generally of only long-term abrasive interest), using Bromoform (Tribromomethane) with specific gravity 2.85. In a few cases, such as with the Antarctic samples, a high percentage of rock fragments necessitated a heavy mineral separation of only the fine sand fraction (125-62 μ). Finally, the magnetic minerals were separated out with a small hand magnet and reported as a percentage of the heavy minerals. Appendix A contains a mineral analysis preparation flow sheet and a detailed procedural description [Brewer, 1964].

C. SAMPLE ANALYSIS

As a part of the analysis, each original (untreated) soil sample was assigned a standard (dry) color code according to the Munsell Soil

Color Comparison Technique [Munsell Soil Color Charts, 1971]. Due to the sterilization treatment, the color of the samples is probably slightly lighter than the in situ color.

1. Microscopic Method

The heavy mineral separates were manually sieved and the 250-125 μ and 125-63 μ fractions were mounted on slides using "Lakeside 70" resin. The slides are being studied by Professor R. S. Andrews for qualitative and quantitative mineralogical content and will be the subject of a later report.

2. X-Ray Diffraction Method

Although the spectrometric powder technique is particularly suited to the study of clay minerals, since statistical sampling, mean crystallite dimension, and preferred orientation are not serious considerations, it was utilized in the present study as a corroborative qualitative refinement to the microscopic analysis. That is, even though the amphibole and garnet groups are fairly distinctive under the microscope, it is more difficult to determine which sub-species is actually present. Riebeckite and pyrope, an amphibole and garnet, respectively, were easily identified using the X-Ray Diffractimeter [Appendix A].

The portion of the 250-125μ and 125-63μ heavy separate fractions remaining after the slide preparation were utilized in the x-ray analysis. Only 11 of the samples could be used however, since the heavy separate quantities from most of the samples were too small for the particular technique employed.

Assuming that the diffractometer is properly calibrated and aligned (and all instrumental factors affecting diffraction profiles at an optimum), in order for the angular positions to be reliable and for the peak intensities to be at a maximum (with little broadening), a number of precautions were observed in the preparation and mounting of the powder [Klug and Alexander, 1954]. The samples were manually ground in an agate mortar and pestle to finer than 37μ (equivalent to passing through a 40 mesh screen) in an effort to get as close to the optimum 5-10μ size range as thought expedient for the purposes of this study. Reduction of the crystallite size by grinding is necessary in order that (1) the number of crystallites contributing to each diffraction peak be sufficiently large, (2) primary extinction and microabsorption be negligible, and most importantly (3) preferred orientation be held to a minimum.

Following sufficient grinding, the samples were then dry mounted on one of two aluminum sample holders [Fig. 3], depending on the amount of sample. Both of these sample holders satisfy the thickeness requirement for maximum beam intensity at a particular Bragg Diffraction Angle (σ):

$$t \geq \frac{3.2}{\mu} \frac{\rho}{\rho'} \sin\sigma$$

where

t = thickness of sample

μ = linear absorption coefficient

ρ = density of solid powder

ρ' = density of solid powder plus intertices

The samples were placed in the holders using a spatula, packed firmly using the pestle, and leveled by exerting pressure and a to-and-fro motion on an ordinary piece of window glass. It is most critical that

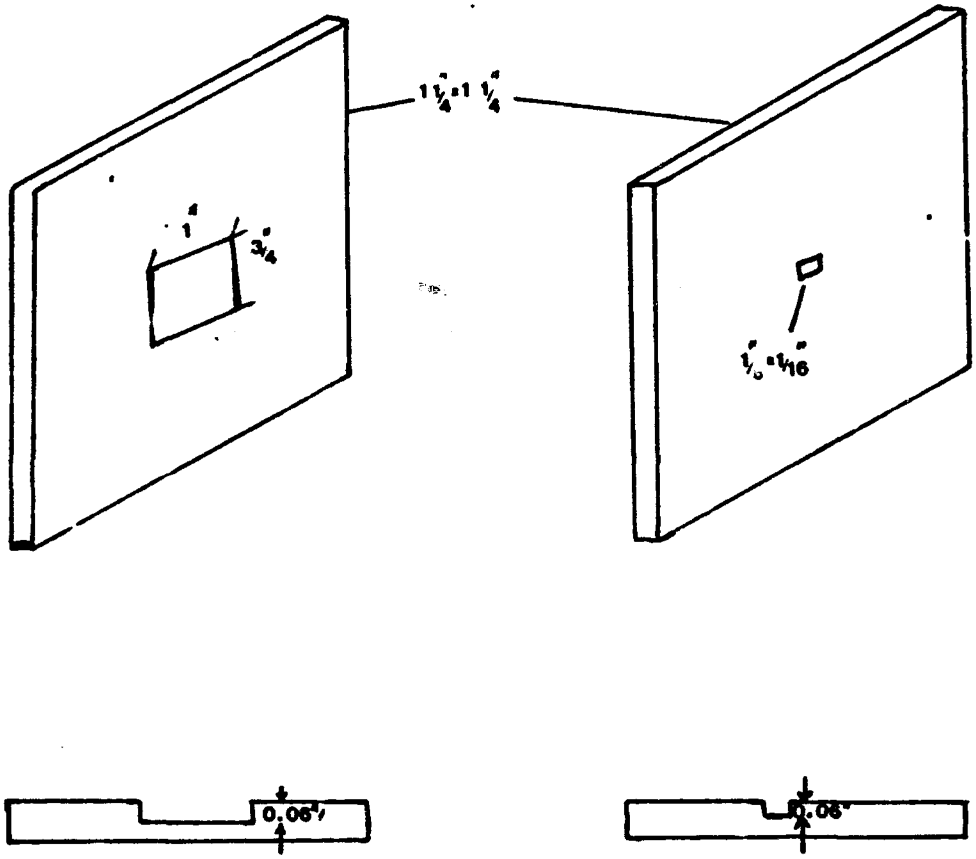


Fig. 3. Aluminum Sample Holders

the sample be perfectly level with the holder in order to obtain accurate angular positions on the strip chart.

Considerable time was saved during the mineralogical determinations by using a transparent acetate overlay for the diffractograms on which were inscribed the most important Bragg angles of the heavy minerals most commonly found in soils.

IV. RESULTS OF MINERALOGICAL ANALYSIS

The mineralogical analyses performed in this study confirm what the literature and a knowledge of geology and weathering phenomena had suggested (i.e., the heavy mineral portion of the sand fraction of most world soil epipedons is very small) and/or indicate that better sampling techniques are required in order to ever observe anomalous heavy mineral concentrations. More likely than not, the former is as accurate an asseveration as the latter. The mineralogical data is listed on Tables III and IV.

Approximately 50% of the samples showed less than or equal to 1% heavy mineral content (by weight), 60% contained less than or equal to 5%, and 80% had less than or equal to 10%, with an overall average of 6.7%. Traces of heavy minerals harder than quartz (zircon, topaz, tourmaline, garnet, spinel, corundum, etc.) were observed in most of the samples, but most of the heavy separate constituents were softer (riebeckite, MOH hardness 4, being the most common species) [Table IV]. Those samples containing a large amount of heavy minerals [Table III, locations 13b, 46, and 52] generally had a high volcanic glass and/or magnetic (magnetite) content, excepting the contact metamorphic beach

TABLE III

RAW MINERALOGICAL DATA

	LOCATION	*H/T %	*M/H %	MUNSELL COLOR	
1.	Agana, Guam	55	10	Reddish-Brown	5YR 4/4
2.	Anaco, Venezuela	0.35	13.6	Brown	10YR 3.5/3
3.	AT 955-805, V.N.	0.31	0.25	White	10YR 7.5/2
4.	Atsugi, Japan	11.5	54	Brown	7.5YR 5/4
5.	Aviano, Italy	0.09	27	Dark Grayish Brown	10YR 4/2
6.	Bien Hoa, V.N.	0.5	5.2	Grayish-Brown	10YR 5/2
7.	Bing Thuy, V.N.	1.1	12.3	Gray	10YR 4.5/1
8.	Bogota, Columbia	0.85	10	Very Pale Brown	10YR 6.5/3
9.	Cam Ranh Bay, V.N.	0.38	55	Light Gray	10YR 7/2
10.	Cape Town, S. Africa	0.0053	3.3	Brown	10YR 5/3
11.	Cherry Point, N.C.	1.6	28	Dark Grayish Brown	10YR 4.5/1
12.	Chimbote, Peru	9.8	18.5	Speckled Gray Sand	
13a.	Clark AFB, Philippines	14.5	41.5	Dark Grayish-Brown	10YR 4.5/2
13b.	Cubi Pt., Philippines	26	34	Pale Brown	10YR 6/3
14.	Coco Solo, Pan.	1.5	69	Dark Brown	7.5YR 3.5/2

	LOCATION	H/T %	M/H %	MUNSELL COLOR	
15.	Columbo, Ceylon	0.27	33	Dark Grayish-Brown	10YR 4/2
16.	Da Nang, V.N.	0.09	63	Dark Grayish-Brown	10YR 4.5/2
17.	Dam Neck, Va.	8.2	0.82	Light Brownish-Gray	10YR 6.5/2
18.	Dong Ha, V.N.	0.44	2.3	Grayish-Brown	10YR 5/2
19.	Eielson AFB, Alaska	3.7	6.3	Grayish-Brown	10YR 5/2
20.	El Centro, Calif.	0.36	20	Pinkish-Gray	7.5YR 6/2
21.	Ft. Clayton, Pan.	19	69	Reddish-Brown	5YR 5/3
22.	Four Corners, USA	0.28	54	Light Reddish-Brown	5YR 6/3
23.	Guatemala City	16.5	60	Dark Reddish-Brown	5YR 2.75/2
24.	Helsinki, Finland	2.5	0.82	Dark Gray	10YR 4/1
25.	Hickam AFB, Hawaii	18	64	Brown	7.5YR 4.5/4
26.	Indian Hd., Md.	0.5	1.5	Very Pale Brown	10YR 7/4
27.	Istanbul, Turkey	2.8	37	Dark Grayish-Brown	10YR 4/2
28.	Jidda AFLD., Saudi Arabia	17	17	Pale Brown	10YR 5.5/4
29.	Keflavik, Iceland	28	42	Dark Brown	10YR 3/3

	LOCATION	H/T %	M/H %	MUNSELL COLOR	
30.	Korat, Thailand	0.52	N	Reddish-Brown	5YR 4/5
31.	Malaya, Turkey	2.7	S	Pinkish-Gray	7.5YR 6/2
32.	Marble Mt., Ma.	0.43	3.8	Light Gray	2.5YR 7.5/2
33.	Midway	4.3	42	Dark Brown	7.5YR 4/2
34.	Missoula, Mont.	0.66	17.5	Dark Grayish-Brown	10YR 4/2
35a.	Monterey AP, Calif.	0.44	2.5	Very Pale Brown	10YR 6.5/4
35b.	Carmel Beach, Calif., (Pay Steak)	97	60	Reddish-Black	
36.	Montevideo, Uruguay	0.5	0.12	Pale Brown	10YR 6/2.5
37.	NAS Albany, Ga.	0.7	21	Dark Grayish-Brown	10YR 4/2
38.	Nha Trang, V.N.	0.17	3.3	Pale Brown	10YR 6.5/3
39.	N. of the Khe Sahn	1.25	80	Pink	7.5YR 7.5/4
40.	Nome, Alaska	94	28	Dark Reddish-Black	
41.	Pensacola, Fla.	0.6	0.7	Brown	10YR 5.5/3
42.	Phnom Phen, Cambodia	0.14	0.14	Brown	7.5YR 5.5/4
43.	Prince Ed. Island, Canada	0.05	60	Reddish-Brown	2.5YR 3.5/4
44.	Queensland, Australia	0.2	83	Reddish-Brown	2.5YR 4/5

	LOCATION	H/T %	M/H %	MUNSELL COLOR	
45.	Rio, Brazil	5.0	6.7	Brown	7.5YR 5/4
46.	Ross Island, Ant.	42	34	Grayish-Brown	10YR 5.5/2
47.	San Diego, Calif.	8.2	3.2	Brown	10YR 5/3
48.	Santo Domingo, D.R.	3.0	27	Dusky-Red	10YR 2.75/2
49.	Sondrustrom, Greenland	8.2	4.9	Light Brownish-Gray	2.5YR 5.5/2
50.	Tananarive, Madagascar	4.7	67	Reddish-Yellow	5YR 6/6
51.	Tanson Nhut, V.N.	0.17	40	Grayish-Brown	10YR 4.5/2
52.	Taylor Valley, Ant.	38	6	Brown	10YR 5/3
53.	Thule AFB, Green.	5.2	21	Grayish-Brown	2.5YR 5.5/2
54.	Yuma, Ariz.	4.5	23.6	Reddish-Brown	5YR 5/3

* H/T - Percentage of Heavy Minerals, by weight, of total

M/H - Percentage of Magnetic Separation, by weight, of heavy Minerals

TABLE IV

QUALITATIVE (X-RAY ANALYSIS) MINERALOGY

	LOCATION	PREDOMINENT HEAVY MINERALS PRESENT
1.	Carmel Beach	Pyrope; Zircon
2.	Cherry Point	Biotite; Hornbende; Trace of Corundum*
3.	Clark AFB	Riebeckite; Rutile,* Apatite
4.	Da Nang	Muscovite
5.	Guatemala	Riebeckite; Rutile,* Topaz*
6.	Nome	Pyrope; Zircon
7.	Queensland (untreated)	Hematite; Magnetite
8.	Ross Island	Amphibole; possibly Riebeckite
9.	San Diego	Riebeckite; Muscovite; Topaz,* Tourmaline*
10.	Saudi Arabia	Riebeckite
11.	Yuma	Riebeckite; Biotite; Zircon*

* Questionable

areas of Carmel, California, and Nome, Alaska. The Ceylon and Cherry Point, North Carolina, samples were the only two found to contain any corundum (trace).

Finally, there was no correlation at all found between percent heavy minerals (individual grains vice hydrous sesquioxides of iron and aluminum) and any of the factors governing weathering phenomena, the qualitative and quantitative heavy mineralogy being highly variable depending on the various combinations of the five factors governing soil genesis.

V. DISCUSSION AND CONCLUSIONS

A. DUST DAMAGE POTENTIAL CONCEPTS

1. Abrasion Aspect

As observed from the data obtained as a result of this study, not only the mineralogical character, but also the abrasion damage potential of soil dust becomes prominent in the fine to very fine sand fractions (250-63μ). Individual heavy mineral grains, due to settling and hydraulic equivalent phenomena [Clifton, 1968], tend to concentrate in the 125-63 μ size range, anything bigger being rock fragments which are much weaker in terms of hardness than individual grains. Individual quartz grains tend to concentrate in the 250-125 μ size range. Since 75-200 μ is the size range of maximum effective abrasiveness [Fig. 4a], especially in the specific case of dust erosion, where (ε), the volume of abrasive wear per load, becomes independent of particle size at the "Saturation Plateau" [Fig. 4b], and since the percentage of heavy minerals found in the samples was generally less than or equal to 5% (in those samples with greater than 5% heavy

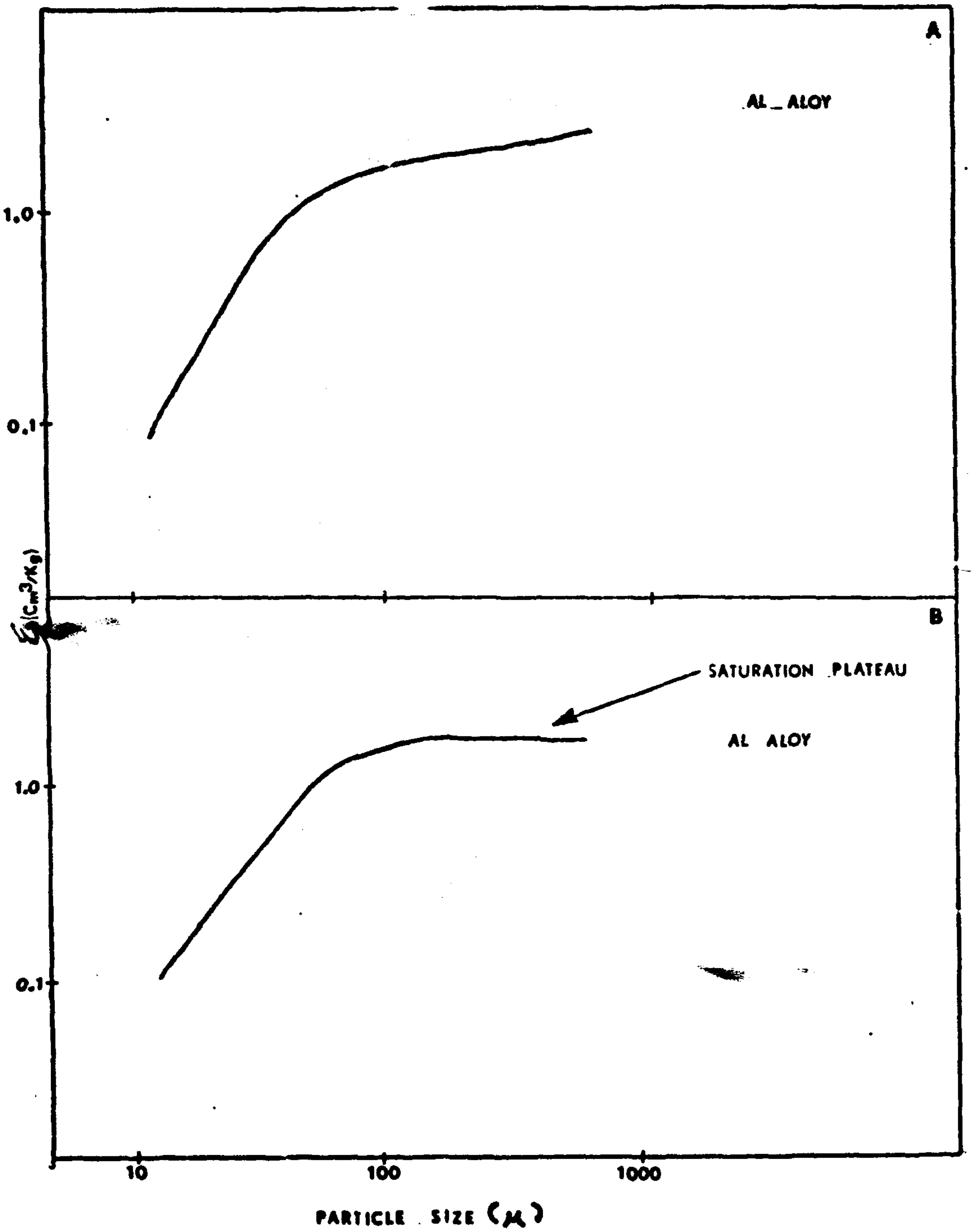


Fig. 4. Extent of Dust Erosion as a Function of Particle Size

(A. After Nathan and Jones, 1966, p. 305.
B. After Tilly, 1969, p. 243.)

minerals, the species present were all softer than quartz), it is the conclusion of this author that quartz is the most common and most abrasive naturally-occurring mineral species.

The only possible exceptions are the lateritic soils [Ultisols/Oxisols, Soil Survey Staff, 1967] of the tropical belt, which are the most highly weathered soils on earth. It is the hydrous oxides and not the gamma or alpha anhydrous Fe_2O_3 (hematite) or Al_2O_3 (corundum) that are in abundance in these soils, although traces of these minerals do exist. Even though the hydrated forms can be highly abrasive ($Al_2O_3 \cdot H_2O$ has a MOH hardness of 7), they generally are not. They are also most prevalent in the clay-size range. Therefore, quartz still may be considered the most representative species regarding dust test specifications and abrasion mechanism investigation due to particle hardness and size considerations and additionally, the fact that the hardness of ordnance metals is in the range of 5-6 on the MOH scale. A table relating engineering hardness [Rockwell Scale] to geological hardness [MOH Scale] has been included in Appendix E [Table VI], since it was discovered that most reference texts do not contain such a table.

2. Corrosion Aspect

In general, in an oxygenated atmosphere, the epipedons of world soils that have a dust potential are chemically inert regarding machinery; they do not react directly with the metal surfaces, considering that iron, stainless steel, aluminum, brass, bronze, and magnesium are the most common metals in use. Extremely acid soils (pH 4.0 and lower) can cause rapid corrosion of most bare metals, but this degree of acidity is uncommon, being limited to histosols and soils made acidic by large accumulations of plant materials such as pine needles in a coniferous forest. It is safe to say that there is no dust problem associated with such soils.

Soil acidity may also be imparted by the formation of carbonic acid from carbon dioxide of biological origin or from the atmosphere and water, from the acid residues of weathering, shifts in mineral types, loss of alkaline earths from leaching or microbial activity, which is generally well below the surface in an anaerobic, waterlogged environment. Most soils range from a pH of 5.0 to 8.0, and corrosion rates are apt to depend on many other factors (humidity, temperature, etc.) rather than soil reaction per se.

The only mechanism by which dust contributes to corrosion is of a galvanic nature in the form of a "Differential Aeration Cell" [Uhlig, 1967], assuming that the dust has adhesive and hygroscopic properties (e.g. - Kaolinite). The principle of such a cell is simple: the metal surface covered by the dust particle is deprived of oxygen (anode), while the surrounding metal is well aerated (cathode). This difference in oxygen concentration produces a potential difference, inducing a current flow [Fig. 5]. Moisture is necessary for the process, with the presence of salts (chlorides, sulfates, and carbonates) greatly enhancing electrolytic continuity. The process is self-sustaining since the rust [$Fe(OH)_2/Fe(OH)_3$] is quite hygroscopic. Surface pitting results, with a decrease in surface continuity and strength and an increase in abrasion potential due to the roughened surface.

The occurrence of the problem would be most prevalent in hot, humid subtropical and tropical regions, coastal regions, and possibly some desert areas, given enough moisture, due to the high salt content of aridosolic dust.

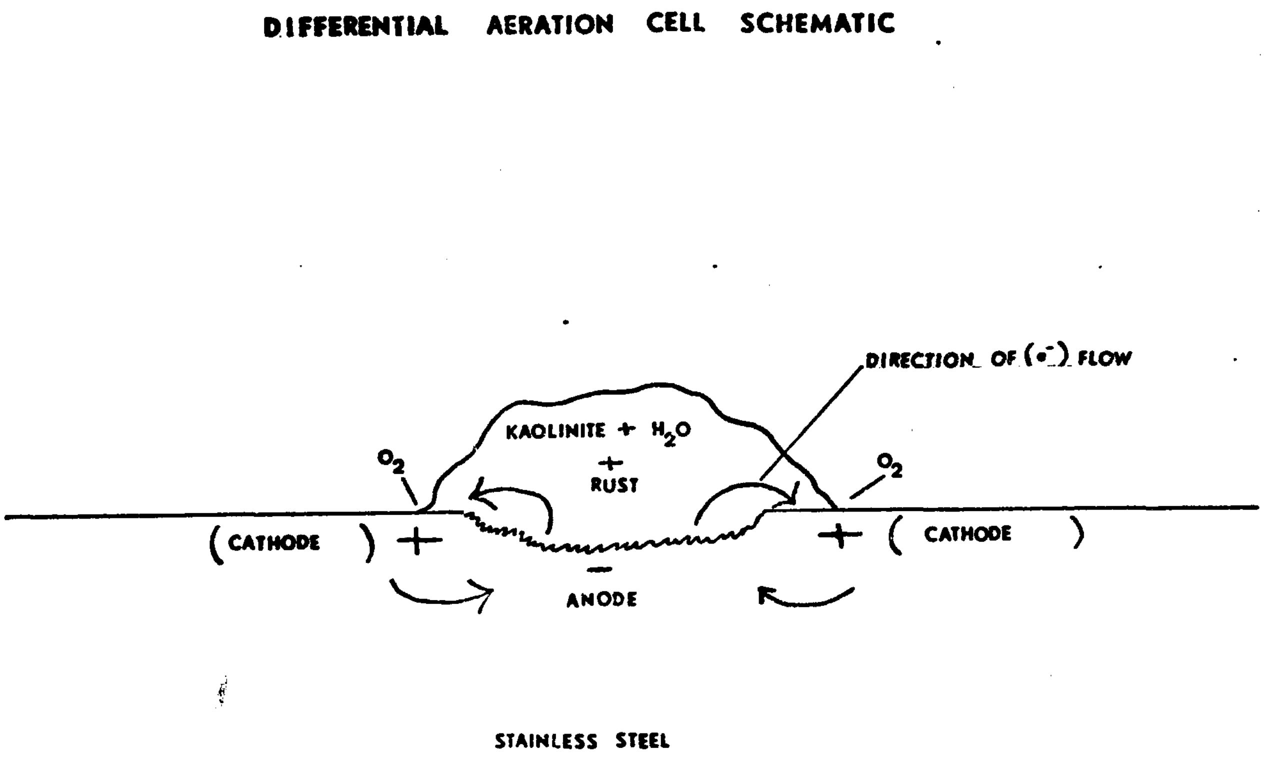


Fig. 5. Differential Aeration Cell Schematic

3. Erosion-Corrosion Aspect

One of the most characteristic features of ordnance and support equipment is that they are mobile and possess moving parts. Therefore, under proper conditions, such material is highly susceptible to erosion-corrosion, both the situation of corrosion followed by erosion (e.g. - corrosion while a piece of equipment is dormant followed by removal of corrosion products during operation) and the simultaneous occurrence of erosion and corrosion resulting from the relative movement between the corrosive fluid and the metal surface. Deterioration or attack on the metal surface is greatly accelerated in both cases, since the metals of concern depend on the formation of a surficial oxide (passivity) for corrosion resistance. Erosion-corrosion results when these protective shields are damaged or worn away, leaving a bare metal or alloy surface open to attack at a rapid rate [Tomashov, 1967].

This phenomenon is most likely to pose the most serious problem in the more hot and humid regions of the potentially dusty areas also. Aircraft are particularly susceptible to this form of damage, since turbulent, high velocity flow and impingement are enhancing effects [Fontana and Greene, 1967].

4. Thermochemical/Pressure Aspect

Up to this point, consideration has been given only to the abrasion/corrosion potential of dust as it occurs naturally and under atmospheric conditions. However, the intial impact of the dust particle could alter the situation in two ways, assuming the collision not to be perfectly elastic and that the particle does not become imbedded in the surface: the increase in temperature resulting from the impact could be large enough to (1) cause the particle to react chemically with the surface and/or (2) alter the chemical structure of the particle to a different (harder) polymorph or possibly a new species.

In light of this consideration, the case of an iron oxide particle impacting the aluminum body (airfoil) of an aircraft has been considered in order to see if surface pitting could be accelerated or even initiated by the "Thermite Reaction":

$$Fe_2O_3 + 2Al^0 \xrightarrow{1000^{\circ}C} Al_2O_3 + 2Fe^0 + 1266 \text{ cal/g}$$

In order to consider the optimum case of the maximum temperature rise possible, it was assumed that all the kinetic energy resulting from the impact was converted to heat energy at the point and instant of impact (in actuality, a good deal of the energy would be lost to momentum considerations, removing the chunk of aluminum, etc.) and that the iron oxide particle and chunk of eroded aluminum were of equal mass. Thus, using the following equation:

$$E = 1/2 \cdot M \cdot V_{a/c}^2 = \left[(Cp)_{Fe_2O_3} + (Cp)_{AL}\right] \Delta T \cdot M$$

where E = kinetic energy

$$\left.\begin{array}{l} (Cp)_{Fe_2O_3} = 25 \text{ Cal/Mole}\cdot{}^{\circ}C \\ (Cp)_{Al} = 5 \text{ Cal/Mole}\cdot{}^{\circ}C \end{array}\right\} \text{Molar Heat Capacities}$$

$V_{a/c}$ = aircraft velocity = 600 Kts

ΔT = temperature change

M = mass

a maxiumum rise in temperature of a mere $30^{\circ}C$ was calculated. As a result, it has been concluded that it is highly improbable that this reaction could occur externally or internally in regard to aircraft and gas turbine engines (or any other ordnance) and therefore, that this reaction does not contribute to the accelerated deterioration of ordnance material, in the form of either thermal fatigue or increased erosion due to the small, hard α-Al_2O_3 particles so formed.

Further, once the dust particles have been ingested, the associated elevated temperatures and pressures characteristic of some equipment could cause accelerated failure due to the extreme nature of the environment alone or again, to the chemical alteration of the particles themselves.

Some studies indicate that erosion may occur at elevated temperatures and pressures in the rear blading of jet engine compressors and turbines. Considering the materials most commonly used in such engines (11% chromium steel and nickel, titanium, and aluminum alloys), the data so far is contradictory. The nickel and chromium alloys exhibit an increase in erosion, while the titanium alloys show a decrease [Tilly, 1969].

Regarding corrosion and erosion-corrosion, both of these phenomena are generally enhanced under conditions of elevated temperature and pressure. The probability of direct chemical attack on the metal surface by the salts present in dust generally increases as the conditions become more anoxic. High temperature corrosion is currently under active investigation, especially in connection with the turbine section of gas turbine engines [George Hemingway, Naval Aviation Rework Facility (NARF), Naval Air Station (NAS), North Island, San Diego, California, Personal communication].

Further, consider the effect of these extreme conditions on the dust particles themselves. Since quartz, clay minerals, and hydrous sesquioxides are the most important constituents of dusty area soils, they are the only components discussed in the following paragraphs.

Quartz has six modifications depending on temperature and pressure [Cotton and Wilkinson, 1962]:

$$\begin{tikzcd}
\beta\text{-quartz} \arrow[r, shift left, "870^{o}C"] \arrow[d, shift left, "573^{o}C"] & \beta\text{-tridymite} \arrow[l, shift left] \arrow[r, shift left, "1470^{o}C"] \arrow[d, shift left, "120\text{-}160^{o}C"] & \beta\text{-cristobalite} \arrow[l, shift left] \arrow[r, shift left, "1710^{o}C"] \arrow[d, shift left, "200\text{-}275^{o}C"] & \text{liquid} \arrow[l, shift left] \\
\alpha\text{-quartz} \arrow[u, shift left] & \alpha\text{-tridymite} \arrow[u, shift left] & \alpha\text{-cristobalite} \arrow[u, shift left] &
\end{tikzcd}$$

all forms are chemically inert and retain a MOH hardness 7.

Of more interest though are the clay minerals (kaolinite, montmorillinite, illite, etc., all approximately MOH hardness 2) and the hydrous sesquioxides. All will undergo endothermic dehydration in the 100-600°C temperature range. In the case of the latter, the γ-Fe_2O_3 or γ-Al_2O_3 thus formed will have MOH hardness approximately equal to 6 and 7, respectively. Also, at these temperatures, the clay minerals will be transformed into either α- or β-quartz and γ-Al_2O_3.

More importantly, at approximately 1000°C γ-Al_2O_3 (the original clay minerals and sesquioxides as well) will undergo an exothermic structural transformation to α-Al_2O_3 (corundum) or to spinel ($MgAl_2O_4$), with hardness 8, if the original clay mineral was montmorillonite [$(Al,Mg)_8$-$(Si_4O_{10})_3(OH)_{10} \cdot 12H_2O$] [Cotton and Wilkinson, 1962; Grim, 1968]. Muscovite will go to corundum at 1200°C and illite to spinel at only 850°C. At approximately 1400°C, γ-Fe_2O_3 will transform to Fe_3O_4 (magnetite), which is not of significance here since both have about the same MOH hardness of about 6.

Since these reaction products are stable at high pressure as well as temperature, considering relative densities (e.g.-- 2.5 and 4.0 g/cm^3 for bauxite and corundum, respectively), the effect of increased pressure upon required temperatures was investigated. It can be shown that the change in free energy (dG) in an isothermal process is related to pressure according to the following equation, considering Dalton's "Law of Partial Pressures" [Moore, 1963]:

$$dG = -R \cdot T \cdot \ln(Kp) = dV \cdot dP$$

where $R = 0.08$ l.atm./^{0}K·Mole

T = temperature (^{0}K)

Kp = equilibrium constant

dV, dP = volume and pressure change, respectively.

Considering the representative reaction:

$$2Al(OH)_3 \longrightarrow \alpha\text{-}Al_2O_3 + 3H_2O \qquad 1\ \text{atm}$$

Gibbsite Corundum

we have:

$$\ln(Kp) = \Delta V/RT$$

$$\ln(Kp) = 7.0\times10^{-4}$$

$$Kp \cong 1.$$

Essentially, this calculation indicates that this exothermic reaction is non-pressure dependent. That is, the maximum pressures encountered in gas turbine engines or aircraft disc brakes, approximately 12 and 23 atm, respectively [D. Neff and D. Peterson of the Aerospace and Defense Division, B. F. Goodrich, Akron, Ohio, personal communication] or even that of drum brakes (100 atm) are not sufficiently high to lower the reaction temperature significantly.

However, even though pressure has no apparent effect, given a soil type that is initially low in abrasion potential, it could be possible that the service life of ordnance materials, which do experience extreme temperatures (in excess of 1000°C) during normal operation, could be substantially reduced due to dust contamination because of (1) accelerated thermal fatigue resulting from heats of reaction (ΔH), even though ΔH is only 25 cal/g for kaolinite vice ΔH equal to 1266 cal/g in the case of the "Thermite Reaction," and (2) increased erosion due to the very small, hard particles formed.

5. World-Wide Dust Abrasion/Corrosion Potential of Soil Orders

Generally speaking, most areas on earth have dry periods of some finite length, no matter how short. Therefore, even though dry, desert-like regions are generally associated with the most adverse dust conditions, most areas possess some relative dust potential. Based on this and the four parameters just discussed (erosion, corrosion, erosion-corrosion, and thermochemical/pressure considerations), the ten soil orders (with mention of pertinent suborders) of the United States Department of Agriculture 7th Approximation Soil Classification System [Soil Survey Staff, 1967] have been ranked as to their dust abrasion/corrosion potential on a scale from 1 to 5, rank 1 being the most severe [Table V].

The aridosols and psammentic entisols of desert regions have been included in potential rank 1 since they are dry most of the year, have a high free-silica content, and represent approximately 20% of the surface of the earth [Foth and Turk, 1972], more than any other soil order. Dry portions of sandy beaches are also in this category.

The lateritic soils have been ranked anywhere from 1 to 5 depending on the season, amount of free quartz available, whether or not the foliage has been cleared away, the operating characteristics of the machinery, the nature of the operations, and the proximity to the coast.

TABLE V

SOIL ORDER DISTRIBUTION AND DAMAGE POTENTIAL RANK

(FOTH AND TURK, 1972)

	SOIL ORDER	AREA (Sq. Mile x 10^3)	% OF WORLD TOTAL	ABRASION/ CORROSION POTENTIAL
1.	ALFISOLS	7600	14.7	3 summer
2.	ARIDOSOLS	9900	19.2	1
3.	ENTISOLS	6500	12.0	1 or 4
4.	HISTOSOLS	400	0.8	5
5.	INCEPTISOLS	8100	15.8	4
6.	MOLLISOLS	4600	9.0	4
7.	OXISOLS	4800	9.2	3-5
8.	SPODOSOLS	2800	5.4	4
9.	ULTISOLS	4400	8.5	1-2
10.	VERTISOLS	1100	2.1	4-5
	ICE FIELDS, RUGGED MTS., UNCLASSIFIED ISLANDS	1400	2.8	5
	TOTAL	51,600		

A map [Fig. 6] depicting the world-wide location and damage potential of aridosols and ultisols/oxisols follows.

Finally, all the other soil orders fall into the intermediate range, except for those that are high in organic content and/or wet most of the time (vertisols and histosols); they have vertually no dust abrasion/corrosion potential. Buckman and Brady [1969] and Soil Survey Staff [1967] contain comprehensive descriptions of the soil orders recognized by the U.S.D.A. Soil Classification System.

B. SOUTHEAST ASIA PROBLEM

As stated in the introduction, the dust problem in Vietnam has been excessive. What are the reasons for the increased ordnance failure rate due to accelerated abrasion and/or corrosion? What is the difference between the general situation at El Centro or China Lake (our Mojave Desert areas) here in the United States and that of reportedly the harshest of the dust environments encountered in Vietnam: Da Nang, Pleiku, and Marble Mountain air bases. For the sake of discussion, two particular problem areas will be treated: (1) gas turbine engines and (2) truck brakes.

Treating the problem in an all-enclusive, systematic manner, three broad parameters were considered as the major basis of comparison: the dust, climate, and the nature of the operations in the two regions.

The nature of the dust in both areas is most pertinent. Just as desert regions are not all sand dunes, as is characteristic of parts of Saudi Arabia (most deserts have a very coarse epipedon composed of rock fragments and salt-flocculated agglomerates scattered over a thin, brittle shell known as the "desert pavement"), lateritic regions are not necessarily areas of completely weathered soils of uniform composition;

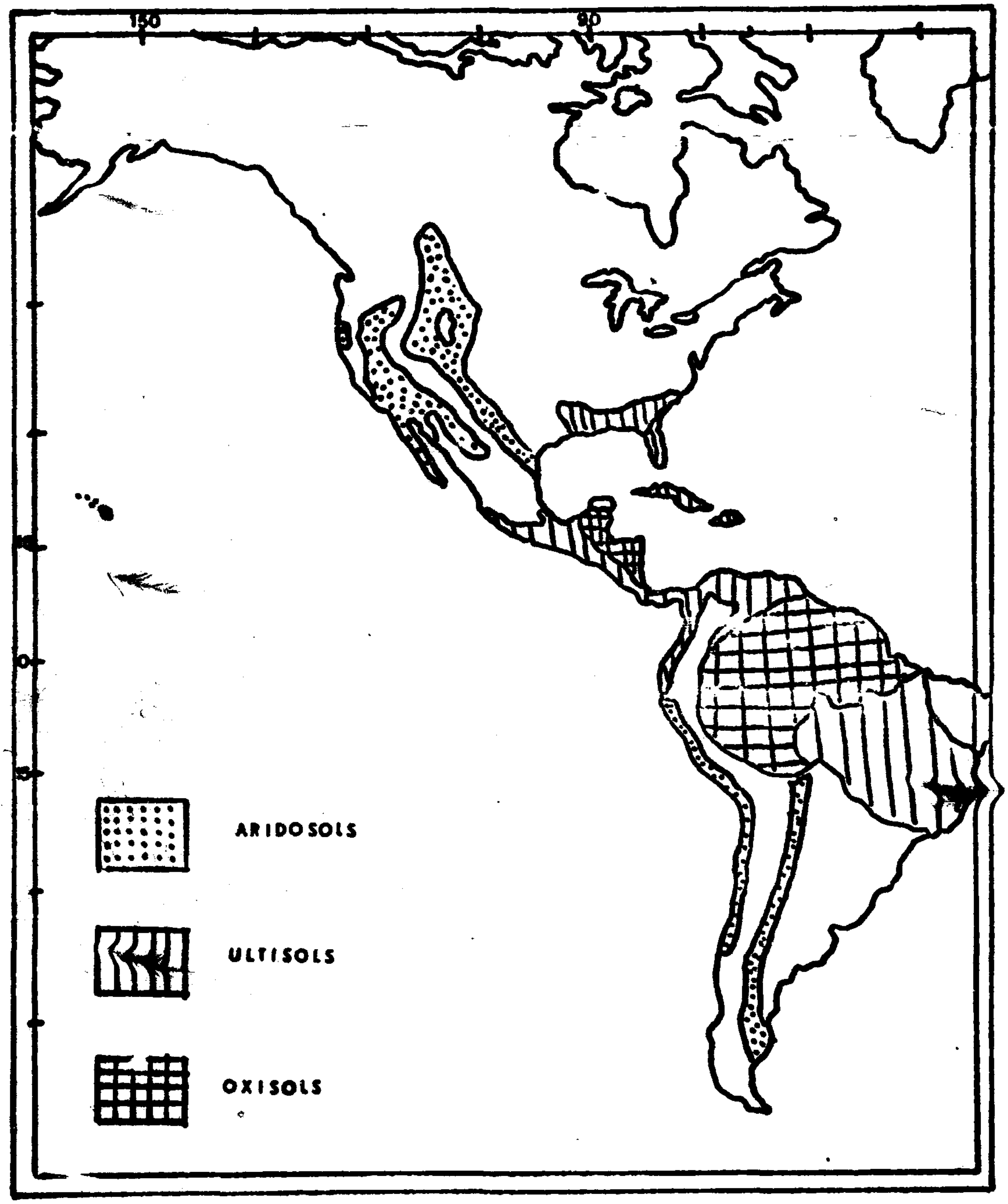


Fig. 6. World-Wide Distribution of Aridosols, Ultisols, and Oxisols

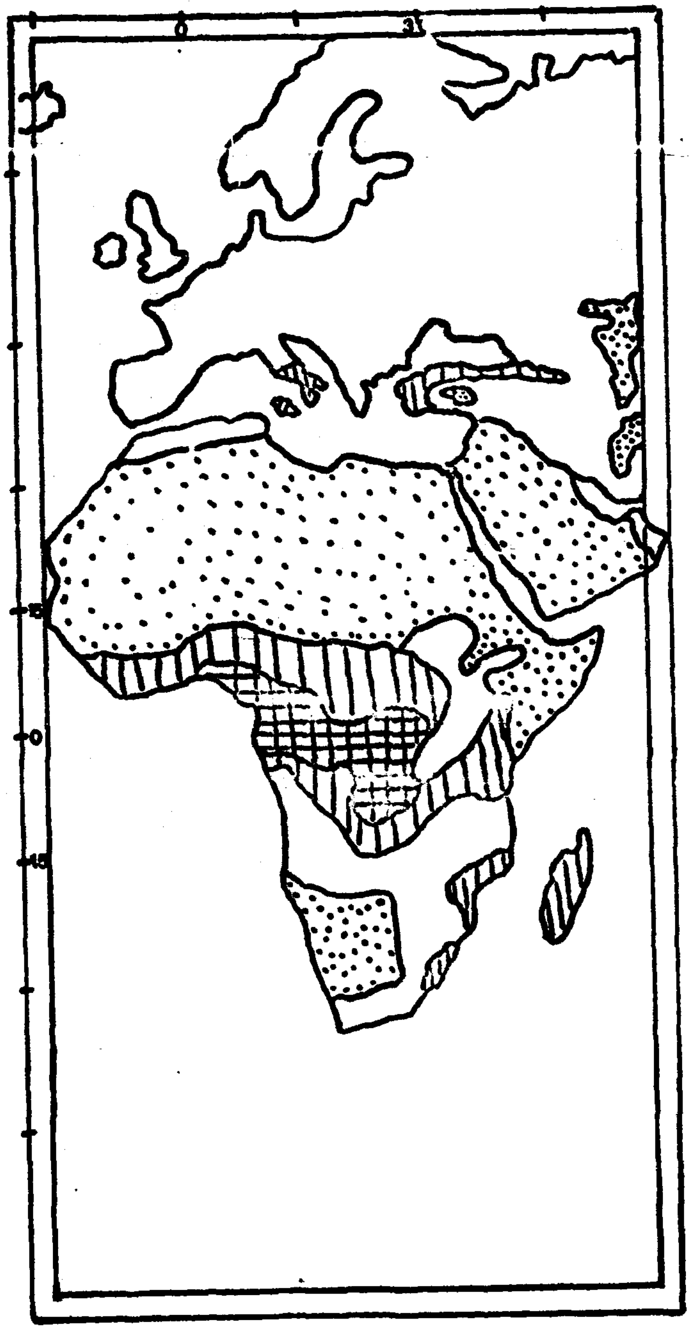


Fig. 6. (Continued)

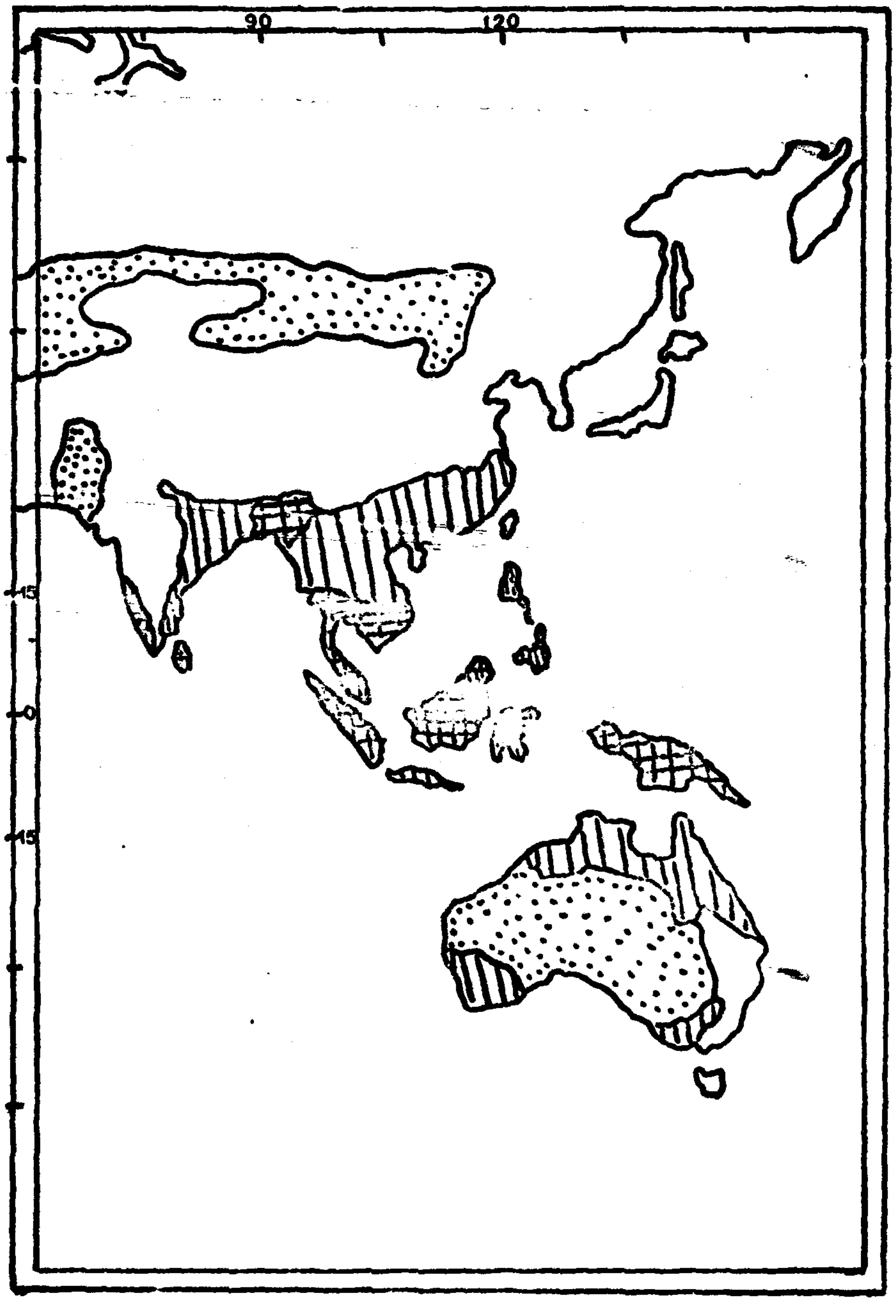


Fig. 6. (Continued)

i.e., all lateritic soils are not 80-90% clay minerals and hydrous sesquioxides of iron and aluminum, with less than 10% free quartz, as are, in general, the oxisols that possess a definite oxic horizon. The ultisols of Southeast Asia, an area of high relief, and the Southeastern United States as well, are surrounded and intermingled with practically every other soil order known. Further, the surface horizon of these soils often contain enough unaltered quartz (and such weatherable minerals as orthoclase and muscovite) to give it a sandy texture [Soil Survey Staff, 1967], as observed also in the Da Nang sample of this study. Smeltzer, et al., [1970] found the lateritic soil from Pleiku to be of standard composition (low in quartz), while those of Cam Rahn Bay and An Khe to be similar to Arizona road dust (crushed granite). The Pleiku sample was identical with the red deposits found inside jet engines and after a series of tests, was found to be non-erosive. (Maybe the epipedon of another Pleiku sample would be high in quartz? This is a good illustration of the problems commensurate with sampling technique.) They came to the conclusion that another soil species, which did not leave a visible trace, was responsible for the erosion problem. This author fully agrees with their conclusion. Further, it is his belief that laterite (in the strict sense) was mistakenly identified as the erosive species, due to its ubiquitous nature and strong fouling ability. This is merely evidence of ingestion, not necessarily indicative of the erosive species. The hypothesis presented here is that quartz in this instance, as in most others, is the villain, whether it be ingested as a surficial constituent of laterite, from surrounding areas (bordering sand dunes), or as a result of actual beach operations (a frequent occurrence).

In addition, using a small magnifying glass, the quartz particles from Vietnam were observed to be of a coarser, more angular nature and relatively more available for dust movement than in the Mojave Desert. This is true, even though the average particle size at China Lake and Da Nang are 60μ and 20μ, respectively, since the principle weathering forces in the desert (disintegration and wind) tend to break off the rough particulate edges and reduce the average size of the particles. Also, due to the lack of water, there is no leaching and thus, carbonate and sulfate salts remain on the surface to help hold particles together. Thus, the average particle size of quartz tends to be much less than the average in general.

With laterites, on the other hand, the hot climate of alternating wet and dry seasons produces extensive leaching removing the salts but not necessarily the free quartz, and concentrating the hydrous sesquioxides, with rapid bacterial oxidation keeping the organic content negligible. Thus, the quartz is relatively free and unaltered from its initial in situ state in the parent rocks. As a consequence, when these areas were first cleared of foliage at the onset of the conflict, the dust hazard was potentially much greater than in our deserts.

Further, considering the clay minerals and sesquioxides in conjunction with the humid climate, the corrosion potential is much greater in Southeast Asia (especially in close proximity to the coast) than in desert regions. The occurrence of brake drums actually falling off [Kuletz and Schafer, 1971] is probably a manifestation of erosion-corrosion and is more prevalent in the wet vice the dry season (dust contamination still a contributing factor), with no thermochemical acceleration. The brakes would fail due to fading (loss of braking action due to molten layer formation between the shoe and the drum) before 1000°C was reached.

It has also been mentioned that the finer particles in the Da Nang area had permeated the painted surface of some equipment [Kuletz and Schafer, 1971] to become part of the coating. This might be merely a function of paint characteristics or a manifestation of corrosion. This is difficult to determine without further study.

Concerning gas turbine engines, erosion (both leading edge and cross-chord) of the compressor blading was (and still is) the main problem [George Hemingway, personal communication], with erosion-corrosion a possible contributing factor. Although temperatures of approximately 300°C in the rear compressor section are not high enough for thermo-chemical processes to occur, the turbine inlet temperatures of the J-79 and TF-30 engines are 980°C and 1270°C, respectively, bracket the necessary 1000°C [Appendix C]. However, the technicians at General Electric and Pratt and Whittney and the mechanics at NARF, NAS, North Island and NARF, NAS, Norfolk, Virginia indicate that there is no evidence of accelerated thermal fatigue or erosion in the turbine sections of either engine. Further, turbine blade cracking due to thermal fatigue is a result of differential heating and cooling and failures after 600 flight hours were reproduced exactly in test areas after 300 throttle bursts [Dick Ehrlick, General Electric, personal communication].

Lastly, probably the most significant factor is that operations in Southeast Asia were of a prolonged, continuous nature, while low altitude flying in our desert areas is of an intermittent nature (e.g.--short hops from NAS, Miramar, to outlying fields for "Field Carrier Landing Practice"). Thus, in Southeast Asia there was simply more continuous subjection to more dust.

C. APPLICABILITY OF CURRENT DUST TEST SPECIFICATIONS

Quartz is definitely a representative test abrasive, but it is not satisfactory in regard to dust-induced corrosion prediction since naturally occurring clay minerals, for instance, are much more strongly adhesive and hygroscopic.

One addition to MIL-STD-810B/510 would be to include a step in which humidity is maintained at 80% or greater to simulate tropical climates.

It is the belief of this author that the determination of a pedologically more realistic world-wide "Standard Dirt" for dust testing is unwarranted. It is simply necessary to be cognizant of these areas of high dust abrasion/corrosion potential and to faithfully take the necessary precautions (i.e., periodic and regular fresh water washdowns, strict utilization of engine and nacelle covers, etc.).

VI. SUMMARY

Investigation described in this report has provided additional knowledge as to the general character of world dust (particularly in the vicinity of military bases).

It is the belief of this author that the heavy mineralogy of world soil epipedons is not a contributing factor regarding dust abrasion potential. That quartz, although probably not a satisfactory indicator of corrosion due to dust ingestion, is the most common and most abrasive mineral constituent of dust, there is little doubt. Thus, quartz is a representative dust test abrasive.

The ten soil orders of the new U.S.D.A. Soil Classification System have been ranked as to their dust abrasion/corrosion potential. A world map presentation for the distribution and dust damage potentials of aridosols and ultisols/oxisols is included.

Lastly, a hypothesis is presented for the excessive dust erosion problem experienced in Vietnam. Contrary to popular belief, the erosive species is believed not to be laterite (primarily a mixture of 1:1 clay minerals and the hydrous sesquioxides of iron and aluminum), but rather the relatively coarser, more angular, and more readily available quartz grains. Further, the situation was accelerated in two ways: (1) the continuous, prolonged nature of the operations produced more dust and (2) the area had a high corrosion/erosion-corrosion potential due to the high humidity, close proximity to the coast, and adhesive, hygroscopic nature of the dust.

VII. RECOMMENDATIONS

Concerning the current research effort being conducted by the Naval Weapons Center, it is felt that further acquisition of soil samples and associated dust environment characteristic investigation be terminated. Aside from the collection of dust particles emitted from the tail pipes of jet engines in order to investigate the possibility of thermochemical alteration of these particles, all further research should be directed toward a prevention or minimization of the problem; i.e., the development of (1) materials with higher abrasion/corrosion resistance, (2) adequate filtering techniques, and (3) techniques to hold down the dust.

APPENDIX A

APPARATUS

1. AGATE MORTAR AND PESTLE
2. METTLER BALANCE
3. NORELCO X-RAY DIFFRACTOMETER
4. U.S. STANDARD SIEVE SERIES
5. 1000 ml BEAKERS (6)
6. 3000 ml BEAKERS (2)
7. HOT PLATE (2)
8. FILTER PAPER (11.0 cm)
9. SEPARATORY FUNNELS
10. THERMOMETERS (2)
11. OTTAWA SAND
12. FUNNELS

REAGENTS

1. SODIUM HYPOCHLORITE
2. SODIUM CITRATE
3. SODIUM BICARBONATE
4. SODIUM HYPOSULFITE
5. POTASSIUM OXALATE SOLUTION (103.7 g/1)
6. OXALIC ACID SOLUTION (95 g/1)
7. MAGNESIUM RIBBON
8. HYDROCHLORIC ACID
9. ACETONE
10. BROMOFORM

PROCEDURE

After the initial aggregate dispersion and separation procedures, place 100 g of sample in a 1000 ml beaker.

A. REMOVAL OF ORGANICS

Add to the sample 200 ml of sodium hypochlorite solution freshly adjusted to pH 9.5. Place the beaker in a boiling water bath for 30 min [Fig. 7A]. Wash three times with distilled water by sedimentation and decantation.

B. REMOVAL OF SESQUIOXIDES

1. Dithionite Method

After washing following removal of organic matter, add 300 ml of distilled water to the material left in the beaker. Add 24 g of solid sodium citrate and 2.8 g of solid sodium bicarbonate. Heat on a sand bath to 75-80°C with stirring [Appendix A, Fig. 7B]. Add 7 g of solid sodium hyposulfite and stir constantly for 5 min and occasionally for 10 min. Wash with repeated sedimentation and decantation.

2. Oxalic Acid-Magnesium Ribbon Method

If carbonates have not been removed, treat with appropriate amount of hydrochloric acid [Brewer, 1969]. Place 2 g of sample in a 150 ml beaker, add 40 ml of potassium oxalate solution and heat to 80°C on a sand bath. Add 10 ml of oxalic acid solution, stir and heat to 90°C. Add about 8 inches of Mg ribbon (0.2 g), stir, and keep at 90-95°C for 3 to 5 min. (This is best achieved by bending a stirring rod into a loop at one end and wrapping the Mg ribbon around the loop. Stirring then introduces the ribbon and it is simply removed by removing the stirring rod.) Add an additional 5 ml of oxalic acid solution and continue heating for 3 min. Wash by repeated sedimentation and decantation. Proceed to step #4 on the following flow sheet.

FLOW SHEET FOR MINERAL ANALYSIS

1. Subsample the bulk sample, after initial dispersion and separation from non-soil matter (thermally altered polyethylene, rock fragments, twigs, etc.), to obtain a representative 100 g.
2. Remove organic matter
3. Remove sesquioxides
4. Separate into size fractions
5. Perform heavy mineral separation
6. Perform magnetic separation
7. Mount portion of remaining separate on slides for microscopic analysis
8. Finally, grind remaining portion to required specifications for x-ray analysis

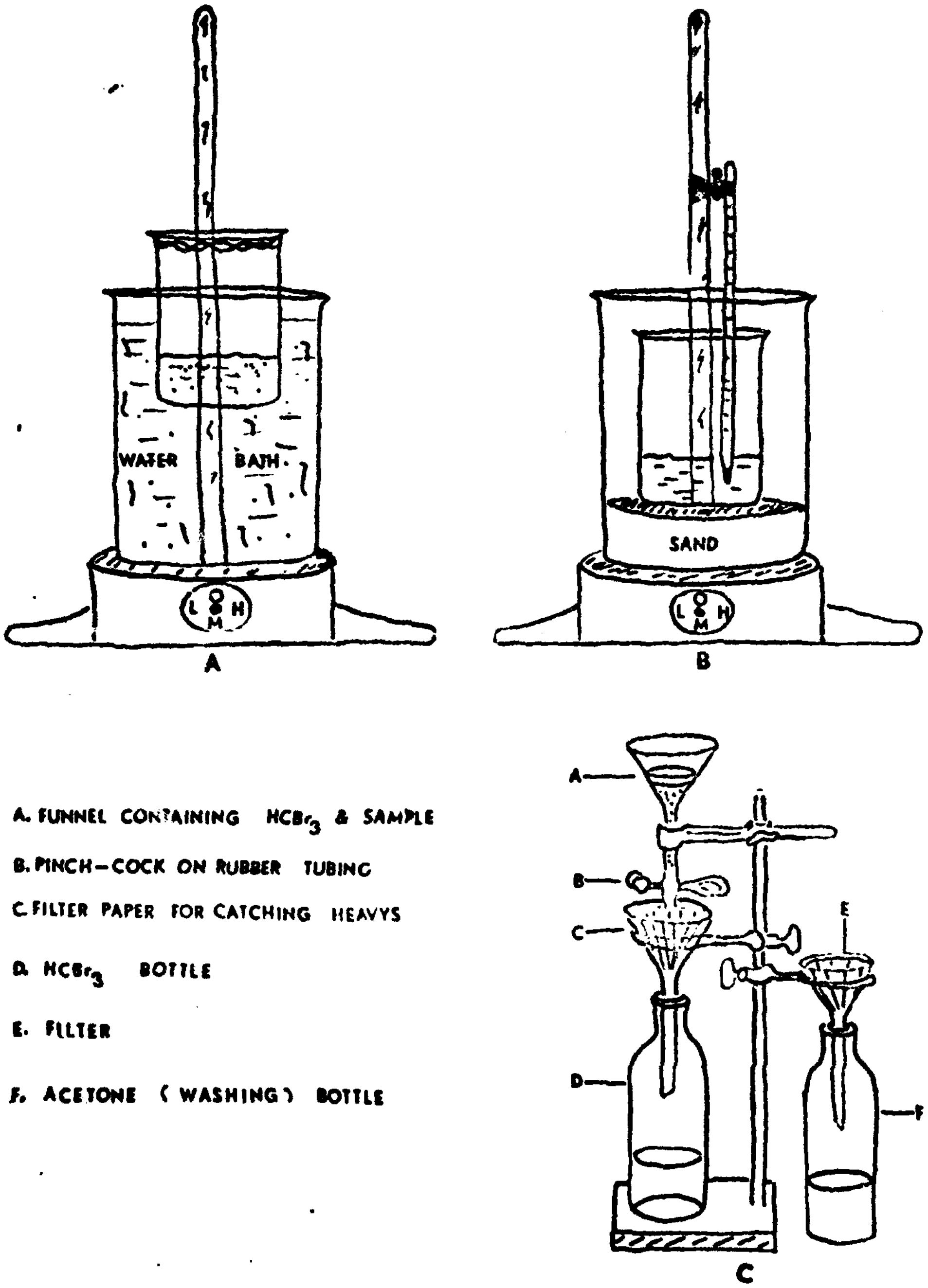


Fig. 7. Soil Preparation Apparatus

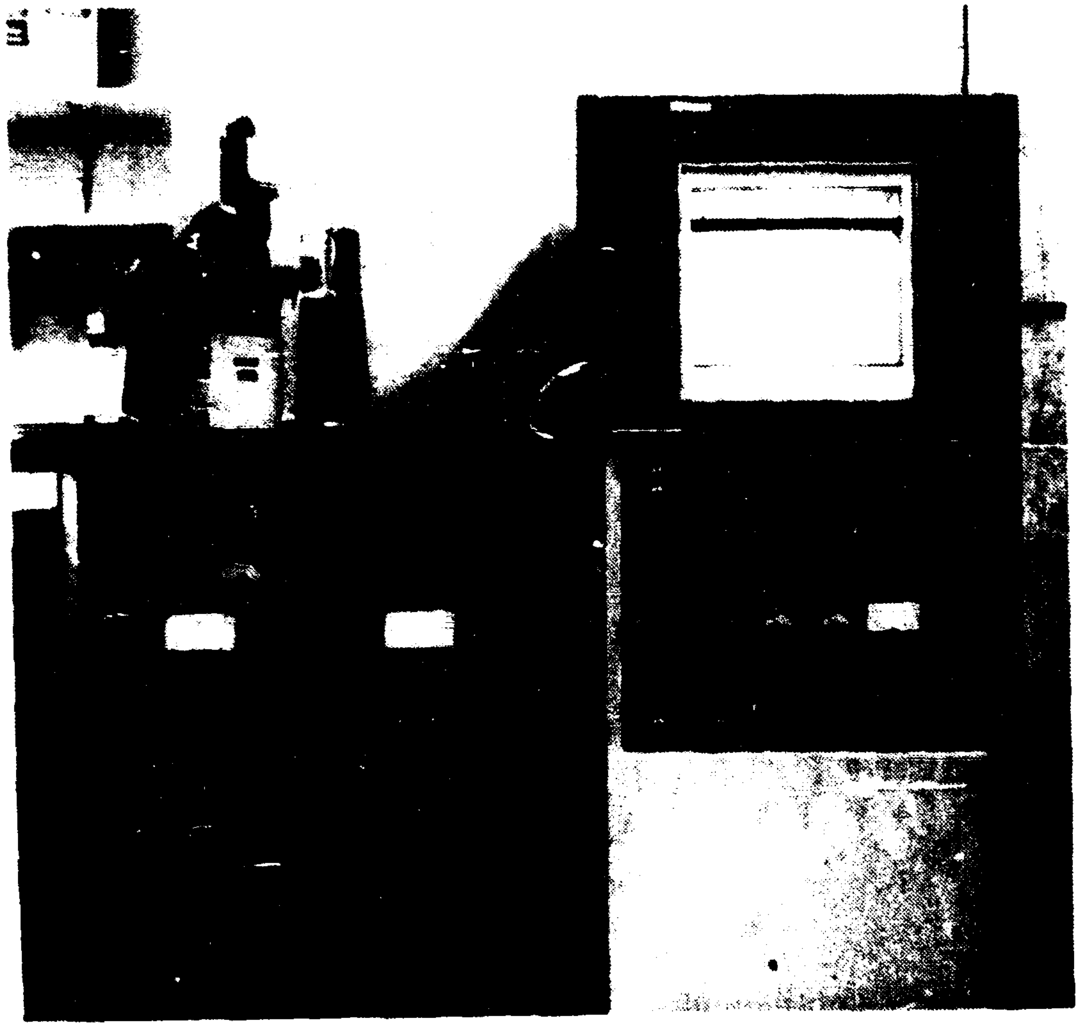


Fig. [illegible] [illegible] Diffractometer

APPENDIX B

TABLE VI

HARDNESS CONVERSION TABLE

ROCKWELL A	KNOOP	MOH
20	77	<3
25	85	<3
30	95	<3
35	107	<3
40	122	<3
	135	=3
45	143	>3<4
	163	=4
50	167	>4<5
55	196	<5
60	241	<5
65	304	<5
70	391	<5
	430	=5
75	518	>5
	560	=6
80	690	>6
	820	=7
85	875	>7
86.5	972	>7
	1340	=8
	1800	=9
	7000	=10

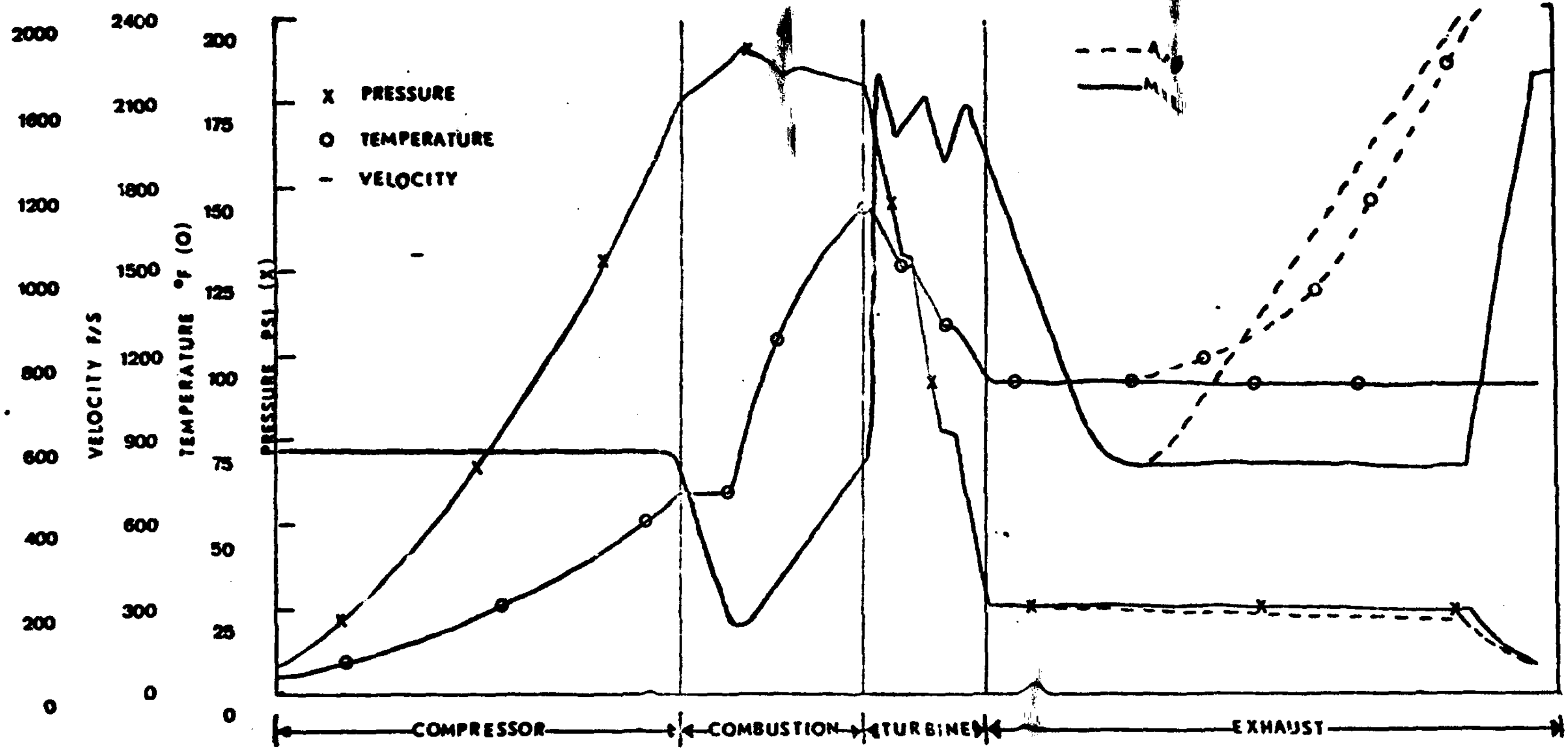


Fig. 9. Temperature, Pressure and Velocity Profile for the J-79 Jet Engine (from NAVAIR 02B-105AGC-503, NAVAIRSYSCOM Tactical Overhaul Manual)

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