SPECTRAL REFLECTANCE QUALITIES OF SOILS WITH VARIOUS SALTS AND MOISTURE LEVELS IN THE ULTRAVIOLET, VISIBLE AND NEAR INFRARED REGIONS OF THE ELECTROMAGNETIC SPECTRUM

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CHAPTER I

INTRODUCTION

General

In this highly scientific age, with the development of most sophisticated high altutide aircraft and earth satellites, it is becoming more possible to survey the earth from a vantage point heretofore unobtainable. Surveillance systems integrated into these high altitude and space vehicles make possible more rapid acquisition of geophysical data over large areas of terrestial environment. Therefore, the need to detect and identify various targets and their conditions in the universe from data collected by sensors which are situated at large distances from the area under investigation, becomes immediately apparent.

God has provided human beings with remote sensors such as eyes, ears, skin, and nostrils; these, however, have their limitations. Owing to the limitations of these natural sensors, a long need has been felt to complement them with highly efficient optical and electronic devices commonly called remote sensors. The function of these devices is to detect and record energy which is either emitted or reflected from the objects and which would otherwise not be detected by human natural sensors.

Remote sensing is possible only when the properties of an object under investigation present some disturbing influence at the point of detection. This disturbing influence then acts upon some sophisticated device which has been devised for detection and measurement.

There are principally two ways that remote sensor data can be profitably used:

(1) For identification of objects, and

(2) For determining some property of an object.

Identification may be simply based on shape, size, or any other criteria, which may best be accomplished through photography and which can be considered a duplicate of human visual senses. The required property of an object on the other hand, may be obtained directly or indirectly from measurements made with remote sensors. For instance, in photography the film which is the sensor directly records the levels of reflectance in different wavelengths of the spectrum, i.e. ultraviolet, visible, and near infrared, and indirectly distinguishes object shape or size. Moreover, with these discriminatory properties of reflectivity, and with the use of proper film filter combination, such things as soil type, soil moisture content, and even the relative geologic ages of soils such as glacial till may be determined (19). Any surface can be viewed by means of an optical device or sensor which detects and measures the energy reflected from the surface or energy radiated by the surface. The character of the reflected or emitted light depends upon the quality and texture of the surface, and also upon the intensity and spectral quality of the radiation falling on the surface. Due to the differences in spectral quality, and intensity of reflected radiation, and in intensity of emitted radiation, certain objects can present quite different views. For example, the view of a cultivated land will be quite different from a barren land, or a waterlogged soil from a dry soil, or a saline soil from non-saline soil.

A portion of the required information may be best obtained, when sensing the energy returns in one part of the electromagnetic spectrum, while another portion of the information requires sensing in a quite different part of the spectrum. It is possible to obtain in the laboratory spectral reflection curves for materials expected to be found in an area covered by an aerial survey. On the basis of these curves, it is also possible to select film filter combinations which can lead to maximum contrast under actual field conditions. For example, if spectral reflectivity curves of two different materials show maximum separation in the unshaded region of Fig. 1, a tri-X film with a 25A filter would be the best combination chosen for detection of one such material surrounded by the other (11). However, in solving actual field problems, things are not so simple, because the earth is surrounded or made up of complex mixtures and patterns even within very small areas. Therefore, no one band of the electromagnetic spectrum would be expected to provide all of the information needed for determining terrain characteristics. Sensing at different wave bands of the spectrum (multispectral sensing) may be the best method of obtaining the maximum amount of information in a certain area.

A device which was recently developed by Itek Corp. for obtaining records in different spectral ranges, is a nine lens multiband camera. The complete data of this camera is given in Table 1 and is shown in Fig. 2. This multiband camera takes photographs in 4,000-9,000A^{o} (wave length) range. This range is further divided into nine matched lenses with different filters. This camera takes nine pictures of the same area instantaneously. It takes six exposures on two rolls of 70

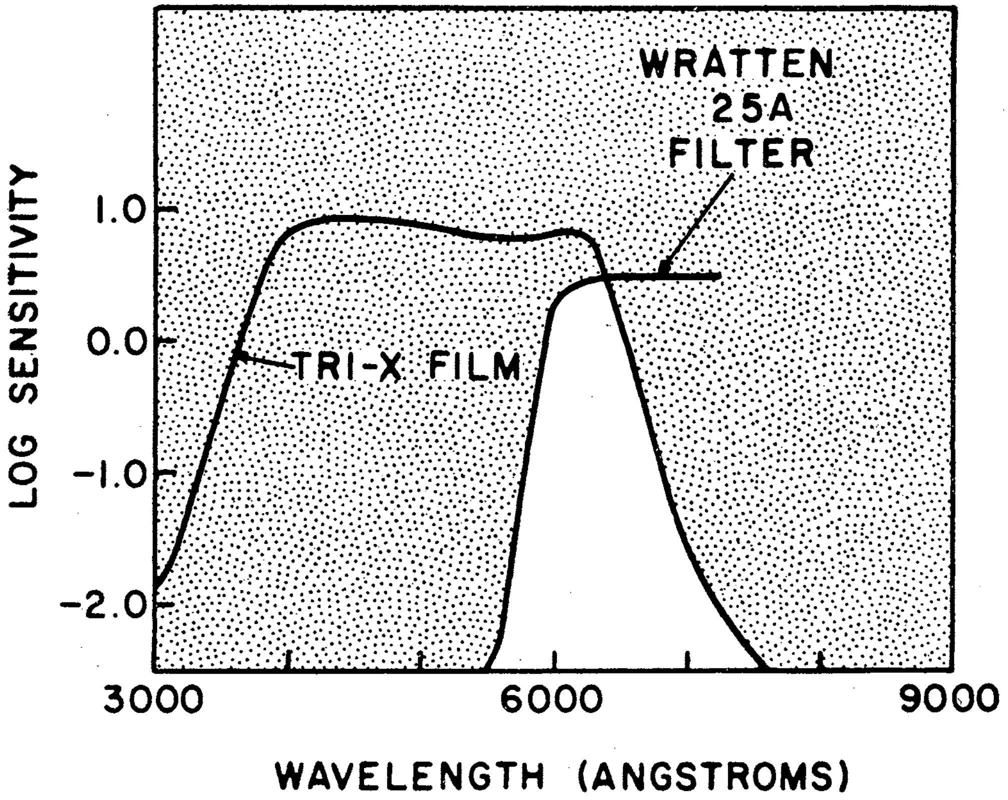


Figure 1. Tri-X Film and Wratten 25A Filter Combination

TABLE I

MULTIBAND CAMERA DATA

Lenses	Nine 6-inch f/2.8 Schneider Xenoter matched lenses
Film Type	Two rolls of 70-mm Plus X Aerographic One roll 70-mm Infrared Aerographic
Frame Format	Nine Frames each 2-1/4 inch by 2-1/4 inch
Exposure Technique	Three exposures on each roll of film
Shutter System	Three parallel focal plane shutters of three slits each, to expose all nine frames simultaneously
IMC	Modified A9-B magazine with film drive IMC

MULTIBAND CAMERA SPECTRAL BANDS

Lens No.	Bandwidth (mu)	Filters Used
1	400-500	Wratten 2B + 35 + 38A
2	450-510	Wratten 3 + 47
3	520-550	Wratten 15 + 65
4	550-600	Wratten 57 + 12 + Balzers 155/116
5	590-640	Wratten 90 + 24 + Optics Tech. Interference
6	670-720	Wratten 36 + 12
7	700-810	Wratten 89B + Balzers 455/141
8	810-900	Wratten 87C
9	Full Sensitivity range of IR film	

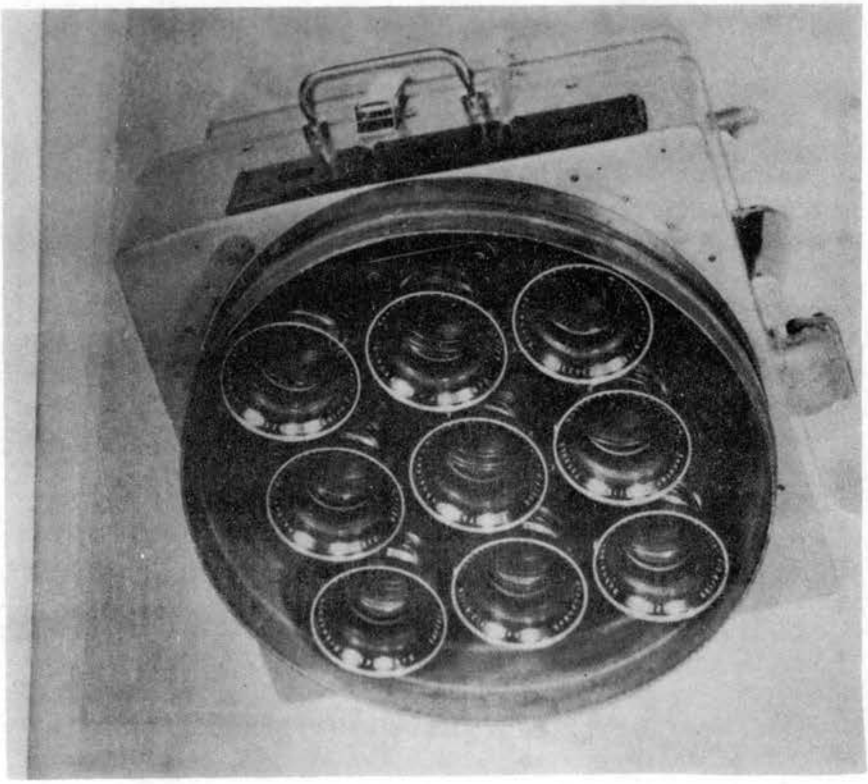


Figure 2. Itek Nine Lens Multiband Camera

mm panchromatic film and the other three exposures on one roll of 70 mm infrared film. Eight different narrow band portions of the spectrum are represented in eight exposures while the ninth exposure is the full sensitivity range of the infrared film (17).

Purpose and Scope of Study

This investigation was undertaken in an attempt to determine the spectral ranges at which a maximum contrast exists between the soils examined.

In this study series of samples were prepared from river sand and common gray silty clay. The variation in moisture was from zero and hygroscopic level, to a hundred percent of the water holding capacity of the soils. The salt concentration varied from zero parts per million (ppm) to 192,000 ppm on the basis of dry soil.

Samples were examined in a spectrophotometer equipped with a reflectance attachment. Reflectance readings were recorded in the ultraviolet, visible and near infrared regions of the electromagnetic spectrum.

CHAPTER II

PRINCIPLES OF ELECTROMAGNETIC SPECTRUM

General

Light and other forms of radiation consist of electromagnetic waves which travel at the rate of 186,000 miles per second in atmosphere. These normally travel in straight lines and are reflected and absorbed by different media. The Electromagnetic waves are usually classified by vibration frequency, and by wavelength. The spectrum of the electromagnetic waves includes radiations of wavelengths varying from 0.0001A^o (cosmic rays) to radiations of wavelengths exceeding 100 meters (radio waves).

Although the energy radiated from the sun occupies a small portion of the electromagnetic spectrum, it is the biggest and most continuous source of radiation. The portion occupied by the solar energy in the electromagnetic spectrum is between 0.22 to 3.3 microns (4). The invisibly short but potent ultraviolet waves which are shorter than 0.4 microns constitute approximately nine percent of the solar energy, whereas, the infrared which lies beyond 0.7 microns constitutes 50 percent of the total solar energy. The visible light waves which lie between these limits constitute the remaining 41 percent of the solar energy. This solar radiation which continuously falls on the outer limit of the earth's atmosphere, normal to the sun's rays, has an average intensity of 1.4 KW per square meter. This quantity of energy (which is known as the solar constant) remains virtually unchanged. From this vast portion of energy only 46 percent actually reaches the earth's surface. 35 percent of the energy is reflected back into space by clouds, and 19 percent is absorbed by the atmosphere.

System of Radiation Measurements

There are two systems of measuring the radiation, namely, the passive system and the active system.

The passive system is one that samples the emitted radiation from an object. The object emits radiation as a result of its physical state. Radiometers that measure the emitted radiation in the infrared and microwave regions are examples of the passive system.

In the active system the object under investigation is actually illuminated with radiation of a particular wavelength and then the portion reflected back is measured. Radar is the best example of this system. Night photography, where an illuminating source is required, is another example. A daylight photographic system operating in the visible range may be classified as a semi-active system. In this system the illuminating source is not physically a part of it, here the illuminating source is the sun.

In nature, objects are not perfect radiators throughout the entire spectrum and hence, will reflect or transmit as well as absorb a part of the incident radiation. Due to this reason, best use of the property of reflectivity rather than emissivity can be made. At the radar end of the spectrum, radar energy of different frequencies can be transmitted and then the reflected amount of energy can be measured. At the visible end solar energy can be used as the illuminating source and the reflected part can be measured. Figure 3 gives an idea of the large amount of radiant solar energy reflected in the visible portion of the spectrum by a comparison of the reflected solar radiation from an object with ten percent (r = 10%) reflectivity to that of the emitted radiation from an object at a temperature of 300^{o}K. Thus it can be seen that with previous knowledge of the values of reflectivity of the soils in different physical conditions, within different spectral regions, predictions as to the appearance of these soils in various physical states can be made without great difficulty just from a display of the reflected radiation.

Path of Electromagnetic Radiation

In order to do remote sensing of the terrestrial environment, there has to be some atmospheric path between the source and the detecting device. There are numerous problems involved in transmitting the radiation from the source to the detecting device because of this atmospheric path in between.

Besides the inverse square law attenuation, the detectable force decreases as the inverse square of the distance between the disturbing element and detector (23), which depends upon the distance between the source and the detector, there are other losses caused by constituents in the atmosphere. If a graph of transmission through the atmosphere is plotted against wavelength, it is observed that the atmosphere is not transparent to all the wavelengths of the electromagnetic spectrum. It is only at certain wavelengths, that the electromagnetic waves can be transmitted, to an extent. Whereas, at certain other wavelengths

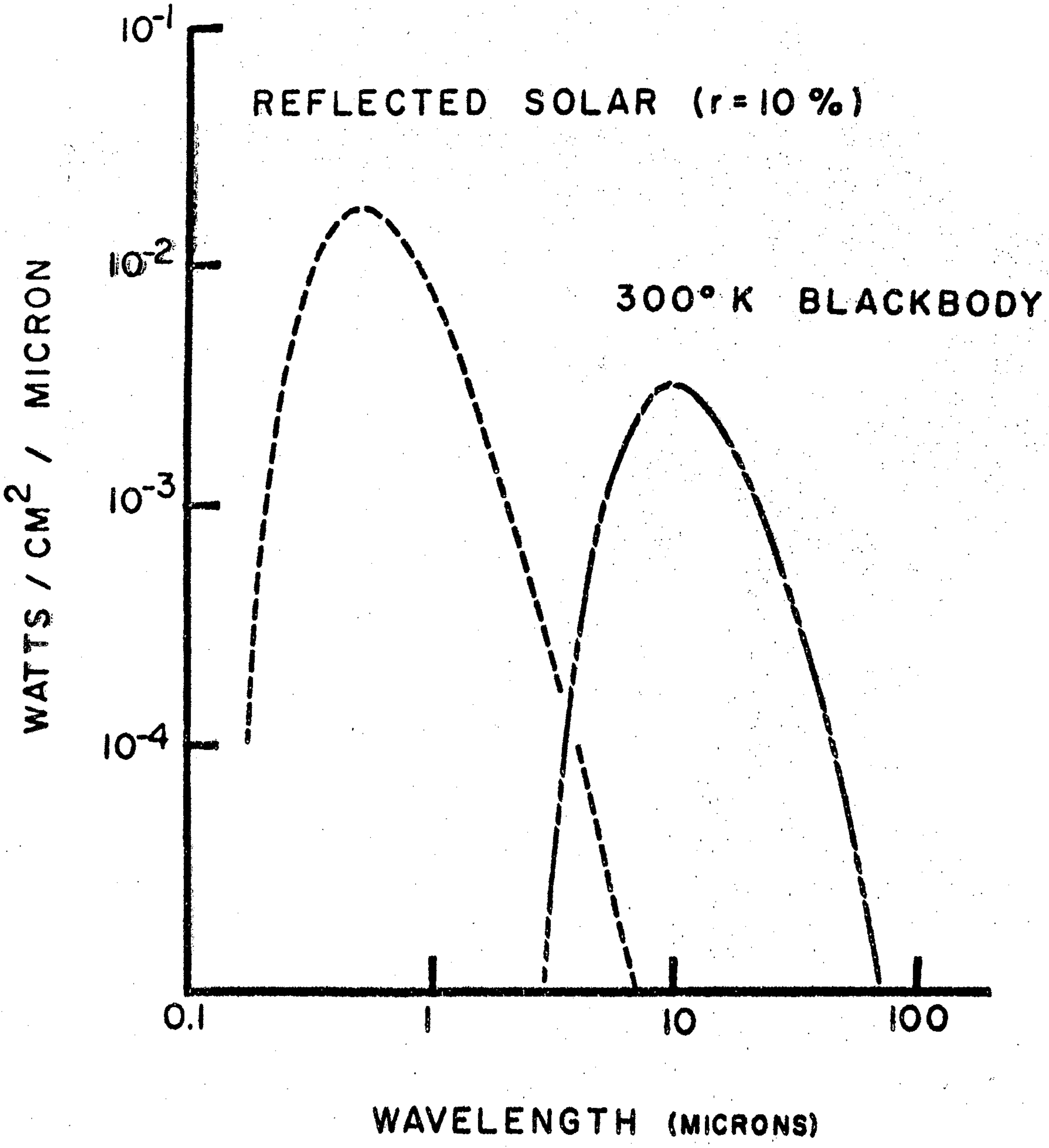


Figure 3. Reflected and Emitted Radiation

the atmosphere is almost completely opaque. A typical transmission spectra of the atmosphere is shown in Figure 4. The closely hatched areas represent the regions in which transmission is completely blocked by the atmospheric constituents. The other regions show the windows for the other wavelengths of the electromagnetic spectrum. It is only due to these windows, that a large percentage of the total energy emitted or reflected is allowed to pass through the atmosphere. Thus, the optimum spectral region for obtaining a certain set of information is determined by the atmospheric transparency to the propagation of electromagnetic radiation.

Besides the absorption of radiation due to certain atmospheric constituents, there is also another problem involved. This problem is the scattering and reflection of radiation by particles, water droplets and clouds. This scattering of the radiation takes place according to a law which was formulated by Lord Rayleigh. The law states that the intensity of light scattered by the atmospheric particles much smaller than a wavelength in diameter is inversely proportional to the fourth power of the wavelength (10). Thus from the above law, it can be deduced that the particles of about 0.25 microns size scatter radiation of ultra-violet and blue frequencies to a great extent. This scattering of radiation decreases towards the longer wavelengths in the visible portion of the spectrum. Also for this reason fog particles of approximately eight microns in diameter will fully attenuate by scattering radiation in portions of the infrared region of the spectrum. Thick clouds of large area act as complete shields between the detector and the source of radiation in visible and infrared regions. As such, it is noted that there are numerous obstacles involved in the

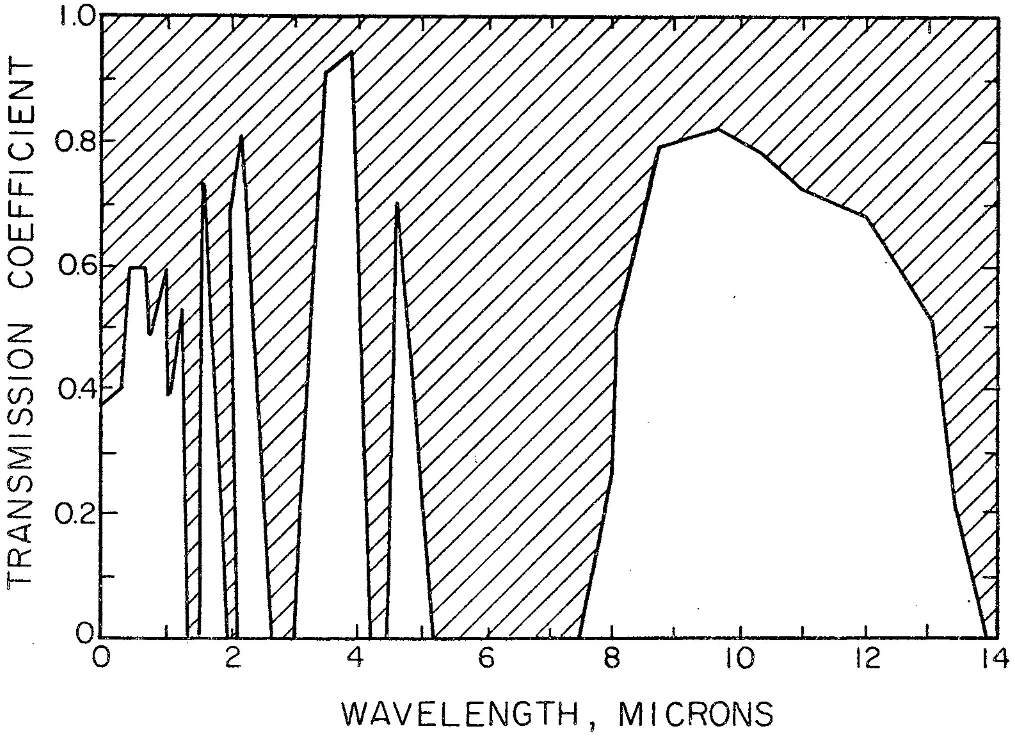


Figure 4. Transmission Spectra of Atmosphere

transmission of electromagnetic radiation.

UltraViolet Radiation

In 1801 J. W. Ritter investigated the blue end of the spectrum and found that a chemical reaction was caused by some form of energy in the dark portion beyond the violet. It was found that silver chloride exposed to radiation in the region beyond the violet decomposed more readily than when exposed to radiation in the visible part of the spectrum (12).

Thus ultraviolet is an electromagnetic radiation whose spectrum band occupies the region between the longest X-ray wavelength and the shortest visible wavelength. Figure 5 shows the region occupied by the ultraviolet in the electromagnetic spectrum. The ultraviolet spectrum is arbitrarily divided into near and far ultraviolet regions. These comprise the regions between the wavelengths 4000A^{o} to 3000A^{o} and 3000A^{o} to 2000A^{o}, respectively. The former includes the wavelengths found in the solar ultraviolet. The portion between 40A^{o} and 2000A^{o} is termed as the extreme ultraviolet, since radiation in this wavelength is strongly absorbed by air, it is necessary to place the apparatus used in its study in a vacuum or a gas which does not absorb ultraviolet. The region from 1850A^{o} to 1200A^{o} is called Schuman region after V. Schuman who was the first to investigate it (12).

Sources of Ultraviolet Radiation

The sources of ultraviolet radiation can be divided into two classes, namely natural and artificial.

The most important natural source of ultraviolet radiation is the

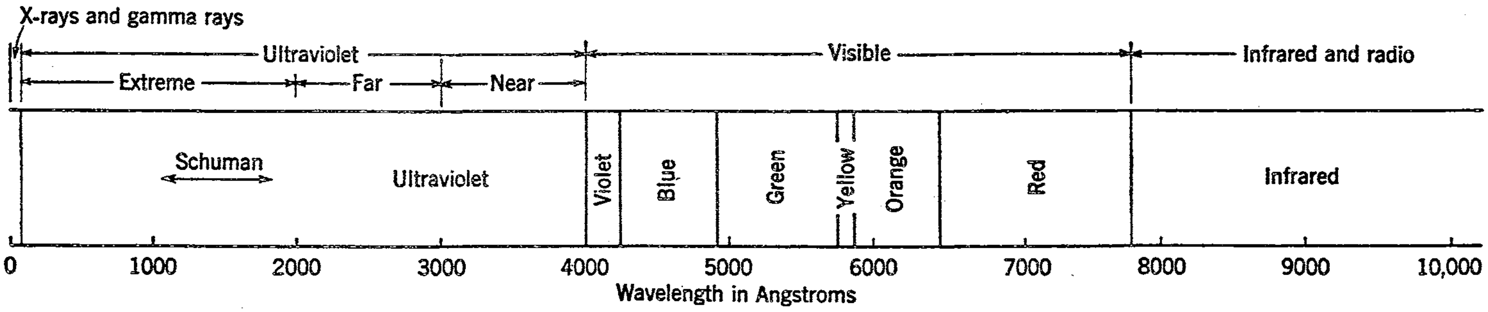


Figure 5. Position of Ultraviolet Radiation in the Electromagnetic Spectrum

sun. Ultraviolet radiation constitutes nine percent of the solar radiation. The solar ultraviolet intensity at the earth's surface depends on a number of factors. These are, time of day, time of year, latitude, elevation above sea level, atmospheric turbidity, and thickness of ozone layer.

The principal artificial sources are the mercury arcs and the carbon arcs. Ultraviolet output from ordinary incandescent lamps is so small that it can be neglected for most purposes.

Transmission of Ultraviolet

There are two most important factors involved in the decrease of intensity of ultraviolet radiation. Part of the decrease in intensity is due to true absorption in the atmosphere, which results in a portion of the original radiation being changed into some other form of energy, such as heat. Another portion of decrease in the intensity of the radiation, is as a result of scattering. This scattered portion is not changed into any other form of energy but is merely diverted from its original direction of propagation.

The transmission of ultraviolet light through clear air is shown in Figure 6. It is observed that for a distance of one meter, absorption in air is negligible, but at greater distances the absorption in the shorter wavelength is quite appreciable. In the presence of moisture and fog, or smoke in the atmosphere, the transmission of radiation may be much lower. It is clear from Figure 6 that the absence of wavelengths shorter than 2900A^{o} is not a result of absorption by air, but it is due to wavelengths being completely filtered by ozone in the upper atmosphere. Pure water in thin layers has a high transmission

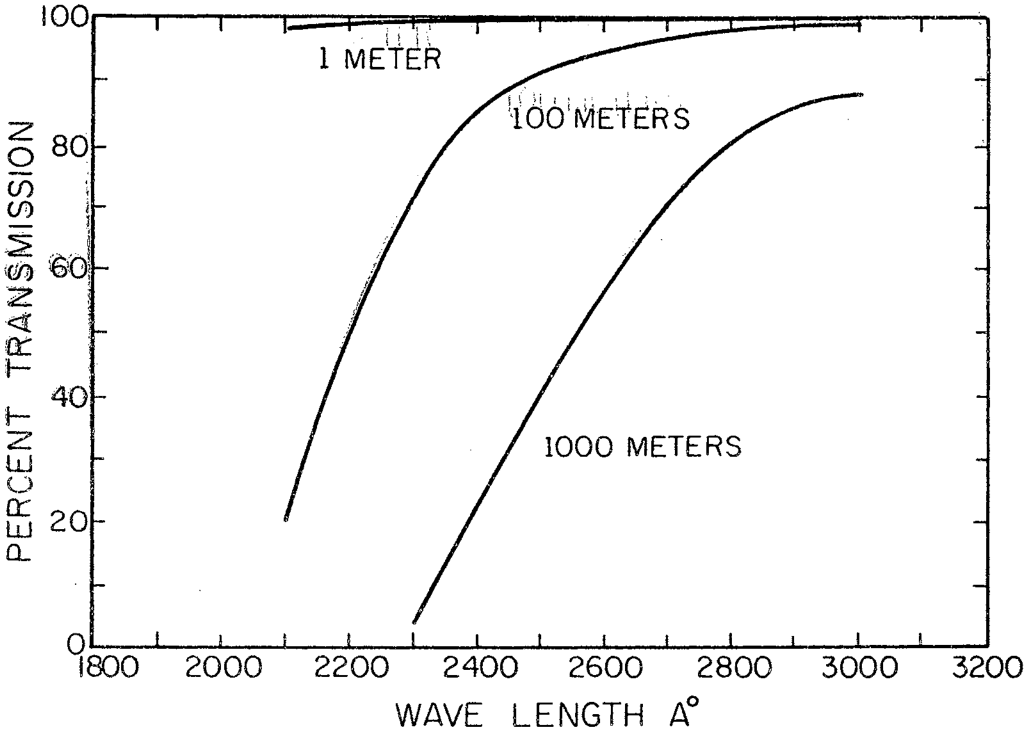


Figure 6. Curves Showing the Percent Transmission of Ultraviolet Through Clear Air

for wavelengths greater than 2900A^{o}, Figure 7. The absorption is quite appreciable when the thickness is 100 cm. Actually, water vapor in the atmosphere does not contribute much towards absorption of ultraviolet radiation, since moisture content of 100 meters of air fully saturated at 20 degrees centigrade is only equivalent of a layer of 0.17 mm thickness. From Figures 6 and 7 it is noted that absorption of such thickness of water is quite small in comparison with the absorption observed in the air. The effect of impurities in the water from different sources in case of transmission is quite different. In case of water containing organic matter the absorption is very high. According to Hodgman (8), "low transmittance of natural fresh water cannot be attributed solely to dissolved substances but may be largely due to the presence of very small particles."

According to Hulbert (9) in the wavelengths between 2500 and 3000A^{o} $MgCl_2$, $CaSO_4$, and the water constituents of sea-water each contribute about one third to the absorption, the other salts giving relatively little absorption.

Infrared Radiation (IR)

IR was discovered by Herschel who found that a thermometer placed beyond the red part of the spectrum gave a higher temperature than when placed in the visible region. IR, like ultraviolet, cannot be detected by the human eye. Thus it is an electromagnetic radiation emitted as a result of vibrations of the atoms within any material having temperature above $-273^{o}C$ ($0^{o}K$).

The infrared spectrum lies between 0.72 and approximately 1,000 microns, which is between the boundary of visible light at the shorter

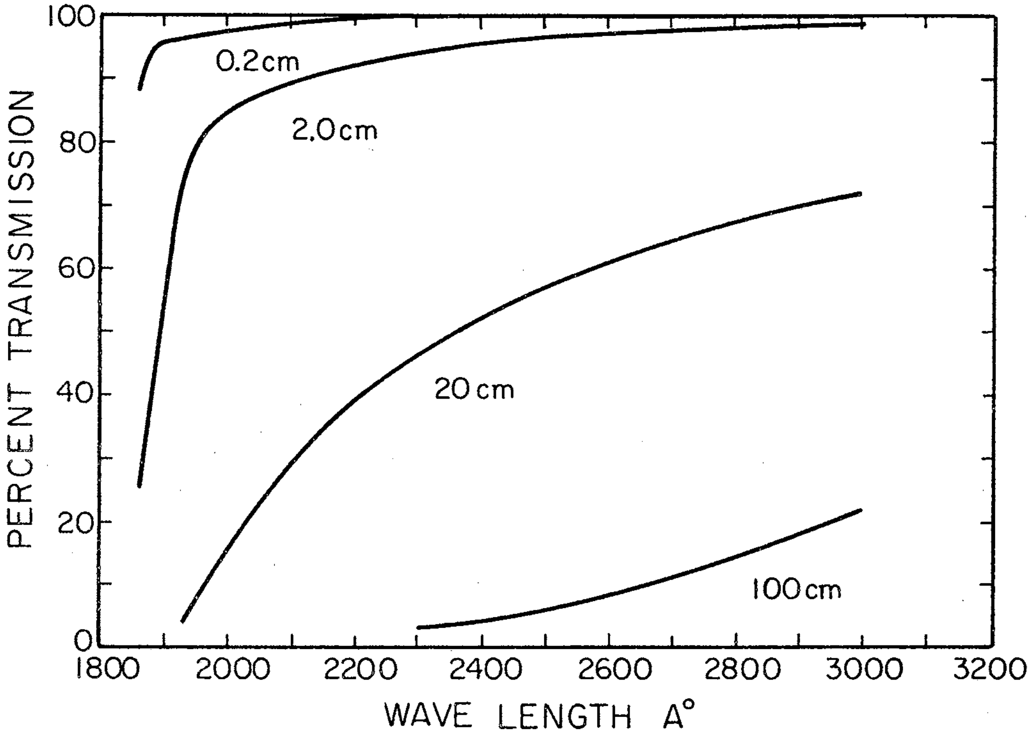


Figure 7. Curves Showing the Percent Transmission of Ultraviolet Through Pure Water Layers

wavelength end, and of microwaves at the longer wavelength. The infrared radiation overlaps the red end of the visible light spectrum on one side and the microwave on the other side. Hence, infrared radiation exhibits some of the characteristics of both visible light and of radar and radio waves. Thus, infrared can be focused and directed by lenses and mirrors like visible light. It can also be transmitted like radio or radar waves through materials which are opaque to visible light.

Due to the development in detecting devices, the infrared radiation is arbitrarily divided into three divisions for the common use. The three divisions are near infrared, intermediate infrared, and far infrared (6).

The near infrared occupies the portion between 0.7 to 1.5 microns. The intermediate or middle infrared occupies the portion between 1.5 to 5.6 microns. The far infrared occupies the portion between 5.6 to 1000 microns. The position of infrared with arbitrary divisions is shown in Figure 8.

Sources of Infrared Radiation

Sources of infrared radiation are numerous, but can be classified under two main categories.

a. Artificial Sources

b. Natural Sources

The artificial sources of infrared radiation are numerous. These include vapor lamps, gas discharge tubes, arcs, flash lamps, and flares. Even an ordinary light bulb emits to some extent infrared radiation, but this is a very poor source. On the other hand, an infrared heat lamp with a tungsten filament serves as a very good source of infrared

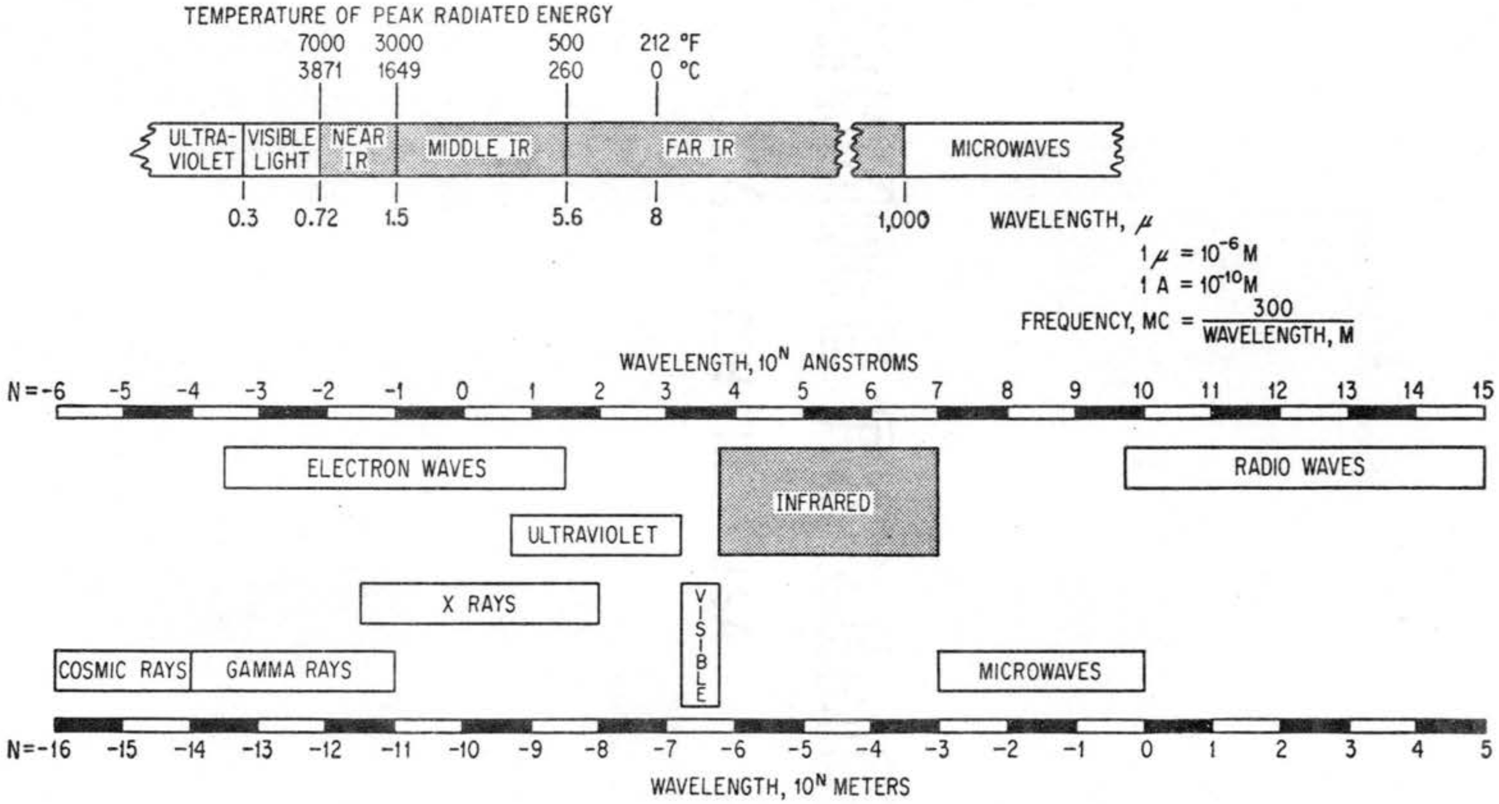


Figure 8. Position of Infrared Radiation in the Electromagnetic Spectrum

radiation. These small tungsten filaments operated at 20 to 30 amperes produce a peak output in the region from about 0.7 to 3.0 microns.

The majority of the above mentioned sources generate a wide frequency spectrum and require the use of filters or monochromators to limit their radiation to the required infrared wavelength.

The natural sources of infrared radiation are also numerous and may be broadly classified into three categories.

a. Terrestrial Sources

b. Celestial Sources

c. Atmospheric Sources

Terrestrial Sources. All the natural sources found on the surface of earth, such as trees, bushes, rocks, soil, and water come under this category. Spectral characteristics of the radiation emitted depend upon the sources, temperature, and surface characteristics such as emissivity and reflectivity.

Celestial Sources. Natural sources of infrared radiation comprise of heavenly bodies like the sun, planets, stars, and moon. Of all these natural sources the best thermal source of infrared radiation is the sun. Nearly 40 percent of its energy is in the form of infrared radiation. Though the energy received from sun peaks in the visible spectrum, considerable radiation extends well out in the far infrared region, whereas on the other hand an incandescent light bulb's energy peaks in the infrared region, Figure 9 (15).

Atmospheric Sources. Atmospheric constituents like dust particles, water droplets, and molecules of various gases also behave ~~like sources~~ of infrared radiation. These scatter, reflect, and absorb and subsequently reemit radiation falling on them from celestial and

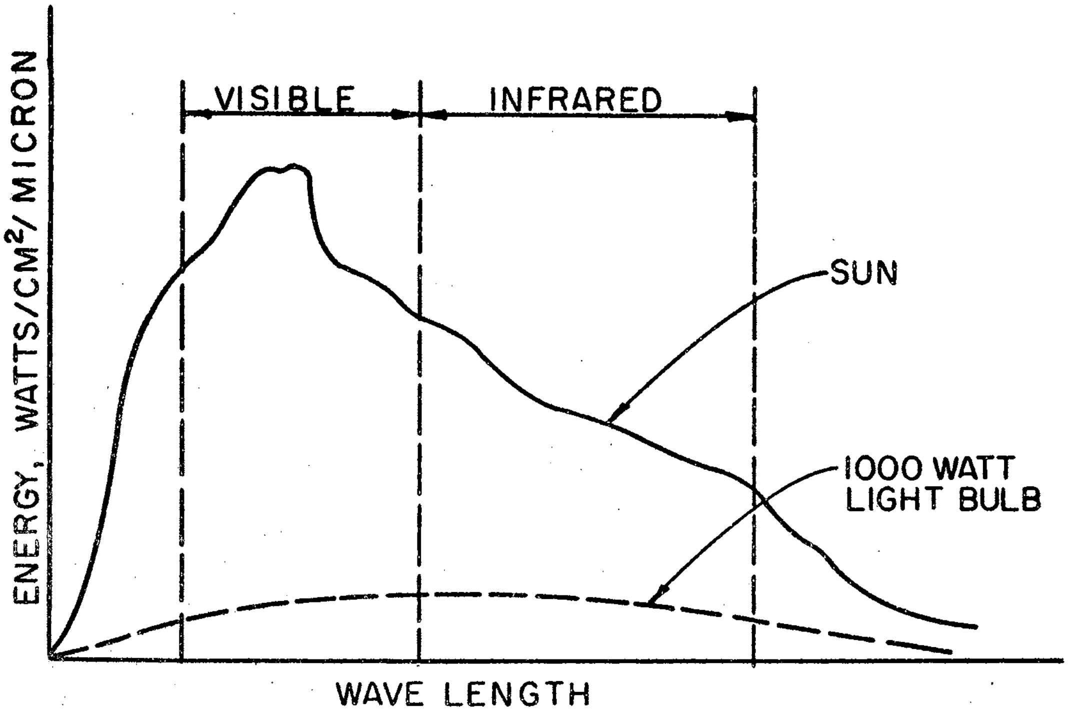


Figure 9. The Relative Energy Emission of the Sun in Comparison to a Light Bulb

terrestrial sources.

Atmospheric Absorption of Infrared Radiation

There are great many obstructions in the path of the infrared radiation from source to object and finally object to the detector. These impose severe limitations, which must be carefully considered.

The atmosphere is far from being a pure substance, it is a mixture of water vapor, carbon dioxide, nitrogen, oxygen, rare gases, and also the suspended particles such as haze, smog or dust. Any radiation passing through the atmosphere is either reflected, scattered or absorbed by the atmospheric constituents before being finally transmitted.

Of the atmospheric constituents, water vapor is the principal attenuator of infrared radiation. It causes the greatest transmission loss over this spectrum. Next to water vapor is carbon dioxide. The distribution of this in atmosphere is practically constant and its attenuation of infrared radiation is independent of changing weather conditions. All atmospheric ozone is limited to a layer at an altitude of approximately 80,000 feet and for most purposes the effect of it on infrared transmission below this altitude can be neglected. Figure 10 illustrates the infrared absorption bands and the transmission spectra of the atmosphere. The darker areas are the regions in which the transmission is completely blocked. The wavelength regions between the darker areas are called windows. These are regions of maximum infrared transmission. As a result of this natural phenomenon, if transmission of radiation is required through the atmosphere, the wavelength regions between absorption bands called the windows will only be

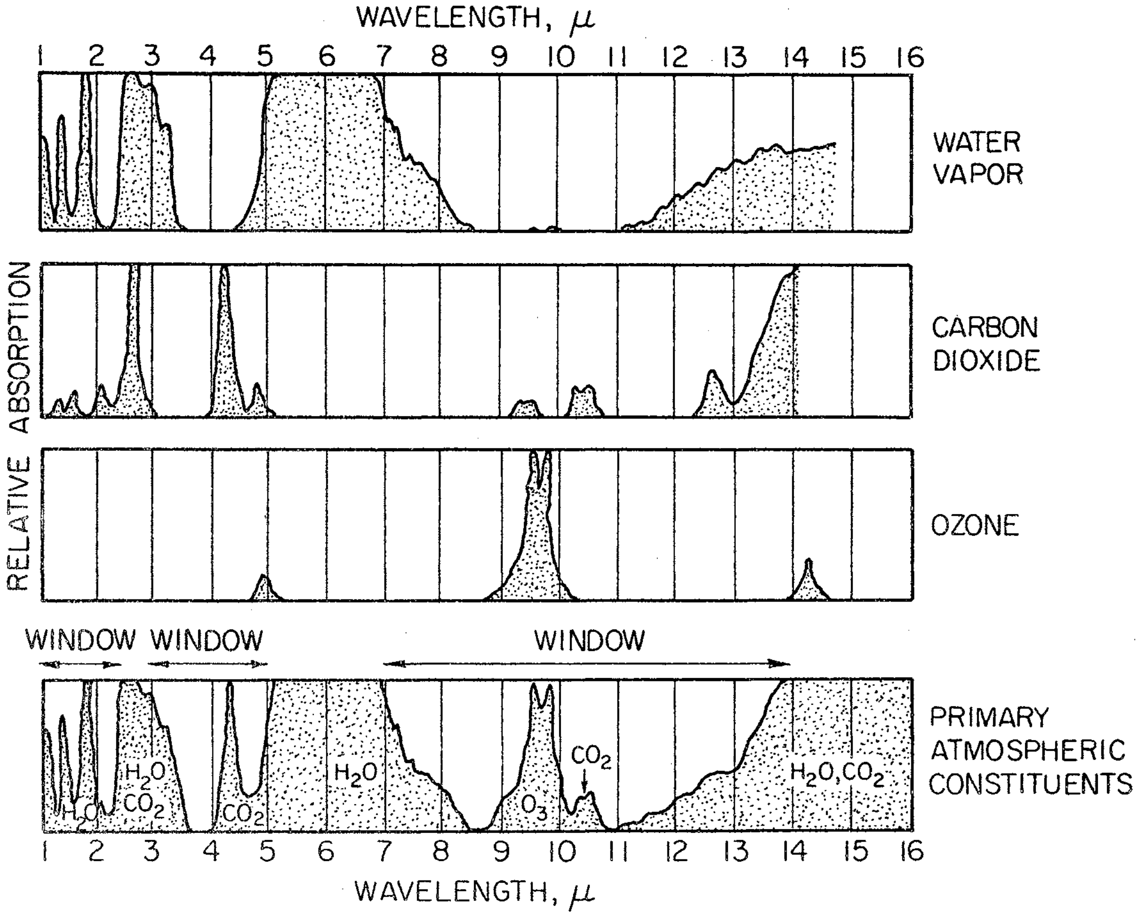


Figure 10. Infrared Absorption Bands of Primary Atmospheric Constituents

of little use.

A different form of attenuation is caused by scattering of the incident radiation, by dust particles, and water droplets. This form of attenuation increases rapidly towards the visible region. It is negligible in the middle regions at wavelengths greater than four microns.

Lastly, it should be noted that infrared radiation does not penetrate mist and fog. Due to longer wavelengths infrared can penetrate atmospheric haze more effectively than visible light, transmission through fog and clouds, however, is only a little better than for visible light.

CHAPTER III

REVIEW OF LITERATURE

Research on reflectance characteristics of soils, rocks, and plants under various conditions of moisture and salinity have been done in the U.S.A. and Russia. These investigations have been for the most part piecemeal research projects conducted at different times by research workers in these countries, for various purposes. In most of the cases, different measurement techniques have been employed with the result that non-uniform data exists but many of these data are quite valuable and are worthy of attention.

Moreover, published works on the spectral reflectivity characteristic of natural and man-made objects at wavelengths longer than one micron are more rare. Some programs of measurements of infrared emissivity and reflectivity values of terrain features have been conducted, but in many cases these are laboratory and not in situ measurements.

In 1947 a Russian scientist, E. L. Krinov (13) showed that spectral reflectance of different natural objects is different for various wavelengths of the spectrum both in the visible and invisible range. Krinov's work contains the results of reflectance measurements taken on 370 natural and man-made objects, in the region of 400 to 900 millimicrons. This investigation on the spectral reflectance of natural formations also included reflectance measurements for dry and wet soils. From the reflectance studies, made by Krinov, it was observed that there exists a clear difference between the reflectance of dry and wet soils. The reflectance in case of dry soils was higher than that of wet soils. Moreover, the relative gap between the reflectance curves increases with the increase in wavelengths from the visible to near infrared. From the studies of E. M. Winkler (25) which included a review of Krinov's investigation, it was concluded that infrared sensitive photographic emulsions should clearly record the difference between dry and wet soils if wavelengths shorter than red are cut off with proper filters.

Shockley et. al. (21) in their study considered the effects of grain size, moisture content, and density on reflectance of Yuma sand, Open Wood Street silt, and Harbor Project Clay. Besides these three soils, many other soils were tested which showed the same general type of relationship; but whose changes in the level of reflectance were different. It was observed that by increasing the amount of water at the surface, there was a continuous decrease in the percentage of infrared reflectance at any one of the wavelengths, i.e., 1.4, 1.75, 1.94, 2.25, 4.0, and 4.5 microns. At or near the optimum moisture content, the rate of decrease in infrared reflectance was reduced sharply, causing an inflexion point on the curve of reflectance versus moisture content, and infrared reflectance tended to reach a minimum. With further addition of water, only small changes in the reflectance were produced. This phenomenon is due to the fact that infrared does not penetrate deeply; the amount of infrared energy reflected from a soil is mainly a surface phenomenon. Addition of water to dry cohesive soil will first coat individual particles with a moisture film and simultaneously infiltrate into the soil to fill up the voids. Shockley observed that at or near the optimum moisture content, when nearly all soil particles have been coated and all interstices have been filled with water, the rate of decrease in infrared reflectance was reduced sharply and infrared reflectance reached a minimum. Further addition of water did not produce significant change in the level of reflectance. This was particularly so in the case of cohesive soils. In the case of sandy soils, Shockley found that the level of reflectance remains low and relatively constant after a certain moisture content.

In addition, a study of reflectance versus percent moisture content curves at a wavelength of 1.4 microns for 120 and 40 blows compaction effort, showed only a slight difference in reflectance (21). This slight difference in reflectance was attributed to the difference in the absolute quantity of water in a thin surface layer.

It was also found in the same investigation that if reflectance levels at the six wavelengths under consideration were known it was possible to produce a soil signature which would identify the unknown soil sample (21).

Obukhov and Orlov (18) conducted laboratory spectral studies on air dry samples passing a sieve with 1 mm openings. The effect of moisture was considered by artificially wetting the samples with distilled water.

The soils considered were (1) medium to coarse clay loam, changing into fine clay, and (2) silty medium clay loam changing to fine clay loam then into boulder free clay loam. In addition to these soils, studies were made on samples of several other soils. Reflection curve for chernozem soils, for example, were obtained for several tens of profiles.

All soils investigated by Obuklov and Orlov (18) had similar spectral reflectivity curves. Minimum reflection was observed in the blue-violet region of the spectrum. The maximum reflectance occurred in the red region of the spectrum (750 millimicrons) where the reflectance of same sample increased from 17 percent to 44 percent. It was very evident that reflectance increased with wavelength and that the greatest difference between the soil groups and soil genetic horizons in a single profile were observed in the red region of the spectrum. It was concluded that because of this general pattern, the long wave region of the spectrum is the most favorable for a qualitative and quantitative description of soils.

These authors (18) also supported the same view of others in considerations of moisture effects on reflectance. It was stated that reflectance decreased very rapidly when soil was wetted, but the spectral curves did not change in appearance upon wetting, nor when various fractions were measured. The decrease in reflectance was most prominent when wetting forest soils containing little organic matter. It was somewhat less prominent in cases of chernozems and red colored soils. It was observed in all soils, at full capillary moisture capacity, that reflectance was reduced by 35 to 50 percent, but further addition of moisture did not produce any change.

The data obtained lead to the conclusion that determination of the reflectance under field conditions did not yield explicit results (18). Comparison of laboratory results with field tests was possible if several constant conditions were maintained. Sometimes moisture variations and change in structure of soil surface, and in illumination conditions was found to cause such an increase or decrease in reflectance, which would even exceed the differences between soil groups.

Ashburn and Weldon (1) studied the spectral reflectance of various types of desert terrain in the spectral range of 400 to 650 millimicron. It was observed that the reflectance increased with increasing wavelength and in general at 650 millimicron, reflectance was about twice that at 400 millimicron. It was concluded that for all types of desert terrain, the reflectance in the blue region was significantly less than in the red region of the spectrum. Results of Ashburn and Weldon's investigation were consistent with Krinov's (13) and Penndorf's (20) measurements.

Several studies have been performed to determine the effect of grain size on reflectance. Shockley, et. al. (21) in their study used slag having relatively constant color and texture, but with grain sizes varying from very fine sand to medium gravel. The moisture content was 0.4 percent and was nearly constant but the density was allowed to vary with grain size. It was observed that as the grain size increases from 0.1 to 1.5 mm, the reflectance decreases, but beyond 1.5 mm the reflectance nearly remained constant. The investigators were of the opinion that beyond 1.5 mm reflectance could be a function of the surface characteristics of grain particles and not the grain size.

Mikhaylova, et. al. (16) expressed the opinion that spectrum of light reflection by soil surface is a complex function which depends on moisture content, structural characteristics, chemical and mineralogical composition. From their studies, it was noted that a slight change in the hygroscopic moisture content had a significant influence on the reflectance, after which spectral reflectivity decreased gradually as the moisture content increased.

Colwell (3) has shown the advantage of the use of multiband spectral reconnaisance as means for distinguishing between four different surfaces of soil, grass, cement and asphalt from a mere examination of aerial photos. Figure 11 shows the different levels of reflectance of the various surfaces with respect to wavelength. It is noted from the figure that the grass surface has lowest reflectance below 450 millimicrons and highest above 700 millimicrons. For this situation, it would be necessary to choose appropriate bands in order to acquire maximum photographic tonal differences which would permit differentiation between the various surfaces. In this case the maximum difference in the levels of reflectance appear to be at 850 millimicrons. Therefore, a film sensitive to the specific wavelength where the maximum reflectance difference between the various surfaces exists should be used in aerial survey of such surfaces.

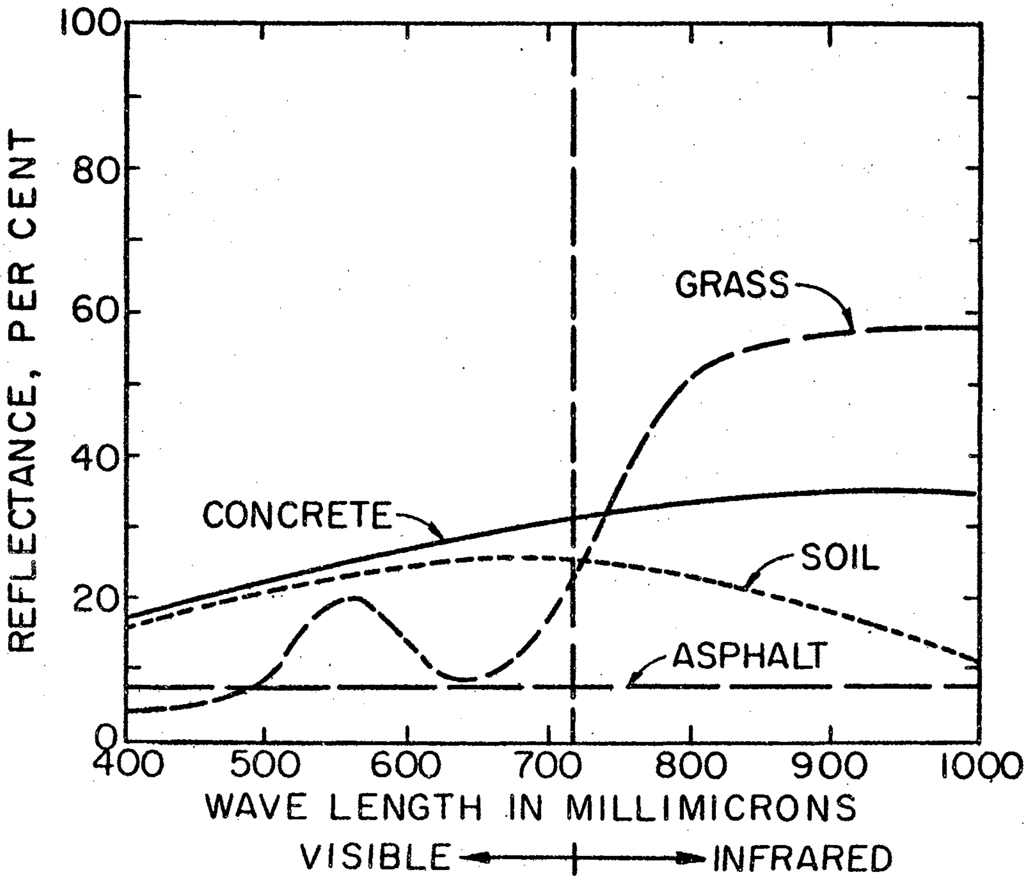


Figure 11. Light Reflectance of Surface Materials

CHAPTER IV

LABORATORY PROCEDURE FOR DETERMINATION OF WATER HOLDING CAPACITY AND HYGROSCOPIC MOISTURE OF SOILS USED

General

The ability of a soil to retain water mainly depends upon its texture, and organic matter. Plants growing on soils, having low water holding capacity, are always exposed to a danger of drought. On the other hand, plants growing on areas containing soils of high water holding capacity, suffer from insufficient aeration, which is a result of excessive water present.

Usually, the water holding capacity is determined after a saturated soil is drained for 24 hours. During this period most of the excess of non-capillary water is drained away by gravity, and the soil attains the field capacity (24).

Generally, the value of the water holding capacity determined in such a way serves as a reasonably accurate expression of the moisture, and aeroation conditions of the soil.

Determination of Water Holding Capacity of Clay and Sand

Fine filter paper of the correct size was first placed in brass containers with perforated bottom. Three such containers were filled to two thirds capacity, with pulverized oven-dried clay and gently tapped. These brass containers then were placed in a dish and water was gradually poured, until one-half of the brass containers were immersed in it. These containers were kept in this state for 24 hours. Then they were placed in a dry dish and allowed to drain for 24 hours. These were then weighed and dried in an oven at 110 deg. C for 24 hours and reweighed in the dried state. The quantity of water retained by the soil was calculated as illustrated below.

Weight of drained sample.......................... X grams

Weight of oven dry clay........................... Y grams

Weight of the container........................... Z grams

Content of water.................................. (X-Y) grams

Percent water holding capacity or field capacity of clay

$$= \frac{(X-Y) \times 100}{(Y-Z)}$$

The determination of the water holding capacity of sand follows a similar procedure as stated in case of clay. The water holding capacity of clay and sand were respectively, 49.97 and 19.1 percent. Figure 12 shows the brass containers with perforated bottom. Figure 13 shows the brass containers filled with clay and sand and placed in a dish partially filled with water.

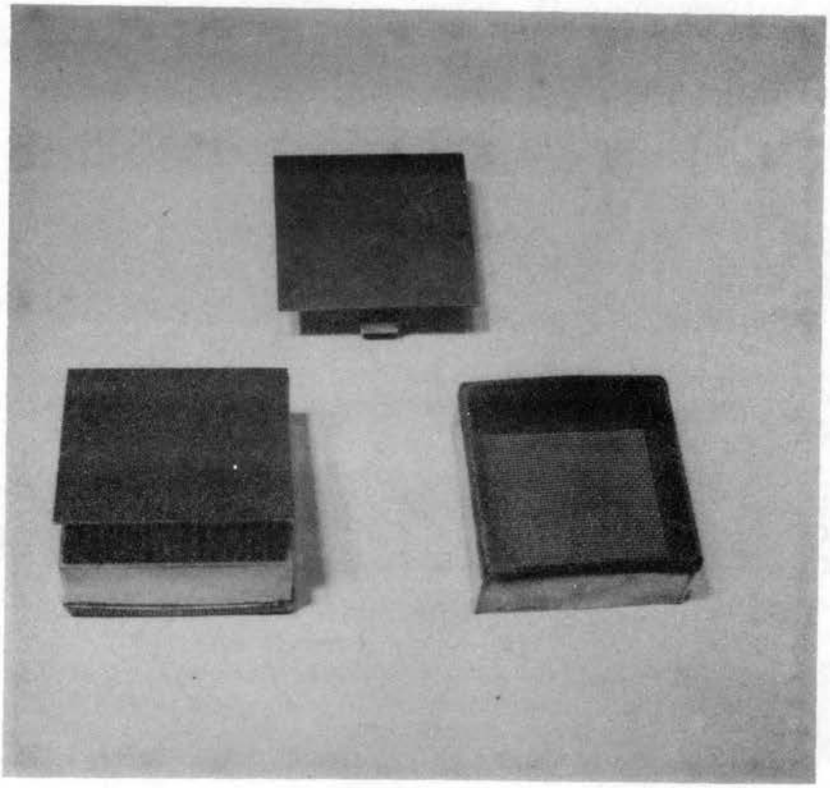


Figure 12. Brass Containers for Determining Water Holding Capacity of Soils

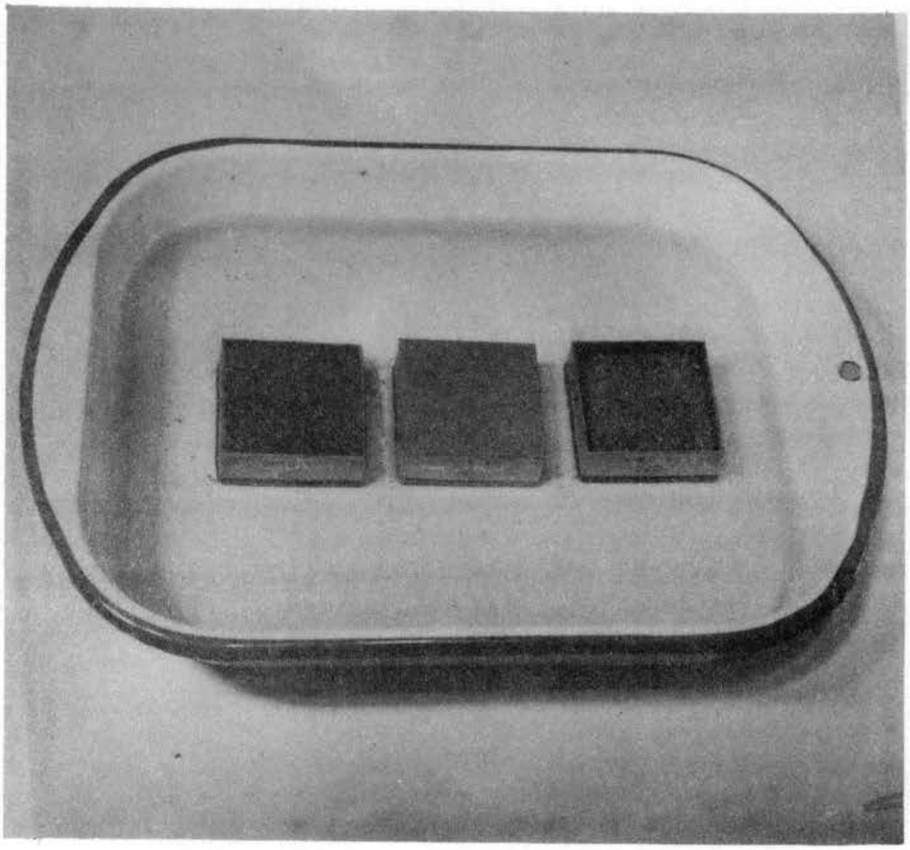


Figure 13. Brass Containers Filled With Clay and Sand and Partially Immersed in Water

Determination of Hygroscopic Moisture Content of the Soils

Hygroscopic Water

The water adsorbed on soil particles and their associated ions is commonly called hygroscopic water. The ability of soil particles to attract water vapor from the atmosphere is called hygroscopicity of soil. A soil sample, which appears quite dry after being kept for a long time indoors, will always retain a certain amount of moisture. The hygroscopic moisture is so firmly retained at the surface of soil particles by forces of molecular attraction that it can only be removed by vaporization such as heating the soil above 100 deg. C for several hours.

The amount of hygroscopic moisture absorbed by various soils under similar conditions depends on soil texture, and on the content of colloidal fraction which has the greatest surface area of particles. The quantity of hygroscopic water usually decreases with increasing grain size (22).

The hygroscopic moisture content was determined according to the method of Anderson and Mattson which corresponds to the quantity of hygroscopic water in the soil kept over 30 percent dilute sulphuric acid. This solution gives a relative humidity of 74.9 percent (2).

Approximately six pounds of clay was dried in an oven for 24 hours at 110 deg. C. After cooling of the clay in a dessicator, it was spread in a pan, and a procelain dish containing 30 percent dilute sulphuric acid was placed in it. The pan was tightly covered with a lid, and kept in this condition for 72 hours. Then a small quantity of soil from the pan was taken and dried in an oven for 24 hours at 110 deg. C. The difference in weight between the moist soil and the dry soil expressed as a percentage gives the hygroscopic moisture content which was 2.38 percent.

Following the same procedure as for clay, the hygroscopic moisture content of sand was found to be 0.173 percent.

CHAPTER V

INVESTIGATIVE PROCEDURES FOR REFLECTANCE

Description of Electronic Equipment

The electronic instrument which was used for the reflectance measurement of radiant energy, as a function of wavelength, was a Beckman Model DU-2 Spectrophotometer. This instrument was equipped with Beckman's 109697 Reflectance Attachment.

This equipment with reflectance attachment and automatic recorder is shown in Figure 14. Figure 15 illustrates the reflectance attachment mounted on Beckman's Model DU-2 Spectrophotometer. Figure 16 shows sample holder with sand and clay samples.

Spectrophotometry

Spectrophotometry is a branch of physics and chemistry which deals with the relative measurements of radiant energy as a function of wavelength. In this technique, the radiant energy transmitted or reflected by a specimen is compared by the radiant energy reflected by some other substances taken as standard.

Spectrophotometer

A spectrophotometer is an instrument which is provided with a photoelectric cell for a detector and a meter for recording spectral

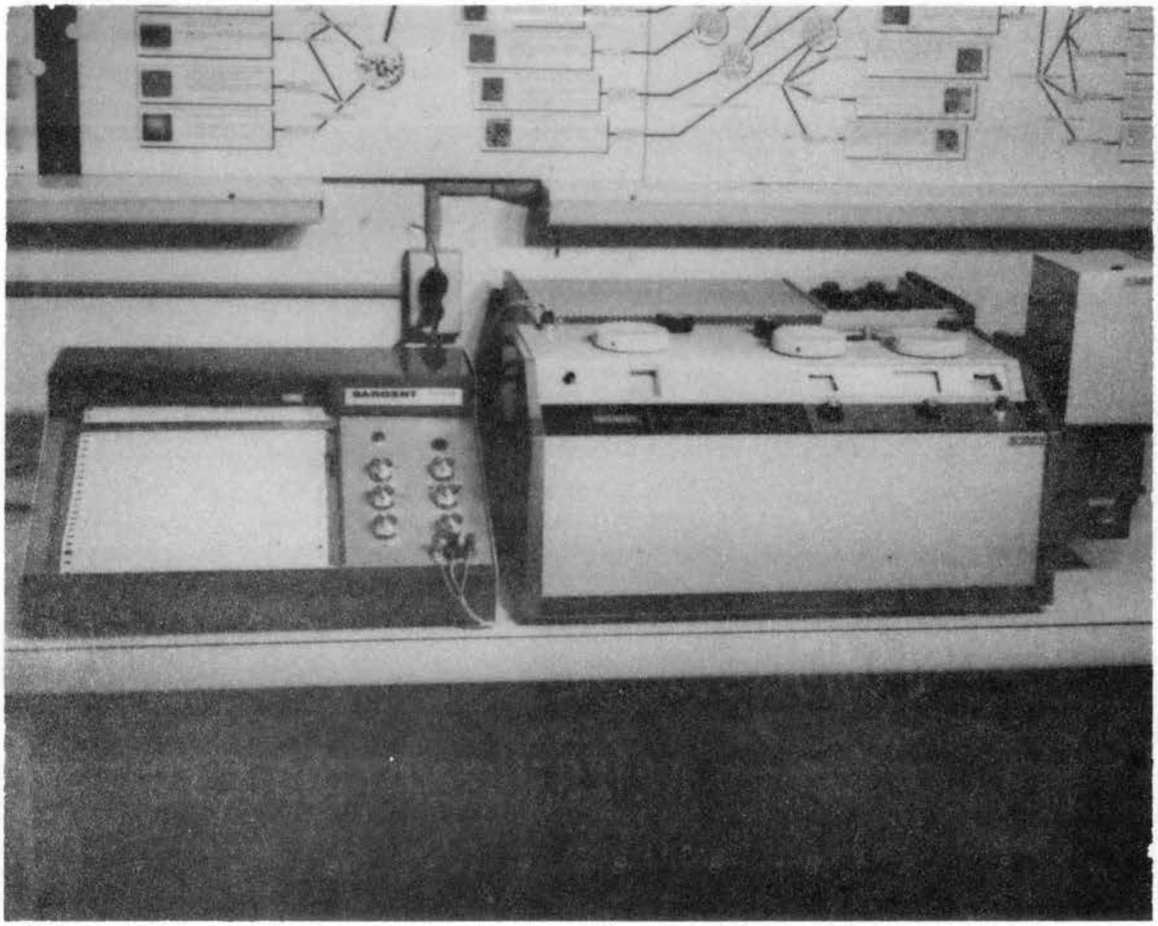


Figure 14. Spectrophotometer Attached to a Chart Recorder

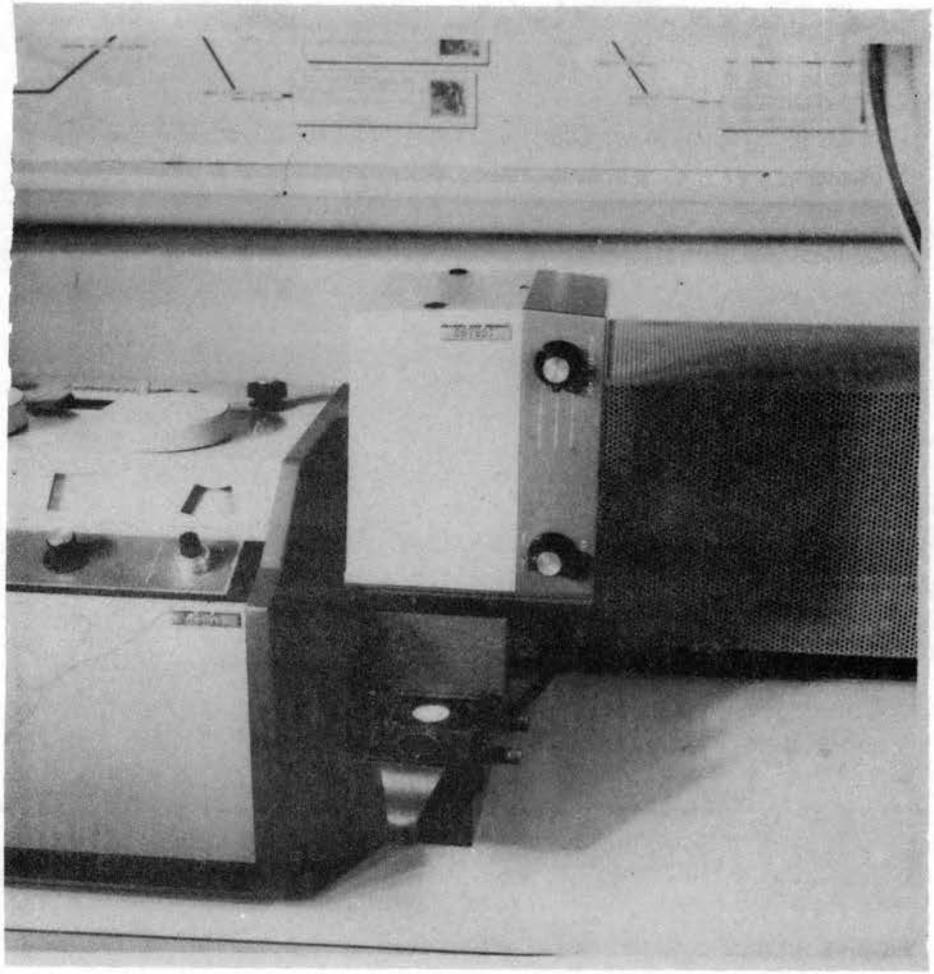


Figure 15. Reflectance Attachment

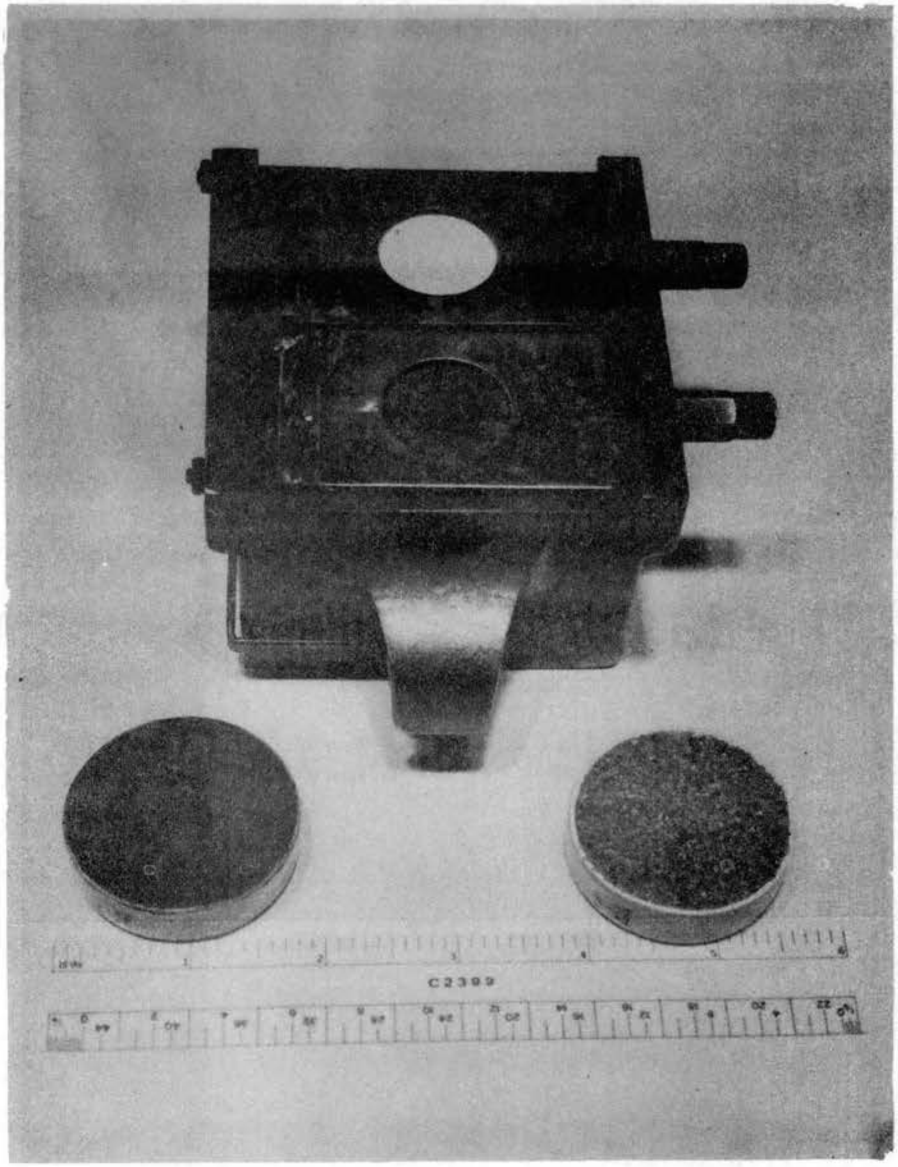


Figure 16. Sample Holder with Sand and Clay Samples

wavelengths and the amounts of absorbed or reflected energy. Although spectrophotometers may vary widely in their design, each essentially consists of the following components: (1) Radiation source, (2) Intensity control, (3) Wavelength control, (4) Sample holder, (5) Receptor, (6) Indicator. Figure 17 shows a block diagram of a Spectrophotometer.

Sources of Radiant Energy. Radiant energy sources are usually hydrogen arc for ultraviolet range, the incandescent tungsten filament for the visible range, and nernst glower for the infrared range.

Intensity Control. This consists of a variable slit, which controls the intensity of the radiant energy falling onto the specimen and the standard.

Monochromator (Wavelength Control). This consists of a grating or a prism. The function of this device is to isolate a narrow spectral band from a continuous source.

Sample Holder. This contains a sample and the reference or standard.

Receptor. This is a detector such as a photocell, which measures the radiant energy reflected by the sample and the reference.

Indicator. This consists of a recorder or a simple galvanometer.

Principles of Reflectance

Reflectance data is obtained with a spectrophotometer by directing radiant energy of various portions of the electromagnetic spectrum, and then determining what portion of the energy is reflected. Energy is provided by a hydrogen or duetrium lamp in 190 to 300 millimicrons, while a tungsten lamp provides energy in the wavelength range extending

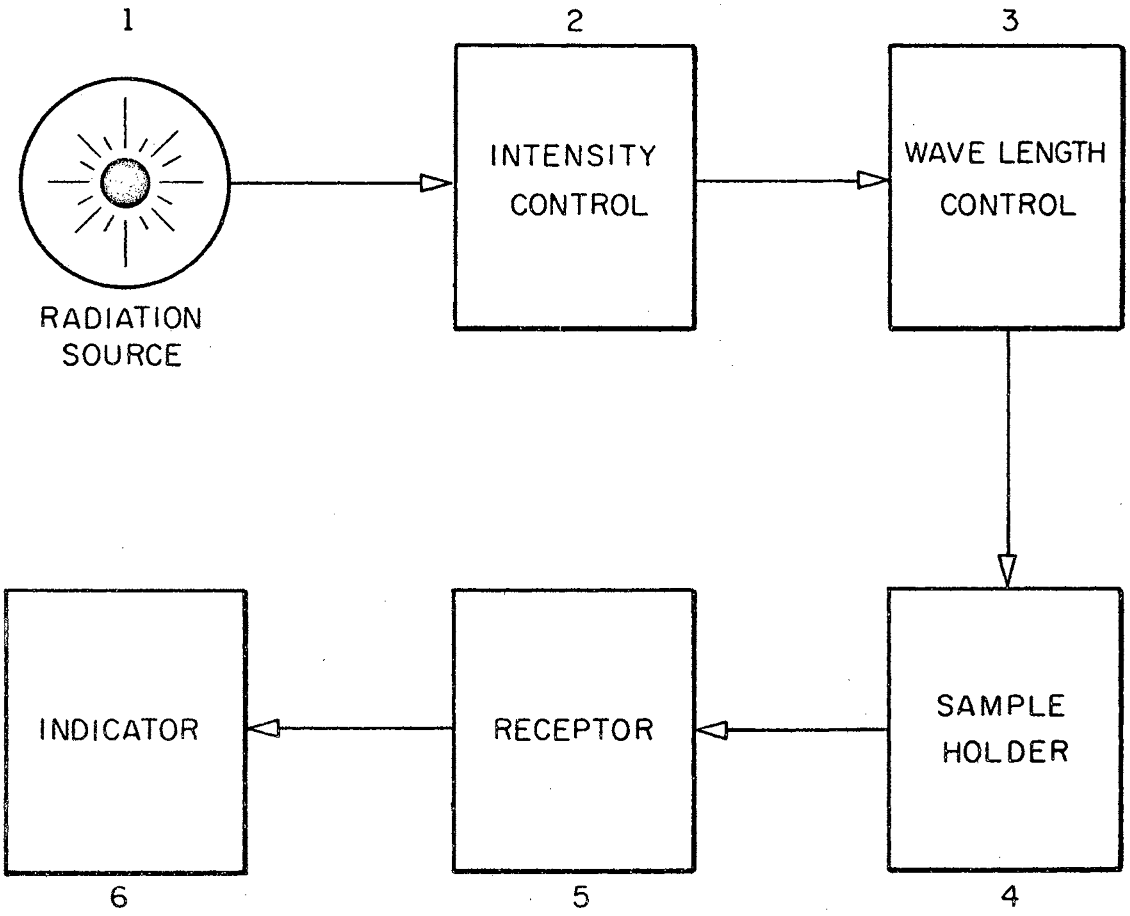


Figure 17. Block Diagram of Spectrophotometer Indicating Components

from 300 to 1200 millimicrons.

Radiant energy is directed from the source into the optical system. Figures 18 and 19 completely illustrate the path followed by a single ray within the radiation beam. The beam is reflected from a condensing mirror within a lamphouse to the slit entrance mirror which directs the beam through an adjustable entrance slit into the monochromator. In the monochromator, the beam is reflected from the collimating mirror in parallel rays through a fused silica prism. The purpose of this prism is to disperse the beam into its spectrum of successive wavelengths.

The back surface of the prism is aluminized so that the beam is reflected back through the prism and is further dispersed as it emerges. It is the rotation of the prism relative to the collimating mirror which changes the angle of incidence of the rays that enables the selection of a particular group of wavelengths that comprise the spectral band. This band of energy is then directed back to the collimating mirror, which in turn focuses the entrance slit image on the exit slit. Upon passing from the monochromator, the selected spectral radiation beam is directed into the reflectance compartment. In the center of this reflectance compartment, there is a plane mirror which reflects the beam through an opening at the bottom of the compartment and finally onto the reference or sample. When the beam of radiant energy strikes the sample or reference, all of the diffused rays that are reflected upward at angles of 35 to 55 degrees are focused by a ring-shaped segment of an ellipsoidal mirror onto a frosted quartz diffusing screen at the top of the compartment (Figure 20). Mounted immediately above the diffusing screen is the photo tube, which detects the amount of radiant energy that falls upon the screen (7).

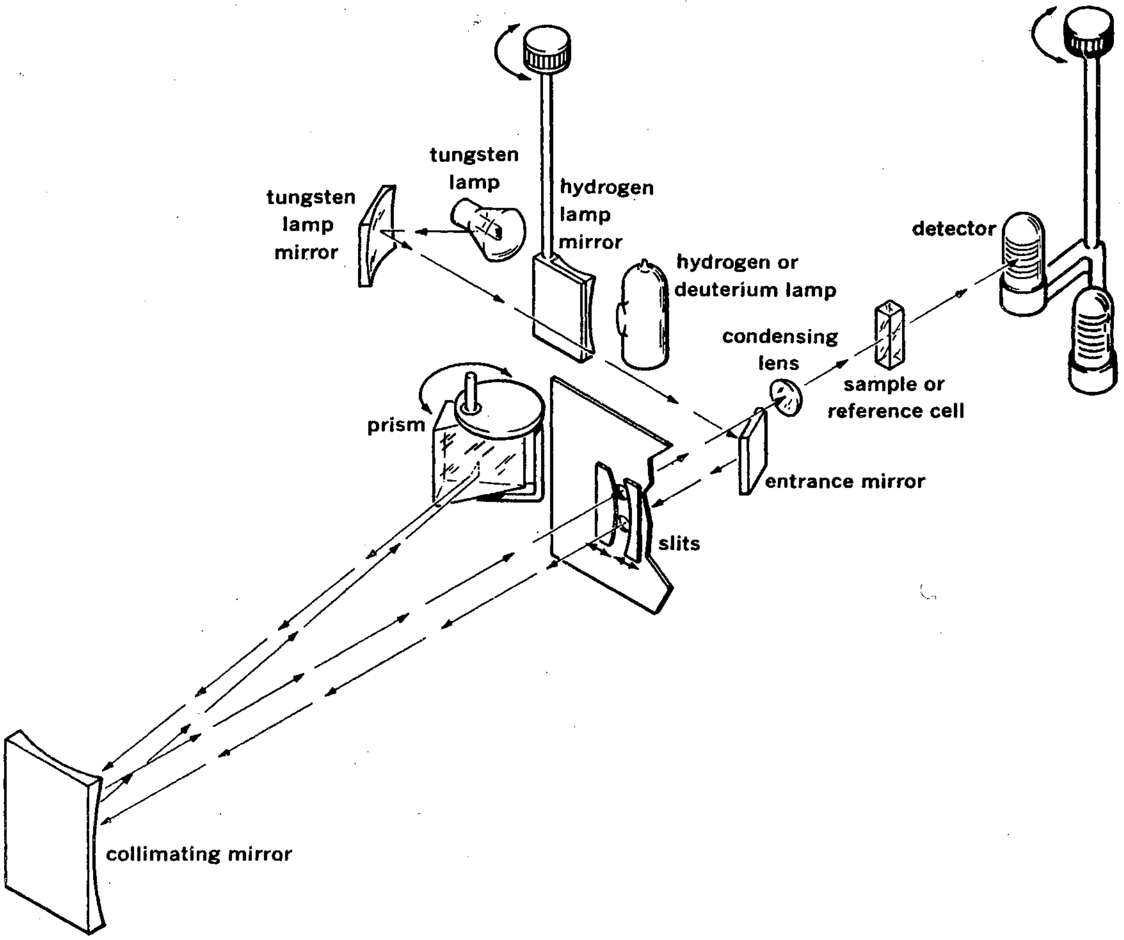


Figure 18. Optical Diagram of Spectrophotometer

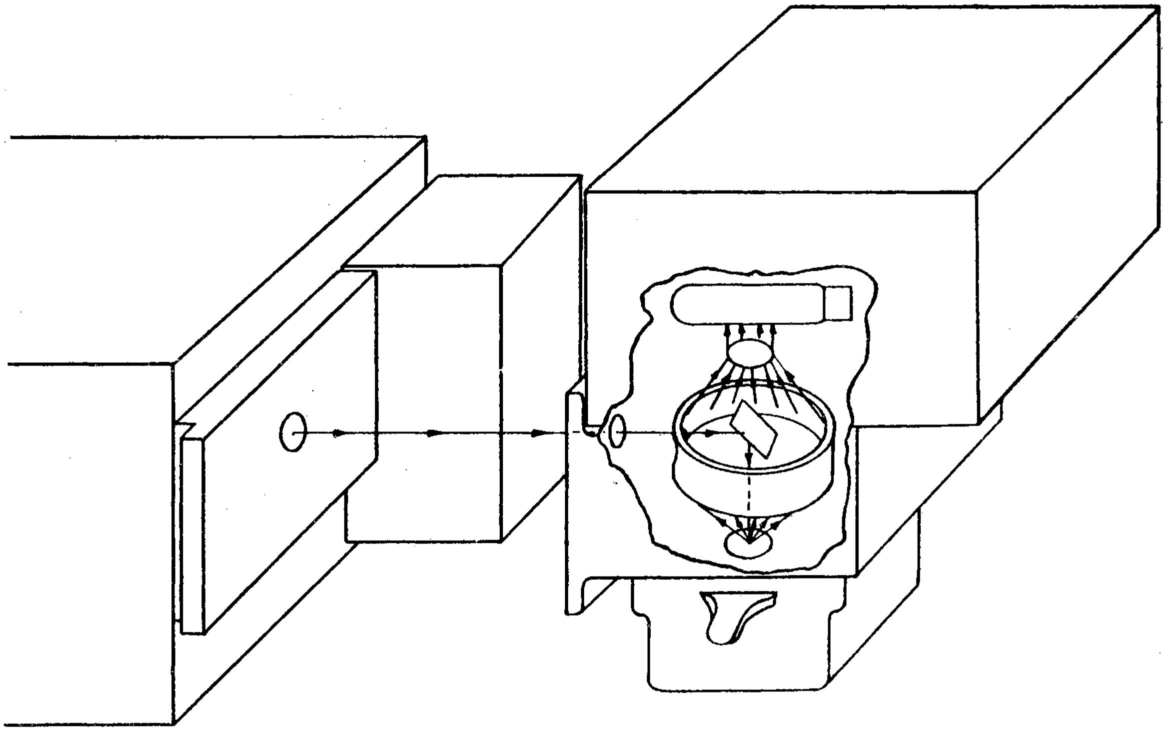
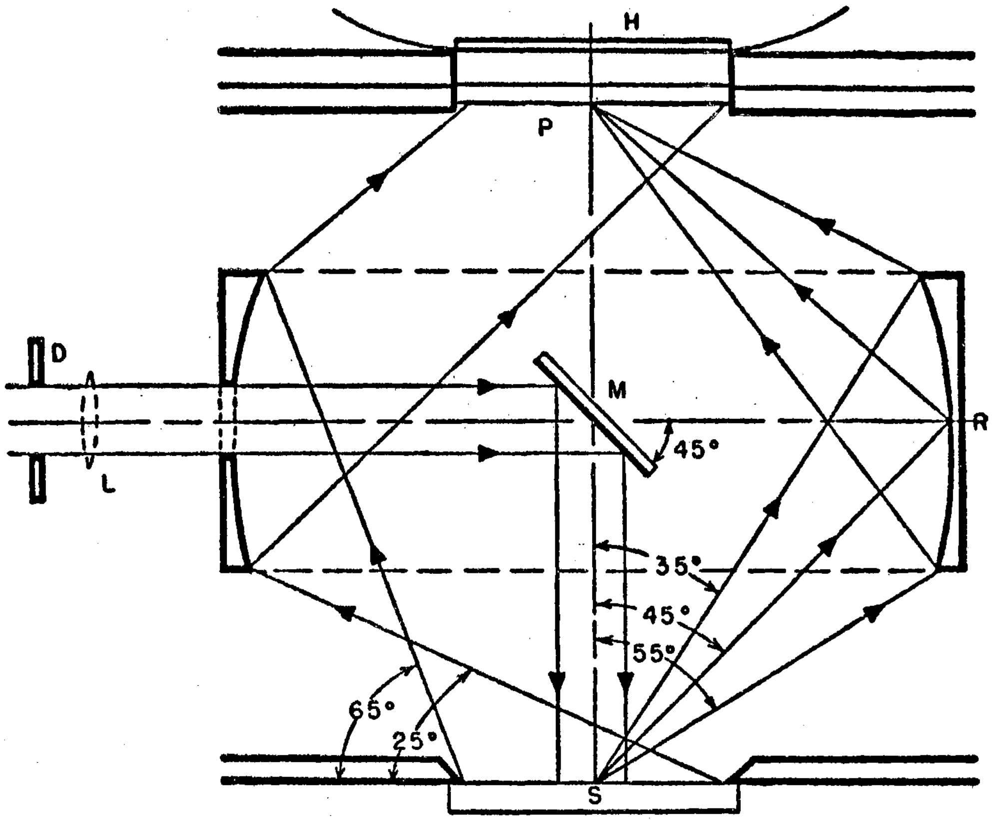


Figure 19. Optical Diagram of Reflectance Attachment



D, slit; L, lens; M, mirror; S, specimen; R, ellipsoidal reflector; P, diffusing quartz plate; H, phototube envelope

Figure 20. Schematic Diagram Showing Geometry of Irradiation and Reception

Materials

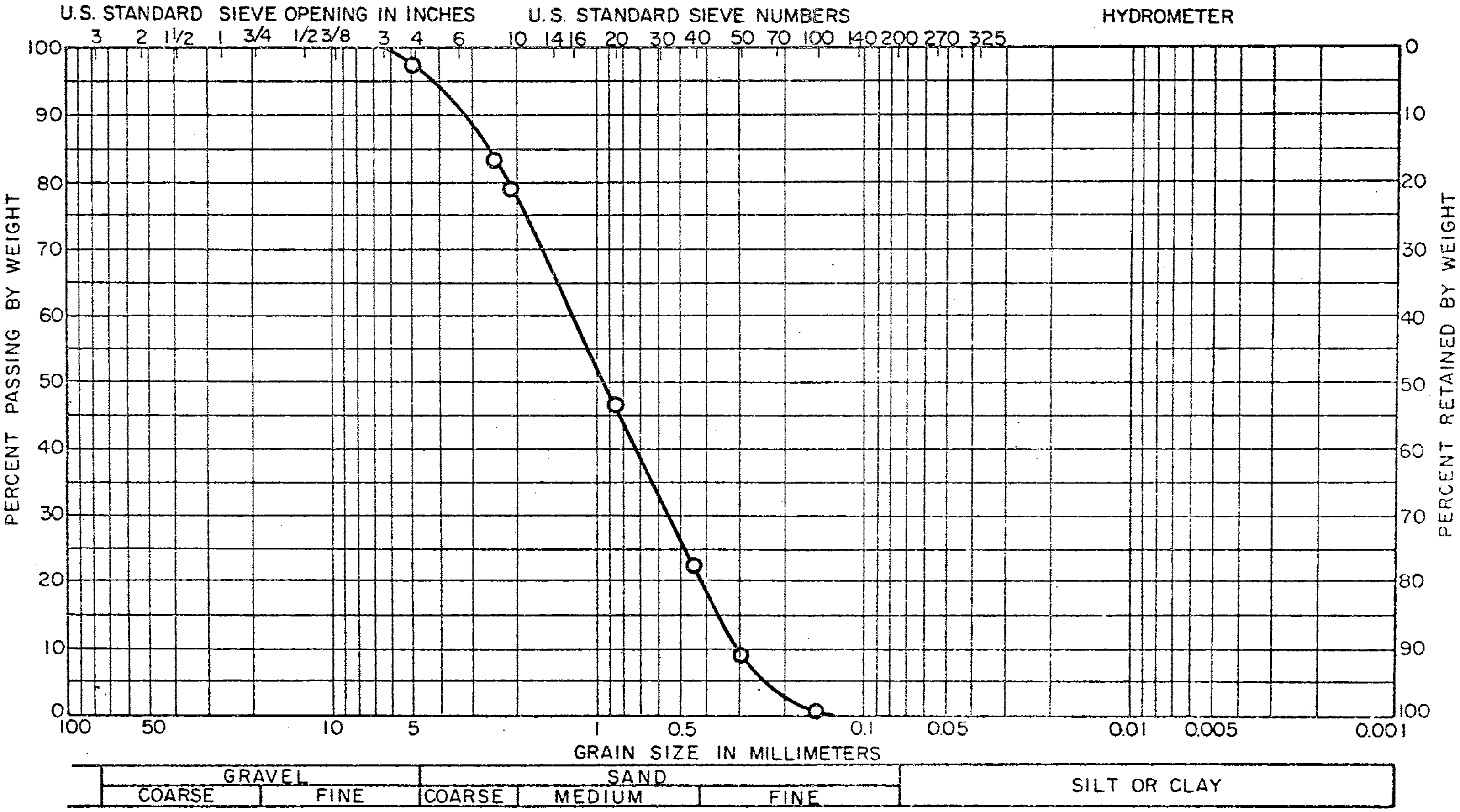
Sand

The sand used in the investigation for the preparation of various treatments was the common river sand. Dry sieve analysis was run on this material. The results are given in Table II and the grain size distribution curve is shown in Figure 21. The specific gravity of this sand was found to be 2.58.

TABLE II

SIEVE ANALYSIS DATA

Sieve Opening	Σ % Passing
3/8	100
4	98.38
8	84.16
10	79.11
20	46.52
40	20.72
50	8.65
100	0.72



Unified Soil Classification System – Corp of Engineers, U. S. Army

Figure 21. Grain Size Distribution Curve for Sand

Clay

A standard hydrometer and sieve analysis were also run on the clay used in the preparation of clay treatments. The results of these analysis are presented in Figure 22.

Furthermore, Atterberg's limits tests were performed, the results of which are given below:

Plastic Limit - 17.9

Liquid Limit - 28.5

In case of clay, the specific gravity was found to be 2.6. The chemical analysis of the two soils, namely clay and sand, are as given in Tables III and IV, respectively.

TABLE III

CHEMICAL ANALYSIS OF CLAY

Soil Test Results	Reading	Adjective Rating
Organic Matter (Nitrogen %)	1.35	Very low
Phosphorous #/A (lbs/acre)	105.6	Very high
Potash #/A (lbs/acre)	375	Very high
PH (Acidity or Alkalinity)	5.95	Moderately Acid

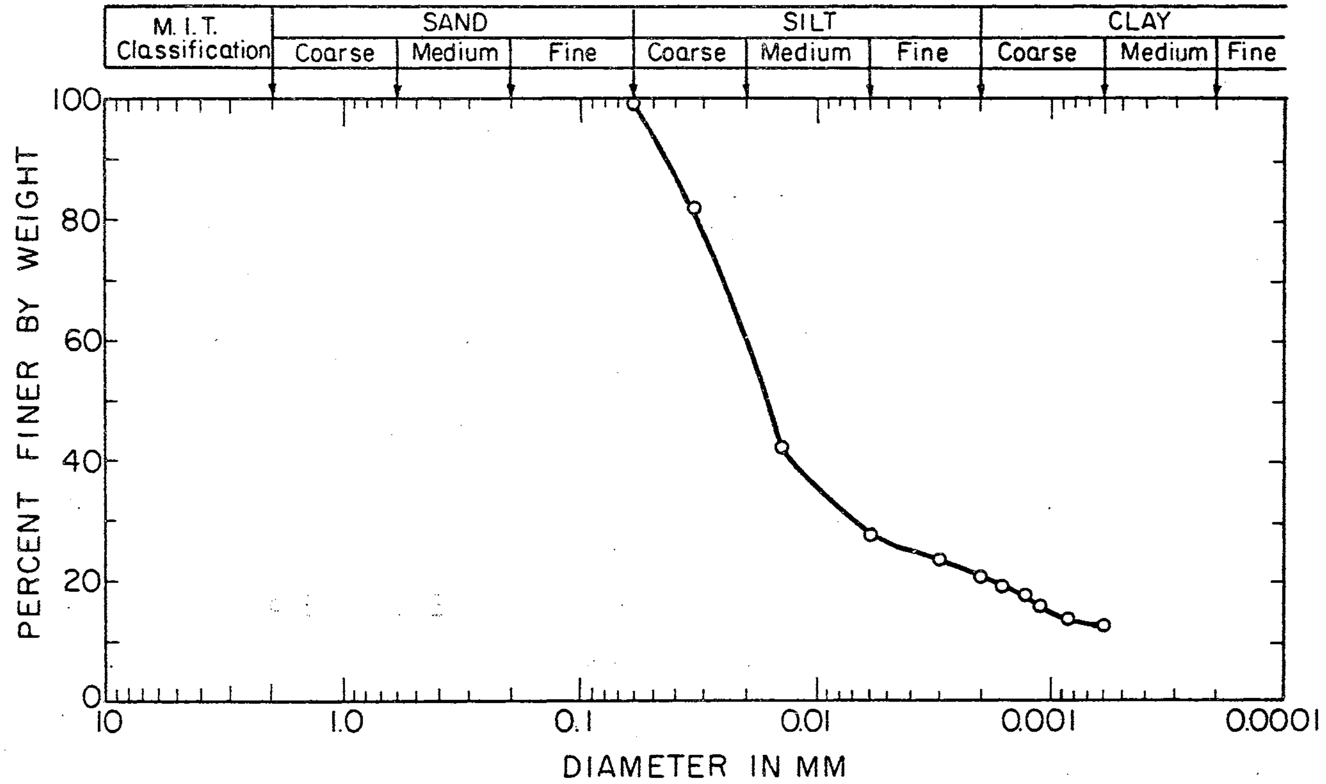


Figure 22. Grain Size Distribution Curve for Clay

TABLE IV

CHEMICAL ANALYSIS OF SAND

Soil Test Results	Reading	Adjective Rating
Organic Matter (Nitrogen %)	0.07	Very low
Phosphorous #/A (lbs/acre)	9.4	Very low
Potash #/A (lbs/acre)	35	Very low
PH (Acidity or Alkalinity)	7.2	Neutral to very slightly alkalinity

Sample Preparation

Determination of Salt Contents

Since further investigations in the future are to be considered on saline soils of the Great Salt Plains Area of Oklahoma, all the variations in salt contents of the soil of this area were considered in the study of the reflectance characteristics. The two salts, sodium chloride and calcium chloride, were added in such a manner that the value established for the sodium adsorption ratio (SAR) was equal to 1/8 or 12.6 percent in terms of concentration. This value chosen for sodium adsorption ratio (SAR) was considered representative for the range of conditions occuring in soil solution of the area.

In calculating the amounts of sodium chloride and calcium chloride which when dissolved in one liter give a solution of a particular osmotic pressure, the equation followed by Lagerwerff and Holland (14) was used.

$$\text{Sodium Adsorption Ration (SAR)} = \frac{Na}{\sqrt{Ca + Mg}} \text{ m moles}^{\frac{1}{2}} \text{ liter}^{-\frac{1}{2}} \qquad (1)$$

As the amount of magnesium in the soil of this area is negligible compared to calcium (usual in soils with high calcium content) the equation (1) can be written by neglecting magnesium. Hence the equation (1) becomes

$$SAR = \frac{Na}{\sqrt{Ca}} \text{ m moles}^{\frac{1}{2}} \text{ liter}^{-\frac{1}{2}}$$

To calculate the amount of sodium chloride and calcium chloride for a solution of one atmosphere at an SAR value of 1/8 the procedure is as illustrated.

$$SAR = \frac{Na}{\sqrt{Ca}} = 1/8 \therefore 8Na = \sqrt{Ca}$$

or

$$64(Na)^2 = Ca \text{ in m moles liter}^{-1} \qquad (2)$$

And since 24 me NaCl per liter constitutes a solution of one atmosphere osmotic pressure and 32 me $CaCl_2$ per liter constitutes a solution of one atmosphere osmotic pressure therefore, (5)

$$\frac{\text{me NaCl}}{24} + \frac{\text{me CaCl}_2}{32} = 1 \text{ atm} \qquad (3)$$

Now substituting for calcium in equation (3)

$$\frac{NaCl}{24} + \frac{64(NaCl)^2}{32} = 1$$

$$NaCl + 48(NaCl)^2 = 24 \qquad (4)$$

The above equation (4) is quadratic equation of the form

$$Ax^2 + Bx = C$$

Hence,

$$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Thus, amount of NaCl is

$$NaCl = \frac{-1 \pm \sqrt{1 - 4 \times 48 \times (-24)}}{2 \times 48}$$

$$NaCl = 40.6 \text{ mg Liter}^{-1}$$

$$64(NaCl)^2 = CaCl_2$$

$$CaCl_2 = \frac{64(66.89)^2}{96} \text{ me Liter}^{-1}$$

$$CaCl_2 = 1{,}740 \text{ mg Liter}^{-1}$$

The amount of sodium chloride and calcium chloride to be used, corresponding to various osmotic pressures, at a fixed value of SAR of 1/8 were calculated.

The calculated amounts together with the corresponding values of total salts in each soil in ppm are shown in Table V.

With the values shown in Table V, graph (Fig. 23) of total ppm

TABLE V

CALCULATED AMOUNTS OF NaCl AND $CaCl_2$ PER LITRE WHICH GIVE DIFFERENT VALUES OF OSMOTIC PRESSURE IN SOLUTION AT FIXED SAR OF 1/8

Osmotic Pressure in Atm.	NaCl(g)	$CaCl_2$(g)	Total Salt in ppm
0.5	0.02865	0.8525	880
1.0	0.0407	1.723	1764
1.5	0.0501	2.610	2660
2.0	0.0570	3.480	3537
2.5	0.0645	4.340	4405
3.0	0.0712	5.250	5321
3.5	0.0768	6.118	6194
4.0	0.0821	6.997	7079
4.5	0.0871	7.882	7969
5.0	0.0918	8.760	8852
10.0	0.1300	17.58	17710
15.0	0.1592	26.35	26509
20.0	0.1842	35.28	35464
25.0	0.2060	43.81	44016
30.0	0.2257	52.98	53206
40.0	0.2607	70.69	70951
50.0	0.2916	87.35	87612
60.0	0.3195	99.75	100069
90.0	0.3914	159.31	159701
110.0	0.436	198.75	199186
130.0	0.4708	250.24	250711

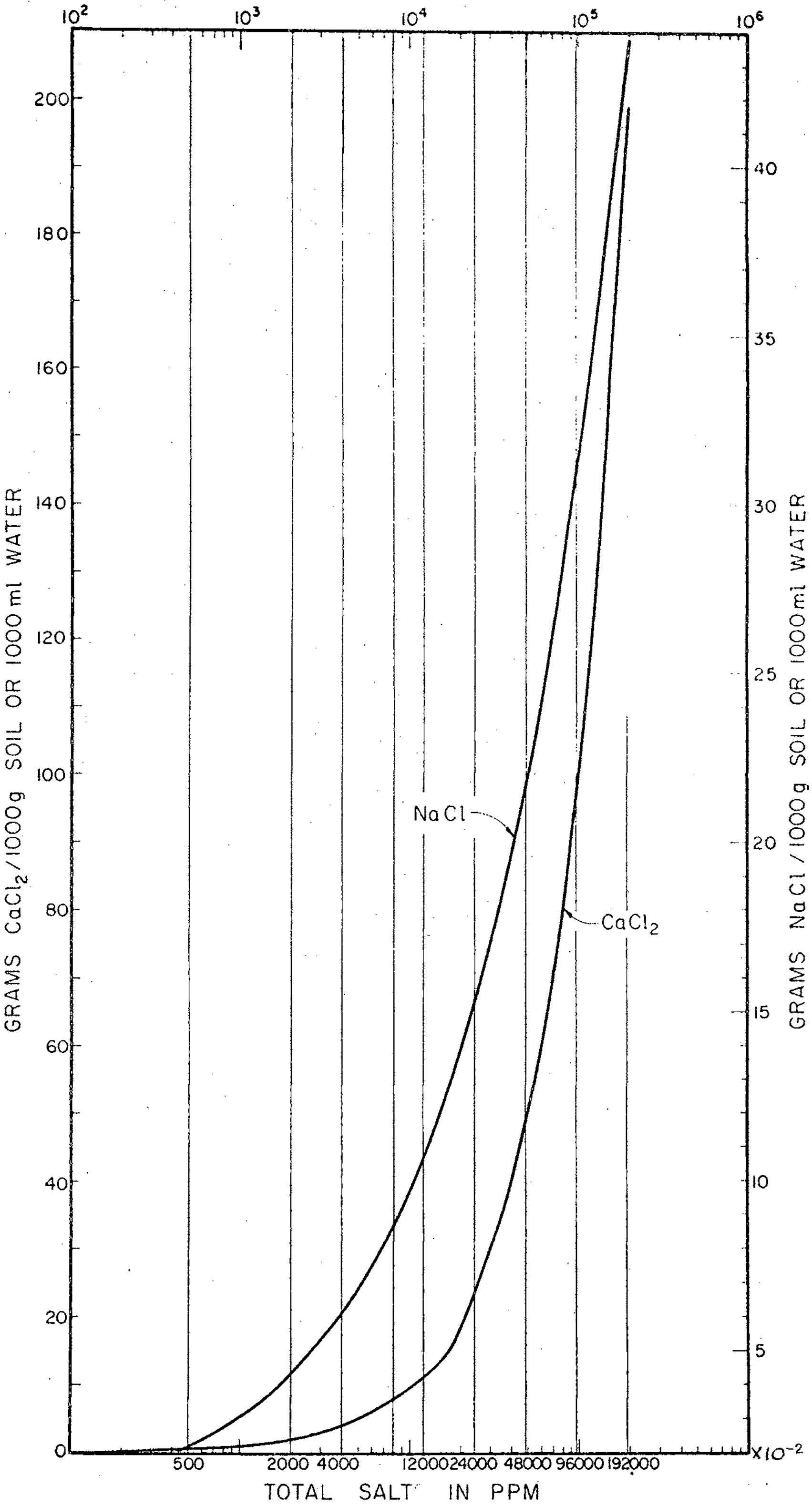


Figure 23. Amounts of NaCl and $CaCl_2$ that Give Concentrations up to 192,000 ppm at Fixed SAR of 1/8

and amounts of $CaCl_2$ per 1,000 gms of soil or 1,000 ml of water and NaCl per 1,000 gms of soil or 1,000 ml of water were plotted.

Finally, from this graph (Fig. 23) amounts of NaCl and $CaCl_2$ in grams to be used with 200 gms of soil were calculated at 500, 2,000, 4,000, 8,000, 12,000, 24,000, 48,000, 96,000, and 192,000 ppm. These are shown in Table VI.

Preparation of First Batch of Clay Treatments

The clay was air dried, pulverized and passed through U.S. Standard sieve #16. This was then dried in an oven for 24 hours at 110 deg. C and cooled in a dessicator.

Two hundred grams of clay were weighed out in ten separate bottles for the ten different treatments. The amounts of different salts which were added to treatments 1 to 10 are as shown in Table VI. Calcium chloride was in anhydrous state. Calcium chloride and sodium chloride were thoroughly mixed with clay, so that there was a homogenous mix. The glass jars containing these mixtures were tightly sealed so as to prevent the soil salt mixture from absorbing any moisture. The reflectance readings were taken immediately after mixing and in some cases after a few hours. The moisture content of the first batch of mixtures was zero percent.

Preparation of Second Batch of Clay Treatments

The clay used in this case was at hygroscopic moisture level. In a similar way as before, the treatments 1 to 10 were prepared and kept in tightly covered bottles so as to prevent any change in the moisture content of the mixtures.

TABLE VI

CALCULATED AMOUNTS OF NaCl AND $CaCl_2$ IN GRAMS TO BE USED WITH 200 GM OF SOIL

NaCl(g)	$CaCl_2$(g)	Total Salt in ppm
0.0000	0.0000	0
0.0044	0.0956	500
0.0086	0.3914	2000
0.0120	0.7880	4000
0.0173	1.5827	8000
0.0213	2.3784	12000
0.0303	4.7697	24000
0.0437	9.5583	48000
0.0618	19.1382	96000
0.0838	38.3162	192000

Preparation of Batches Three to Ten

In the preparation of these batches of treatments various percentages of the water holding capcity of the soil were added each time. In the third batch, 20 percent of water holding capcity of clay was added. In the fourth, fifth, and sixth batches, 40 percent, 60 percent, and 80 percent of the water holding capacity of clay were added. In the above cases, salt was not added in dry form with clay. The salt was first dissolved in water, the solution was then added to the soil and mixed thoroughly.

Table VII shows the quantities of water used in different batches.

TABLE VII

WATER REQUIRED FOR DIFFERENT TREATMENTS

% Water Holding Capacity of Soil	Water Required For 200 Grams	
	Sand	Clay
100	38.2cc	100cc
80	30.6	80
60	22.92	60
40	15.3	40
20	7.64	20

Preparation of Batches of Sand Treatments

A well graded river sand was utilized in these investigations. To insure uniformity, the sand was passed through #10 U.S. Standard sieve. The sand was dried in an oven for 24 hours and cooled in a dessicator before the preparation of the various batches.

The quantities of salts and water used in the preparation of the various batches of treatments were the same as used in the case of clay samples.

Reflectance Measurement of Clay and Sand Treatments

Both sample (contained in a small porcelain dish) and reference (a small magnesium carbonate piece) were first placed in the compartment provided below the reflectance attachment. The sample and reference should always fill the area of openings. The diameter of the openings in the compartment is one inch, and the size of the compartment is two inches in length and one and one-half inches in breadth. Hence, anything bigger than this cannot fit in respective compartments. After placing sample and reference in the respective compartments, the null meter was set at zero position by adjusting the phototube dark current, for the range 200 to 350 millimicron wavelength. Source selector was set for the hydrogen lamp. After setting the phototube selector for blue sensitive or photomultiplier the wavelength selector was set at the desired wavelength. At this instant, if the null meter needle moved out from the null position, it was reset at this position.

The reference was then placed in beam and the slit width so adjusted that 100 percent reflectance was obtained at the particular wavelength set previously. After closing the shutter, sample was placed in beam and on opening it, the needle once again deflected. Finally, galvanometer needle was brought to zero mark by means of transmittance control. The percent reflectance was read from the dial.

The above stated procedure was repeated and reflectance readings noted for 200 to 350 millimicron wavelengths. After 350 millimicron wavelength, the hydrogen lamp was switched off and the tungsten lamp was turned on and the reflectance readings from 350 millimicrons to 600 millimicron wavelengths were noted.

After 600 millimicron wavelength the phototube selector switch was set on the phototube normal or red sensitive phototube. The same procedure was repeated and reflectance readings were noted from 650 millimicron wavelength to 1200 millimicron wavelength.

The reason a hydrogen lamp should be used up to 350 millimicron wavelength is that this lamp emits continuous spectrum approximately up to 350 millimicron; after that wavelength, the hydrogen lamp emits sharp and discontinuous lines. Furthermore, the radiation from tungsten lamp was used above 350 millimicron wavelength because below this wavelength the glass envelope begins to absorb the ultraviolet radiation.

CHAPTER VI

DISCUSSION OF TEST RESULTS

Reflectance of Dry Soils Without Salt

In the reflectance studies involving the various mixtures of soils containing different concentrations of salt and percentages of water, preliminary investigations were conducted on dry samples of sand and clay without salt. It has been observed that in both sand and clay samples, the reflectance readings increased with increasing wavelength (Fig. 24). This trend was recorded in the three regions of the electromagnetic spectrum; namely, ultraviolet, visible, and near infrared. In both soils minimum spectral reflectivity value was observed at 250 millimicrons wavelength, after which the spectral reflectivity values increased quite sharply in sand and gradually in clay.

The reflectance qualities of sand are quite different from that of clay. In case of sand, the level of reflectance was considerably higher than that of clay. It was noted that in the three regions of the spectrum, the reflectance of sand was approximately twice that of clay. From the figure it can also be noted that maximum differences in reflectivity between dry sandy and clayey soils exist at the near infrared range of the electromagnetic spectrum. This indicates that an infrared sensitive film with wavelengths lower than 600 millimicrons is filtered out would give best results for showing maximum

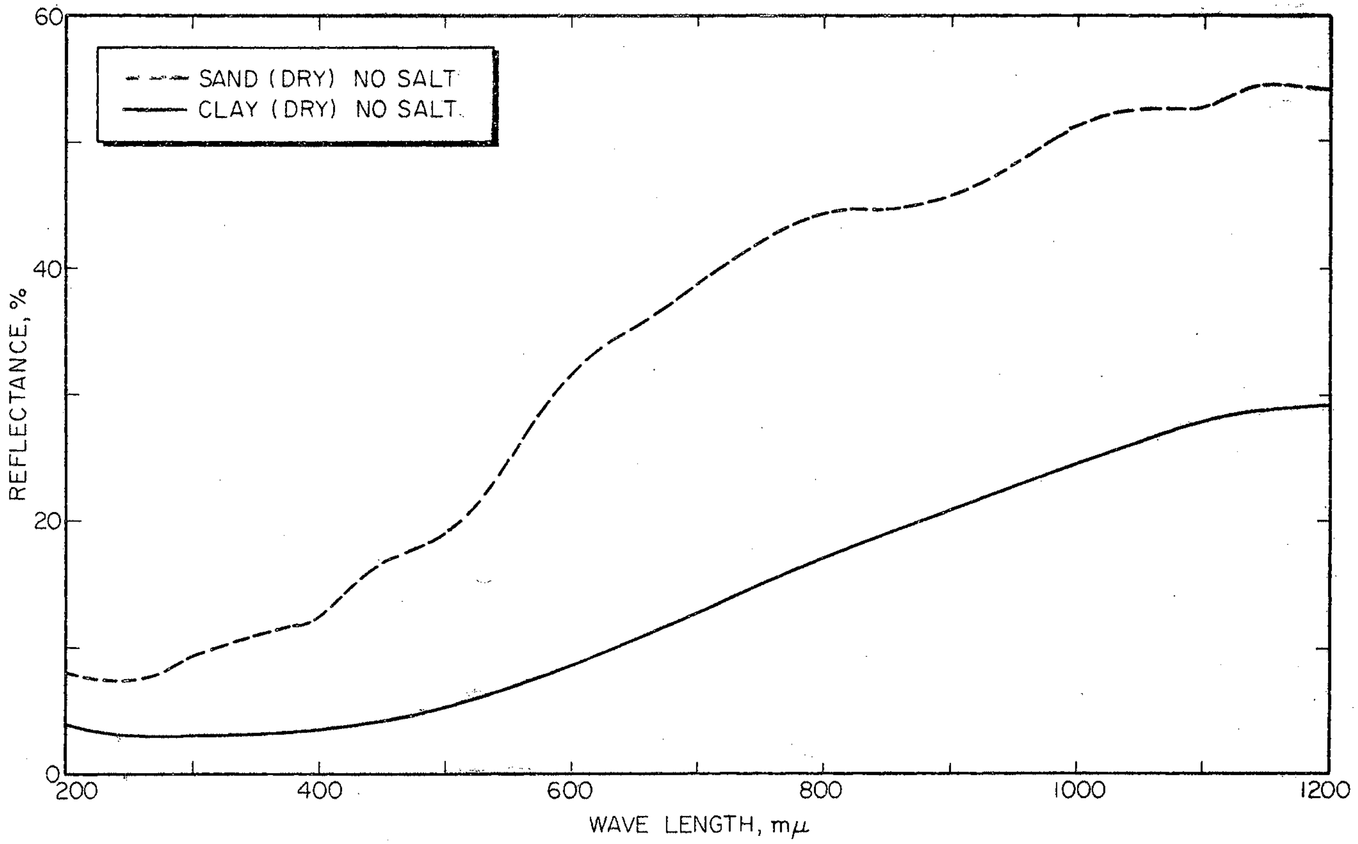


Figure 24. Reflectance of Dry Clay and Sand Without Salt

contrast between dry clayey soils and sandy soil.

In case of clay, in the ultraviolet region and partly in the visible region of the spectrum up to 400 millimicrons wavelength, there was hardly any increase in reflectance with increase in wavelength (Fig. 24). Whereas in the remaining region of the visible spectrum, and in the near infrared region, the rate of increase in reflectance was appreciably greater. In any event, the rate of increase in reflectance in all the three regions of electromagnetic spectrum for clay was generally lower than sand.

From the curves of sand and clay, it was also observed that both are convex downward up to 550 millimicrons wavelength. After this wavelength, the curves are convex upward. This was also observed by Penndorf (20) in his study of spectral reflectance of natural objects.

Effect of Salt on Reflectance of Dry Soils

Spectral reflectivity qualities of clay and sand having different concentrations of salt were also studied. Reflectance studies of dry soils were recorded with salt concentrations ranging from 0 to 192,000 ppm. In both these soils, the sample with highest concentration of salt gave the highest reflectance values. In case of dry clay and sand samples with salt concentrations of 192,000, 96,000, and 48,000 ppm, the difference between the levels of reflectance was greatest in the ultraviolet region of the spectrum. However, in the visible and near infrared regions, this difference was gradually reduced with increasing wavelength.

In case of clay samples with lower salt concentrations, the spectral reflectivity values were nearly the same in the ultraviolet and in a portion of the visible region (Fig. 25). The spectral reflectivity values of clay samples having salt concentrations of 12,000 and 8,000 ppm were lower than in sample without salt (Fig. 25). Spectral reflectivity values of samples with salt concentrations of 192,000 and 96,000 ppm were lowest at 400 millimicrons wavelength. In other samples with lower salt concentrations, reflectance values were practically constant only in the ultraviolet region, and the lowest value existed at 250 millimicrons wavelength.

Figure 26 shows the curves of reflectance versus salt concentrations at different wavelengths for dry clay.

The following observations can be definitely stated by studying Figures 25 and 26:

1. Reflectivity increased for dry clay soils with the increase of wavelength and at all salt concentrations. Maximum difference between the highest and lowest reflectivity with the change of salt concentration between ≈ 4,000 - 12,000 ppm was observed in the near infrared range.

2. The increase in salt concentration in dry clay soils did not produce a consistent pattern of change of reflectivity.

3. It appears that the maximum reflectivity in dry clay soils with various amounts of salt will take place at relatively lower salt concentrations (≈ 4,000 ppm). This will be followed with a sharp decline in reflectivity up to about 12,000 ppm, after which it starts to rise again.

4. Lowest values of reflectance in this case will be, for almost all visible and near infrared bands, between ≈ 8,000 - 12,000 ppm.

5. It can be assumed then, that if the area is flown over by an

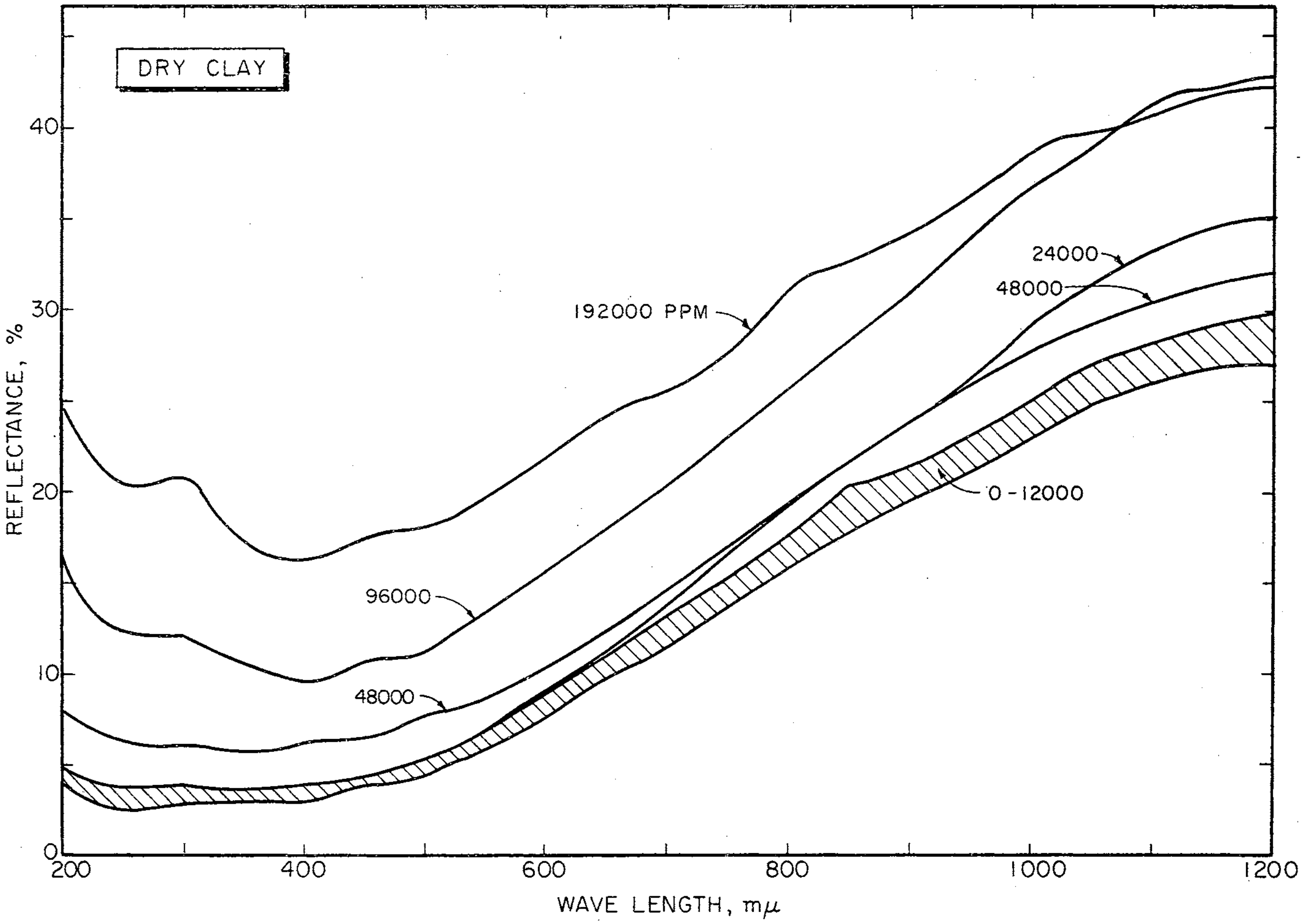


Figure 25. Effects of Salt on Reflectance of Dry Clay

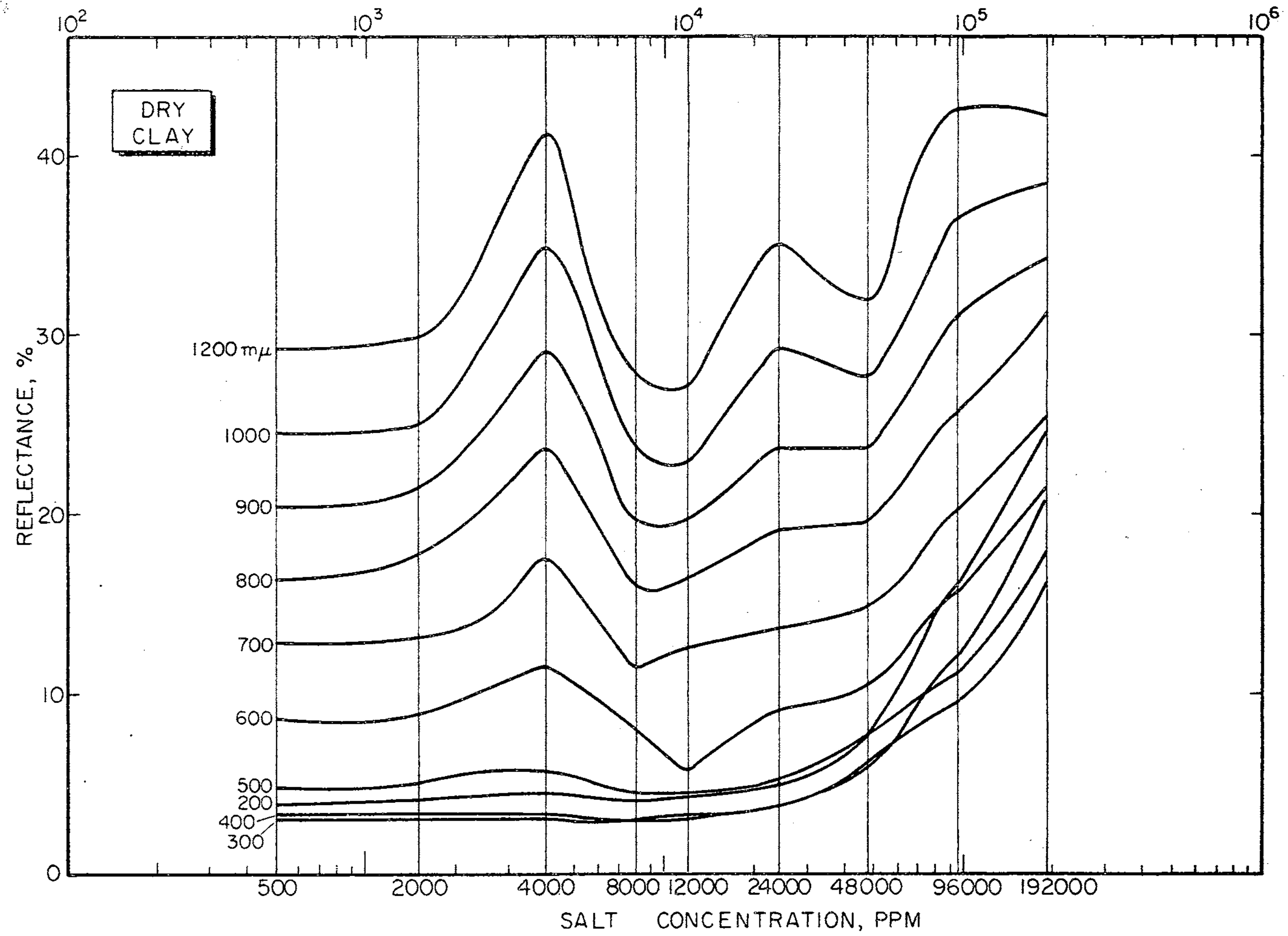


Figure 26. Reflectance Versus Salt Concentration at Different Wavelengths for Dry Clay

infrared sensitive film, that maximum difference between salt concentrations will be more apparent. It would be necessary in this case to filter out reflectance in wave bands below 600 millimicrons. In another way, a film filter combination sensitive in the range of ≈ 650-900 millimicrons, would be expected to give best results as far as showing maximum contrast between certain amounts of salts in dry clay soil. Brightest areas on film will indicate lower salt concentrations between 2000-8000 ppm and darkest areas will be for soils containing ≈8000-12000 ppm. Very high concentrations between ≈ 50,000-190,000 ppm may also appear light in tone. However, by comparing this record of the area in the near infrared and that in the visible range ≈ 400-650 millimicrons, discrimination between areas of 2000-8000 ppm concentrations and those of very high concentrations 95,000-190,000 ppm, would then be possible, as there will be a consistently higher reflection with higher salt concentration in visible and ultraviolet regions of the spectrum.

In case of sand, the spectral reflectance values of samples with low salt concentrations seem to fall in one band (Fig. 27). There was a maximum difference in the levels of reflectance in the ultraviolet region, but this difference reduced in the infrared region. In the visible and infrared regions, reflectivity values of some sand samples of lower salt concentrations were less than the sample without salt. The differences between the reflectance readings of some soil samples with salt, and one without salt, increased with increase in wavelengths and were maximum in the near infrared region.

Figure 28 shows curves of spectral reflectance versus salt concentration for sand at different wavelengths of the electromagnetic

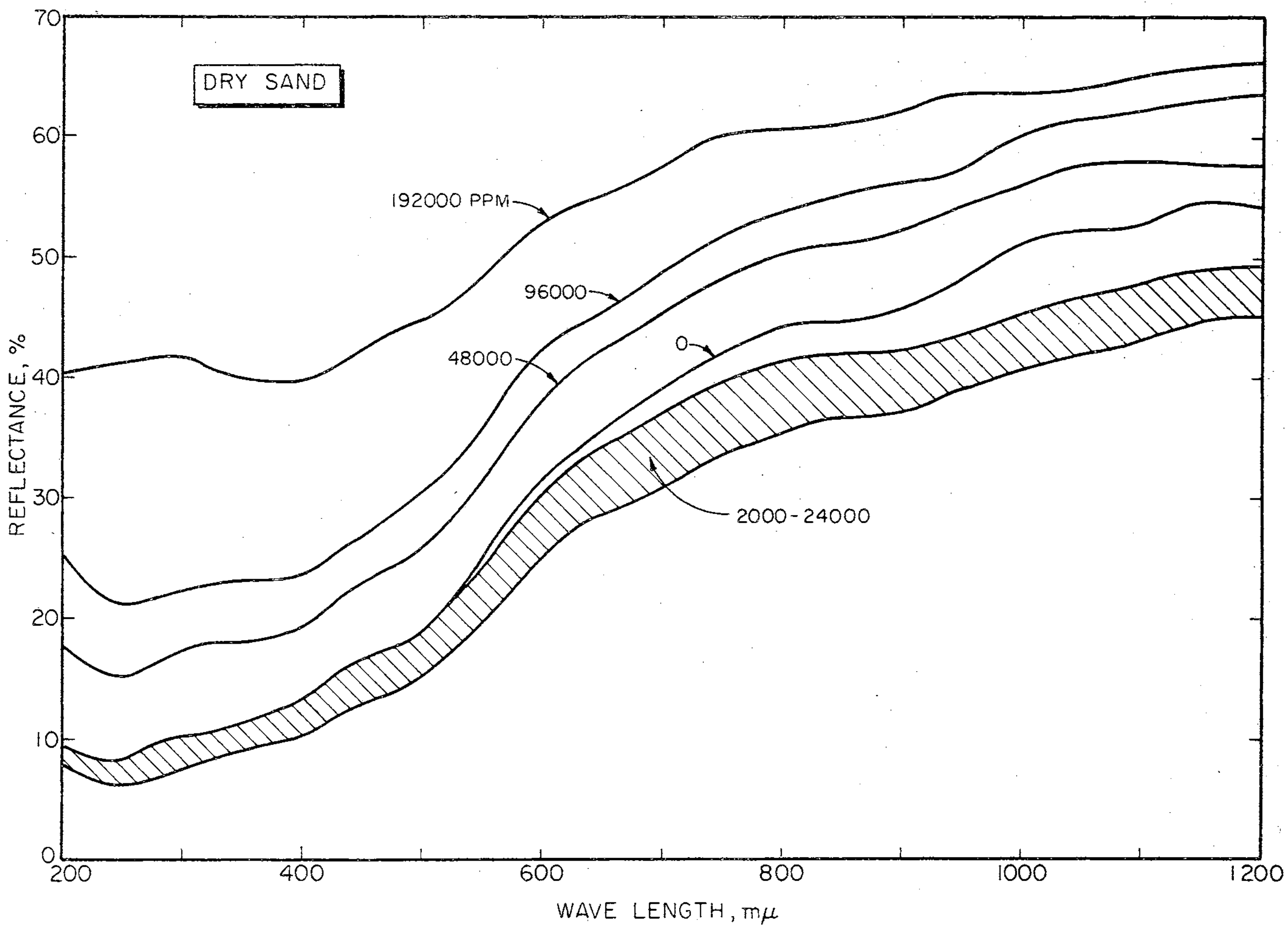


Figure 27. Effects of Salt on Reflectance of Dry Sand

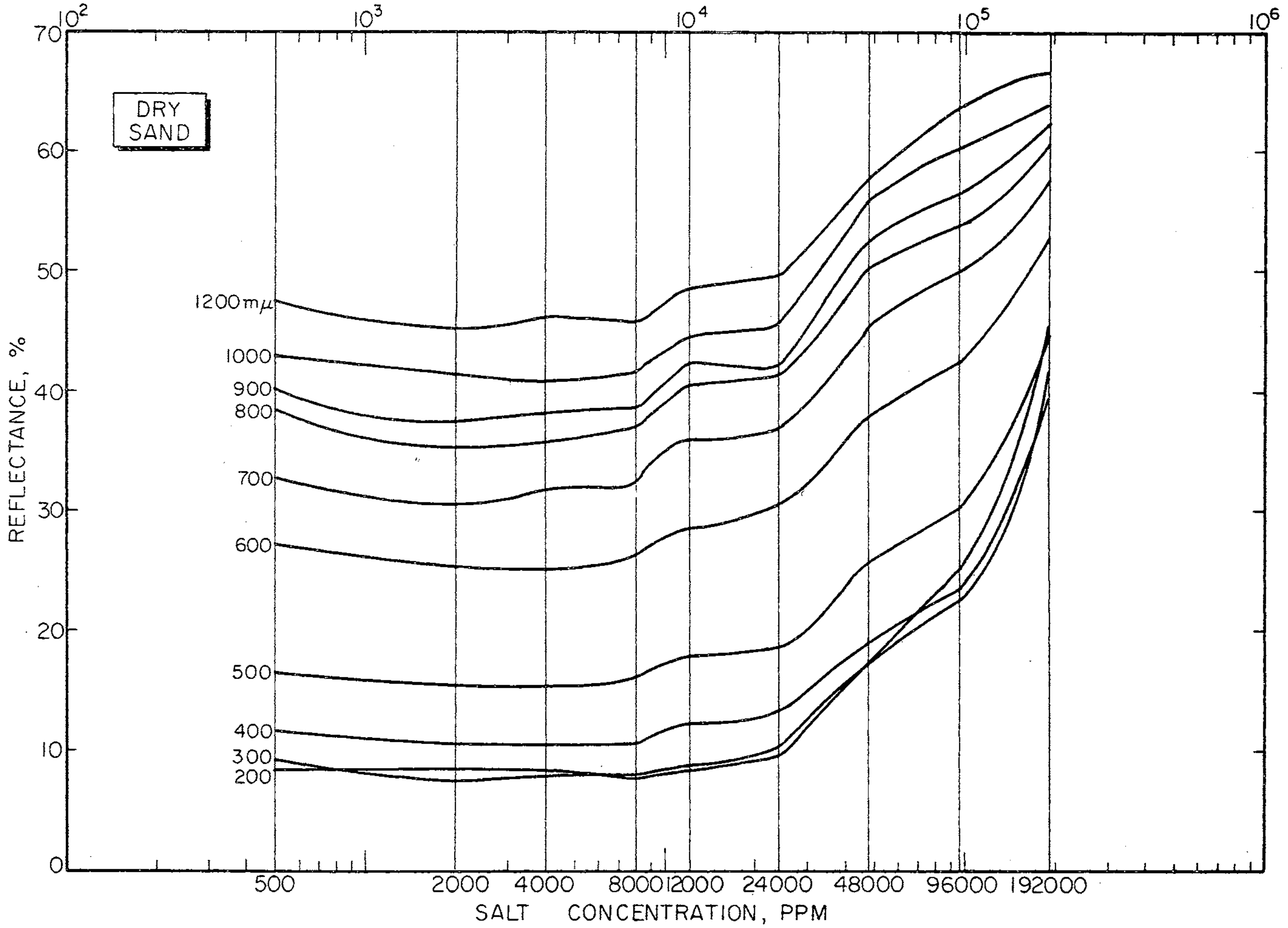


Figure 28. Reflectance Versus Salt Concentration at Different Wavelengths for Dry Sand

spectrum. It was noted that up to 8000 ppm salt concentration the reflectivity is practically constant for each recorded wavelength. It was only after 8000 ppm salt concentration that the spectral reflectivity increased sharply with increase in salt concentrations.

Except for some minor irregularities, the reflectance values at all salt concentrations in dry sandy soils were consistently higher for each increasing wavelength above 400 millimicrons. It would be expected from these results that photographs taken at any waveband for dry sandy soils will exhibit lighter tone with increasing amounts of salt. No noticeable change in tone would be expected with variations of salt concentrations between 0 to 8000 ppm.

No irregular pattern of reflectance was noticed in case of sandy soils as that obtained with clay soils.

Effect of Moisture on Reflectance

The influence of moisture on spectral reflectivity was also studied on samples of clay and sand without salt. In the laboratory, spectral reflectance curves were recorded by observing the various effects of moisture caused by artificially wetting the samples with distilled water. The moisture contents varied from hygroscopic level up to 100 percent of the water holding capacity of sand and clay respectively.

In case of sand at hygroscopic level of moisture, it was noted that in ultraviolet region and a part of the visible portion of spectrum, i.e., up to 550 millimicrons, the spectral reflectivity was practically the same as in the case of dry sand. It was after 600 millimicrons wavelength that the reflectance was lower than that of dry sample and this continued for all higher wavelengths (Fig. 29). Fig. 30 illustrates the curves of reflectivity versus moisture content at different wavelengths in case of sand.

Data as recorded in Figures 29 and 30 indicate in general:

1. Reflectance increases in sandy soil, at any moisture content with the increase in wavelength. This means that the same area photographed in the ultraviolet, visible or infrared ranges of the spectrum will register with a lighter tone in the infrared region.

2. At any specific wave band, reflectance decreased with the increase of moisture content. This is in agreement with the general principle that in the same type of soil, areas of higher moisture content will register in aerial photographs with darker tone. It is very significant however, to notice that the change in reflectance with moisture content is much sharper in the infrared region of the spectrum. This signifies the use of the 600-900 millimicrons range of the spectrum in studying variations in moisture content in sandy soils. Film filter combinations sensitive in this range are therefore recommended for mapping sandy soils to detect variations in water content.

In case of clay samples, it was noted that reflectance of sample at hygroscopic level of moisture showed a trend which was quite different from that of sand, Fig. 31. At this level of moisture in the ultraviolet and in a part of the visible spectrum, the spectral reflectivity was practically the same as in dry sample. It was after 500 millimicrons wavelength with hygroscopic moisture content that the reflectance increased sharply.

From the curves of reflectance versus moisture content of clay, Fig. 32, it was observed that:

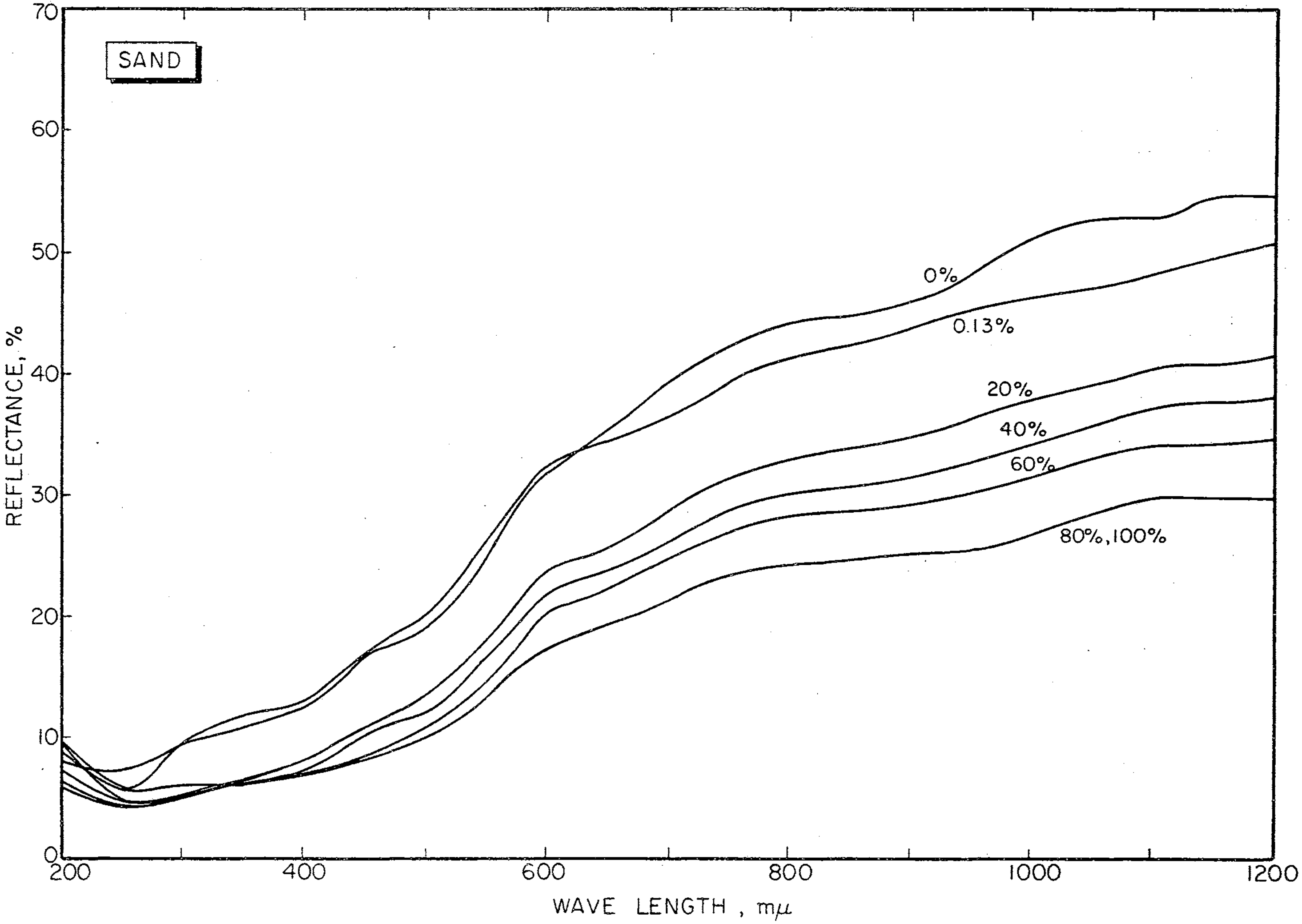


Figure 29. Effects of Moisture on Reflectance of Sand Without Salt

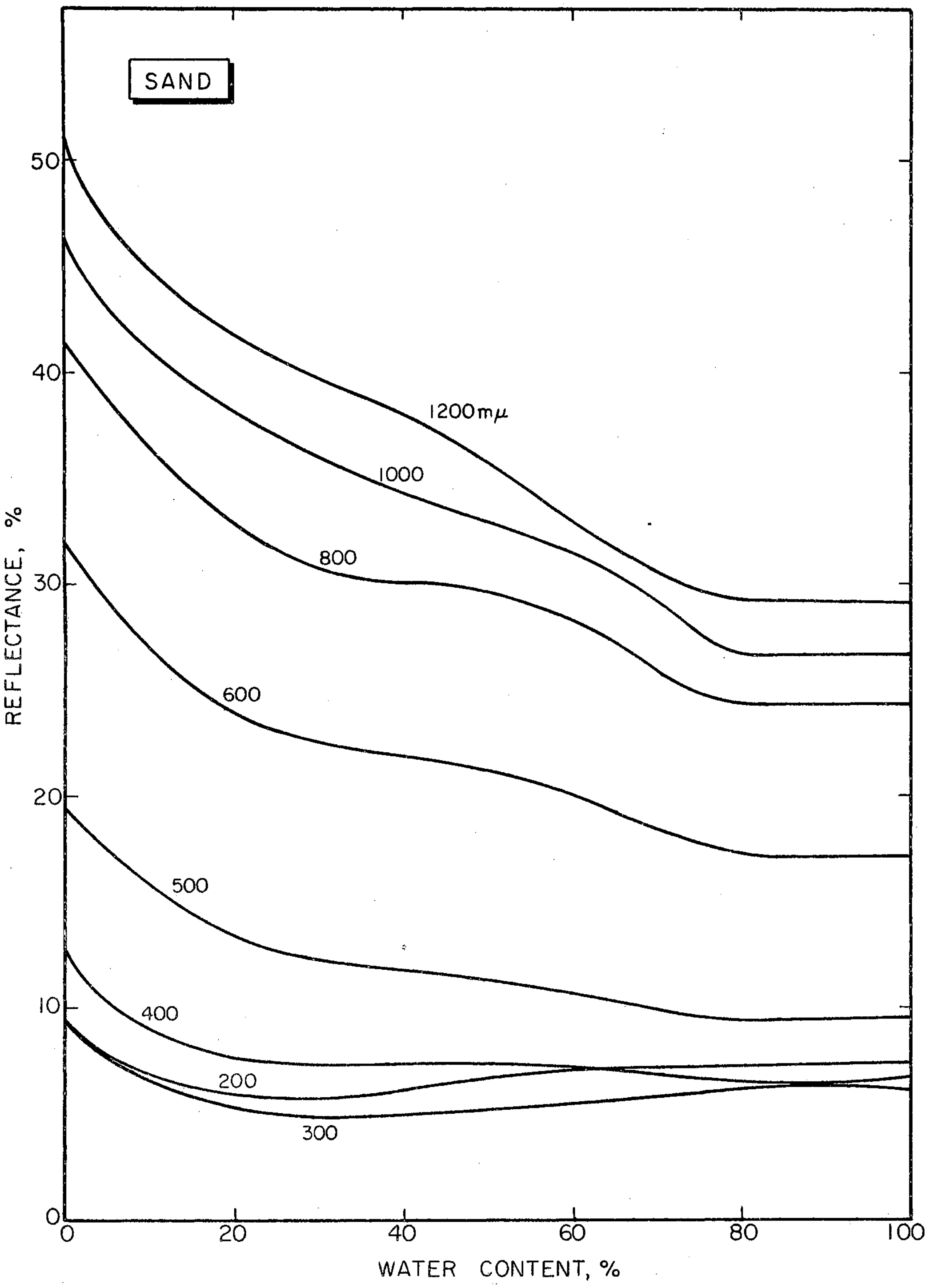


Figure 30. Reflectance Versus Moisture Content at Different Wavelengths for Sand

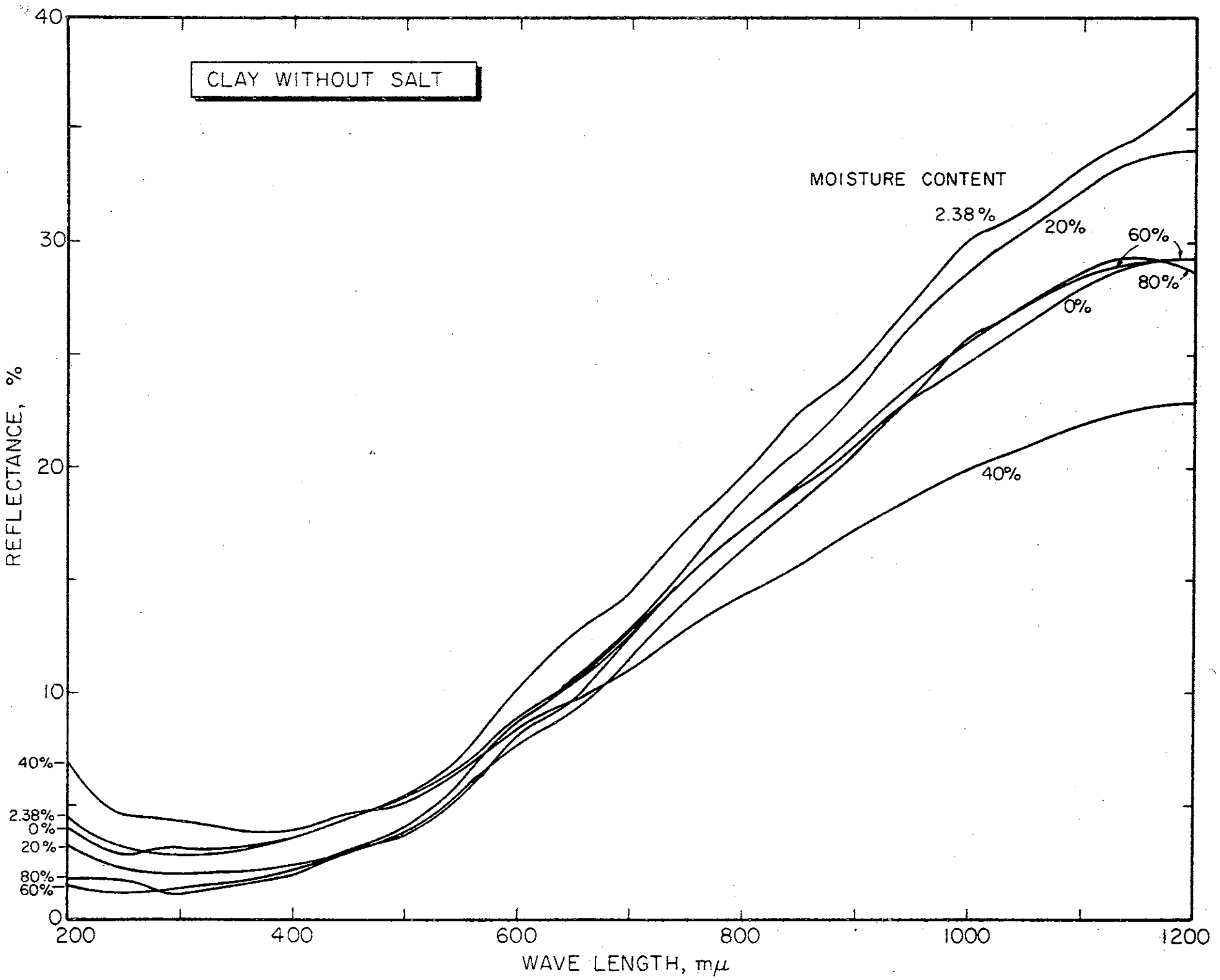


Figure 31. Effect of Moisture on Reflectance of Clay Without Salt

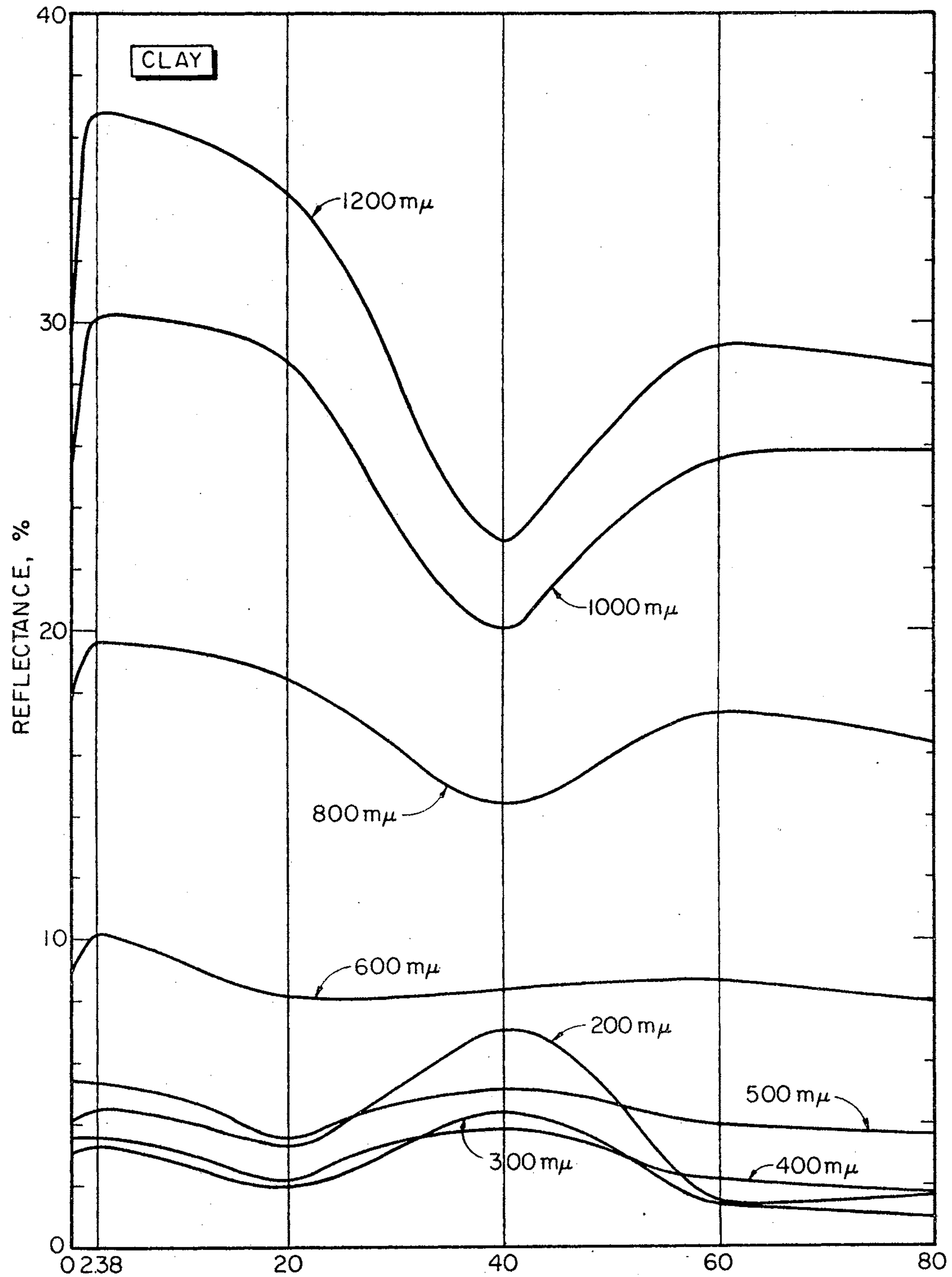


Figure 32. Reflectance Versus Moisture Content at Different Wavelengths for Clay

1. There is a significant effect on reflectance of clay soils when wetted to the hydroscopic level. This is more obvious in the red and infrared regions of the spectrum.

2. For the same area and at constant level of moisture, reflectance increases when sensed at higher wavelengths. There was some irregularity, however, in this relationship up to about 550 millimicrons, beyond which a consistently sharp increase in reflectance was noticed with each increase in wavelength.

3. A general pattern for reflectance versus water content was noticed above 600 millimicrons wavelength. That is, a sharp increase in reflectance up to the hygroscopic level, followed by a gradual and sometimes sharp decrease in reflectance with the increase of moisture content up to about 40 percent, where the reflectance was the lowest. Further addition of moisture did not result in further decrease in reflectance, but surprisingly, resulted in a gradual increase in level of reflectance where it reached a stabilized level at moisture content of about 60 percent.

4. Results also indicate that best wavelength band to show variations in moisture content in clay soils is in the red and infrared regions of the spectrum. Tonal differences recorded should be interpreted, however, with great care, since there was no uniform pattern noted for the relationship between moisture content, wavelength and percentage reflectance.

Effects of Salt Concentrations and Moisture Variation on Reflectance

The effects of the interaction of salt and water on spectral reflectivity of clay and sand were also studied. The salt concentrations at various levels of moisture were varied from 0 to 192,000 ppm. It was noted that there was no single general pattern as observed in case of moist samples without salt. Here, there seemed to be a critical salt concentration level, after which the general pattern changed. It appeared that after a certain point the effects of salt on spectral reflectivity diminished and the changes produced were primarily due to the increase in moisture content. Results in general were most interesting.

Figure 33 illustrates the curves of reflectance versus salt concentrations at three different levels of moisture which seemed to be the critical ones. It was observed that up to 2000 ppm salt concentration the spectral reflectivity values remained constant. It was only after this concentration that the changes were noticed.

For all 20 percent moisture content, Fig. 34, the reflectance values decreased between 2000 and 4000 ppm salt concentrations. With further addition of salt the reflectance gradually increased with a small peak at 12,000 ppm. Beyond 48,000 ppm reflectance increased sharply and at all wavelengths.

When increasing moisture content to 40 percent, Fig. 35, there was only a slight increase in reflectance with the increase of salt content up to 12,000 ppm, beyond which there was a gradual decrease in reflectance. The lowest level of reflectance was recorded at 48,000 ppm, after which reflectance sharply increased again.

In case of samples with 80 percent moisture content, Fig. 36, reflectivity was almost constant with the increase of salt content up to about 48,000 ppm, where it was followed by a gradual decrease in

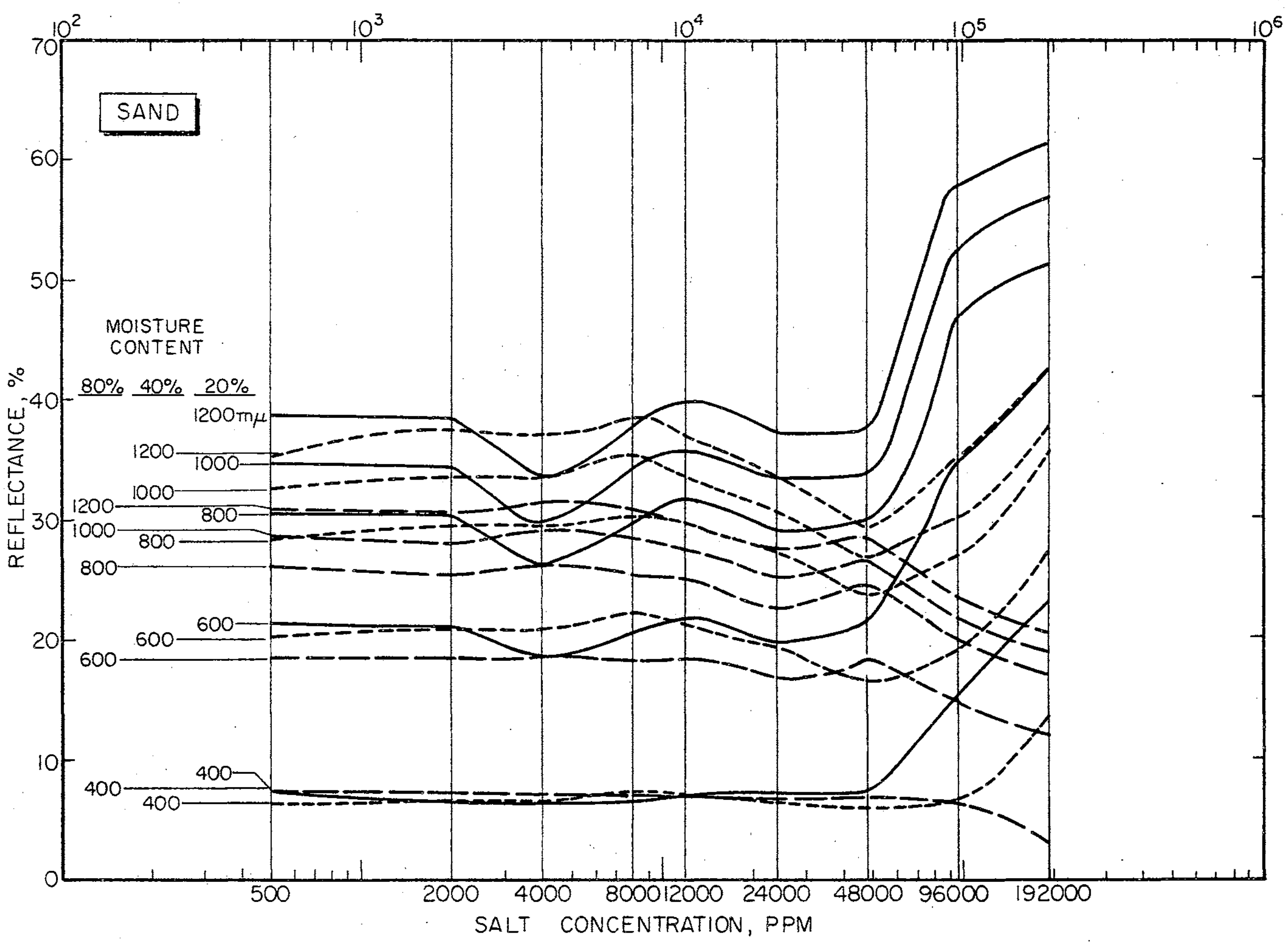


Figure 33. Effects of Salt and Moisture Variation on Reflectance of Sand

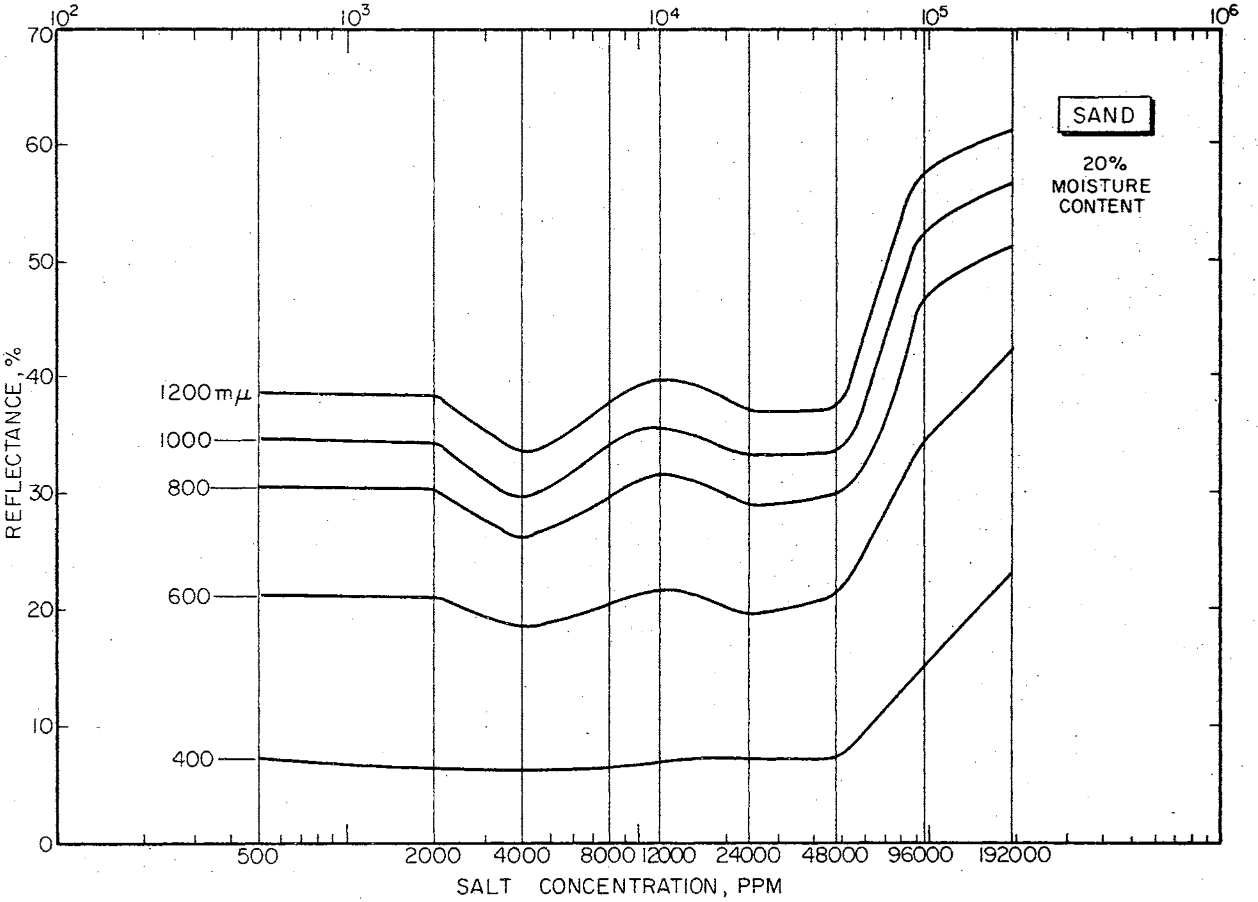


Figure 34. Effects of Salt on Reflectance of Sand at Twenty Percent Moisture Content

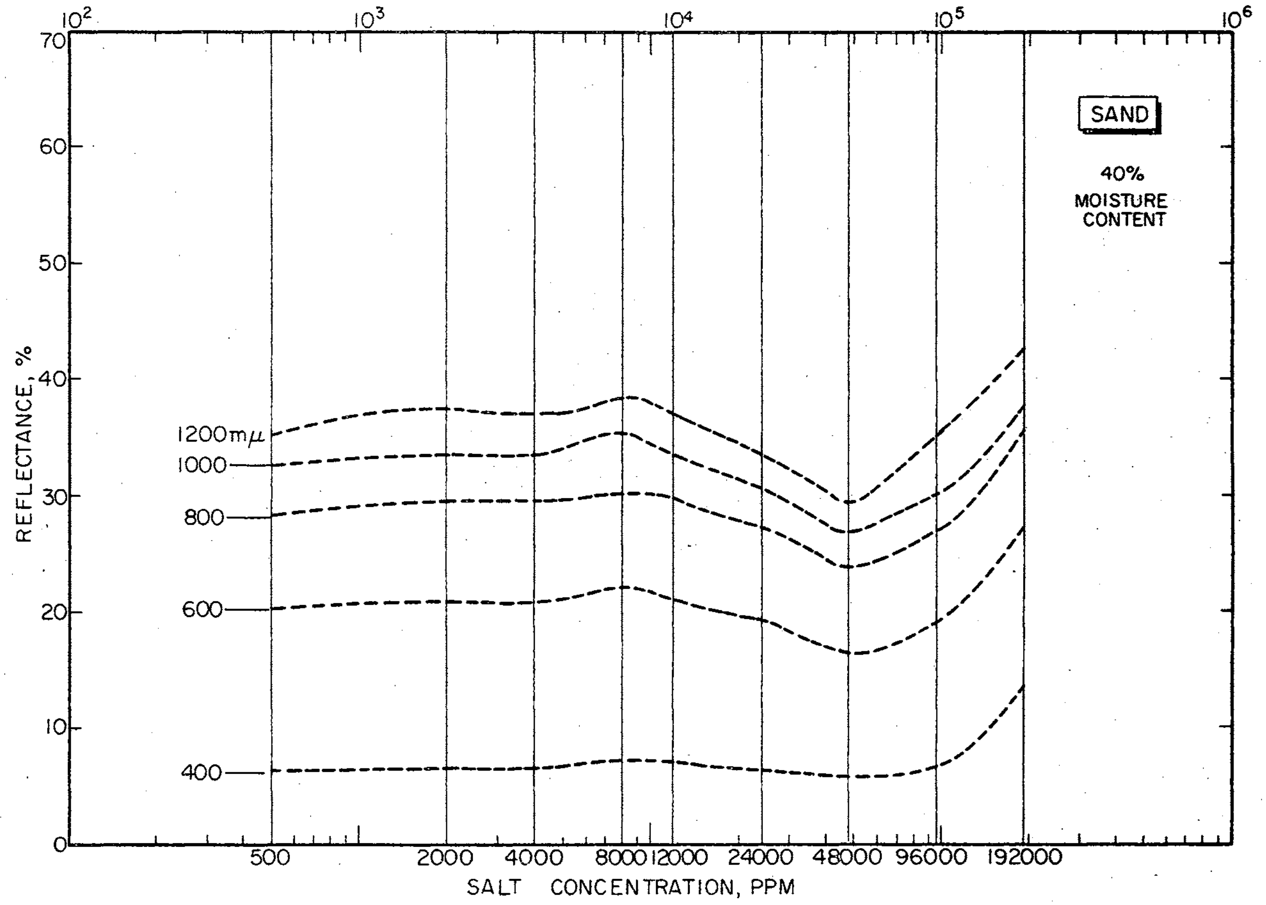


Figure 35. Effects of Salt on Reflectance of Sand at Forty Percent Moisture Content

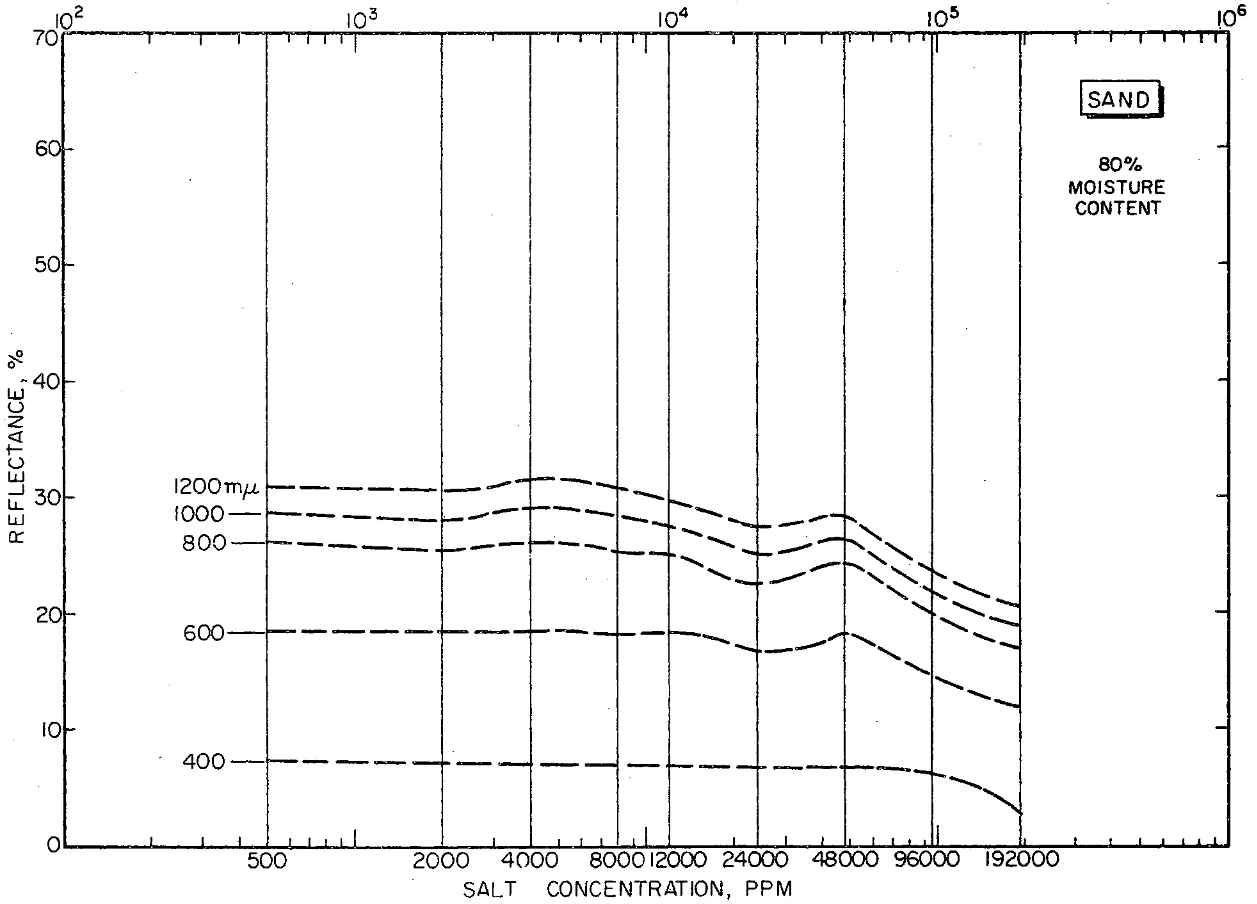


Figure 36. Effects of Salt on Reflectance of Sand at Eighty Percent Moisture Content

reflectance.

In general, all patterns of relationships were consistent at different wavelengths and there was no particular band at which a specific deviation could be detected. It was also noted that at any salt concentration, higher moisture content resulted in a lower level of reflectance and this was particularly true in the infrared range of the spectrum.

From the studies of clay samples containing various concentrations of salt and moisture, it was noted that there was no single general pattern in all the cases. It was observed that after a certain level of moisture, the effect of salt on reflectivity diminished and the spectral qualities were partly governed by water and partly by the interaction of salt, water, and other impurities present in the soil. In this case also, curves of reflectance versus salt concentrations at three critical levels of moisture contents, namely, 20, 40, and 80 percent of the water holding capacity were plotted (Fig. 37). From Fig. 38, it was noted that at 20 percent moisture content, the spectral reflectivity values at all wave bands increased slightly up to 4,000 ppm salt concentration followed by a gradual decrease up to 96,000 ppm. Beyond this salt concentration, the spectral reflectivity values increased sharply. The minimum reflectance values were at 96,000 ppm salt concentration at this moisture level.

In case of samples with 40 percent moisture content, Figure 39, the reflectance values generally decreased up to 2000 ppm salt concentration, followed by two small peak values between 4000 and 8000 ppm, and another at 24,000 ppm. After 24,000 ppm salt concentration, the spectral reflectivity values at all wavelengths gradually decreased

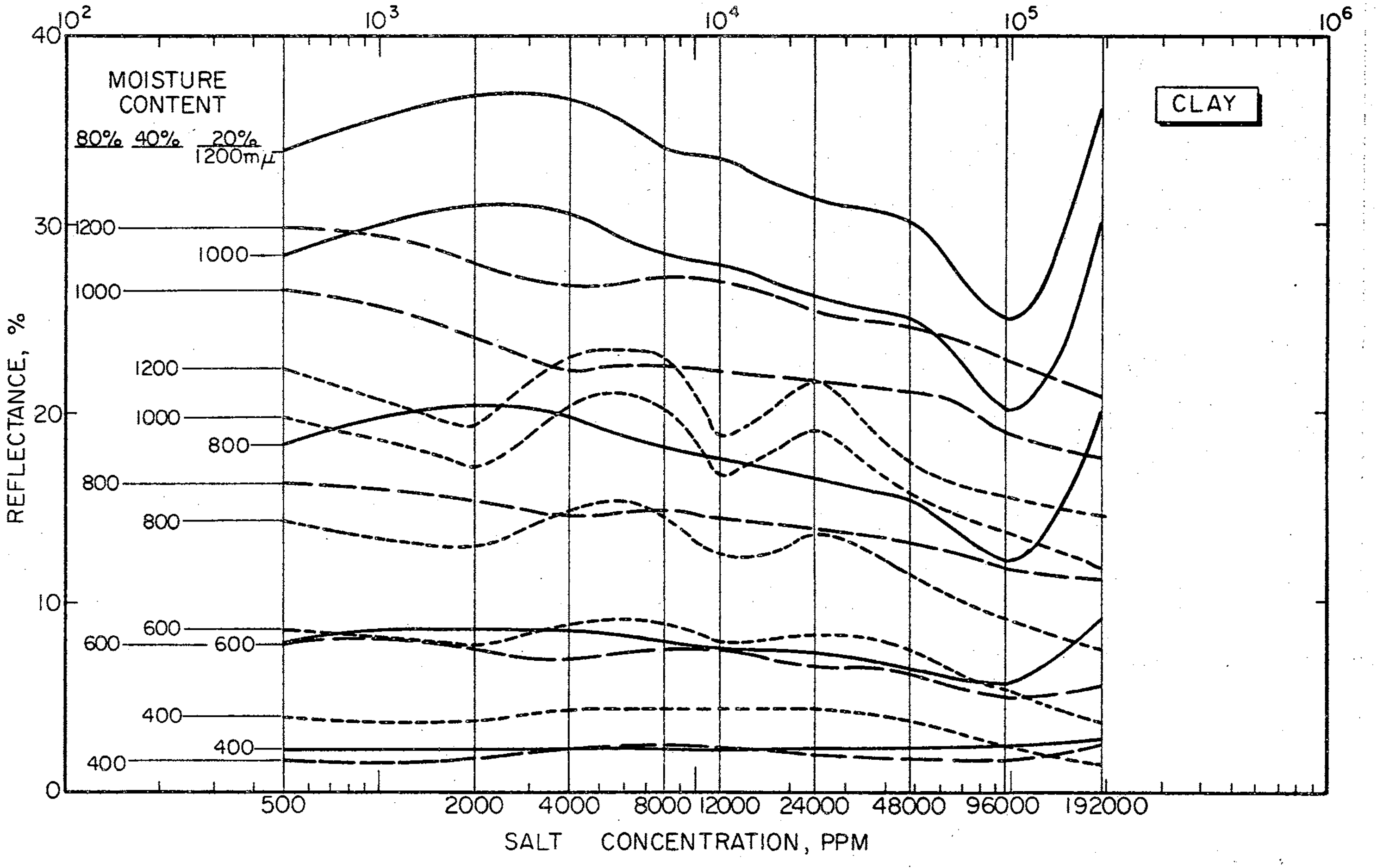


Figure 37. Effects of Salt and Moisture Variation on Reflectance of Clay

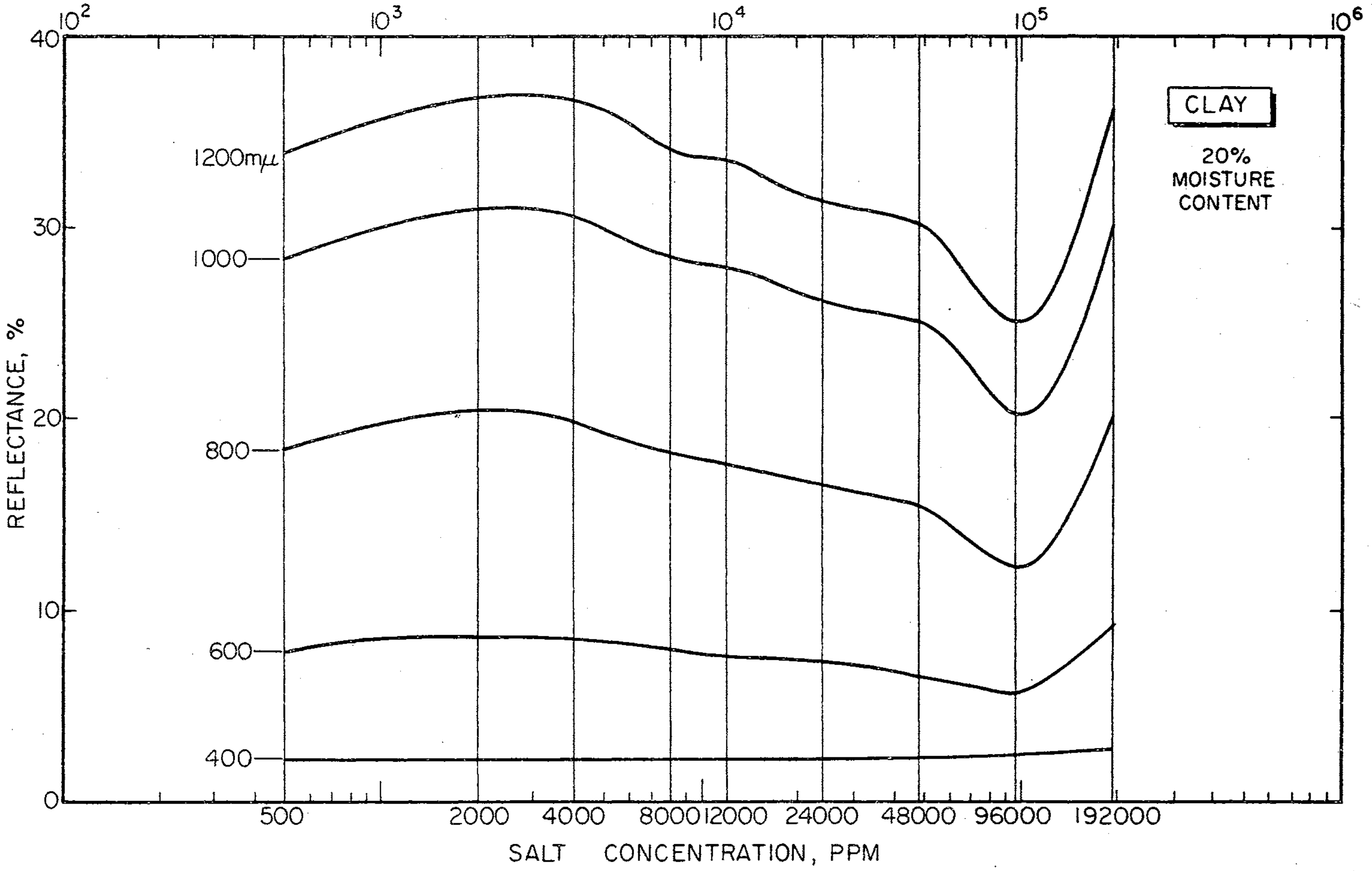


Figure 38. Effect of Salt on Reflectance of Clay at Twenty Percent Moisture Content

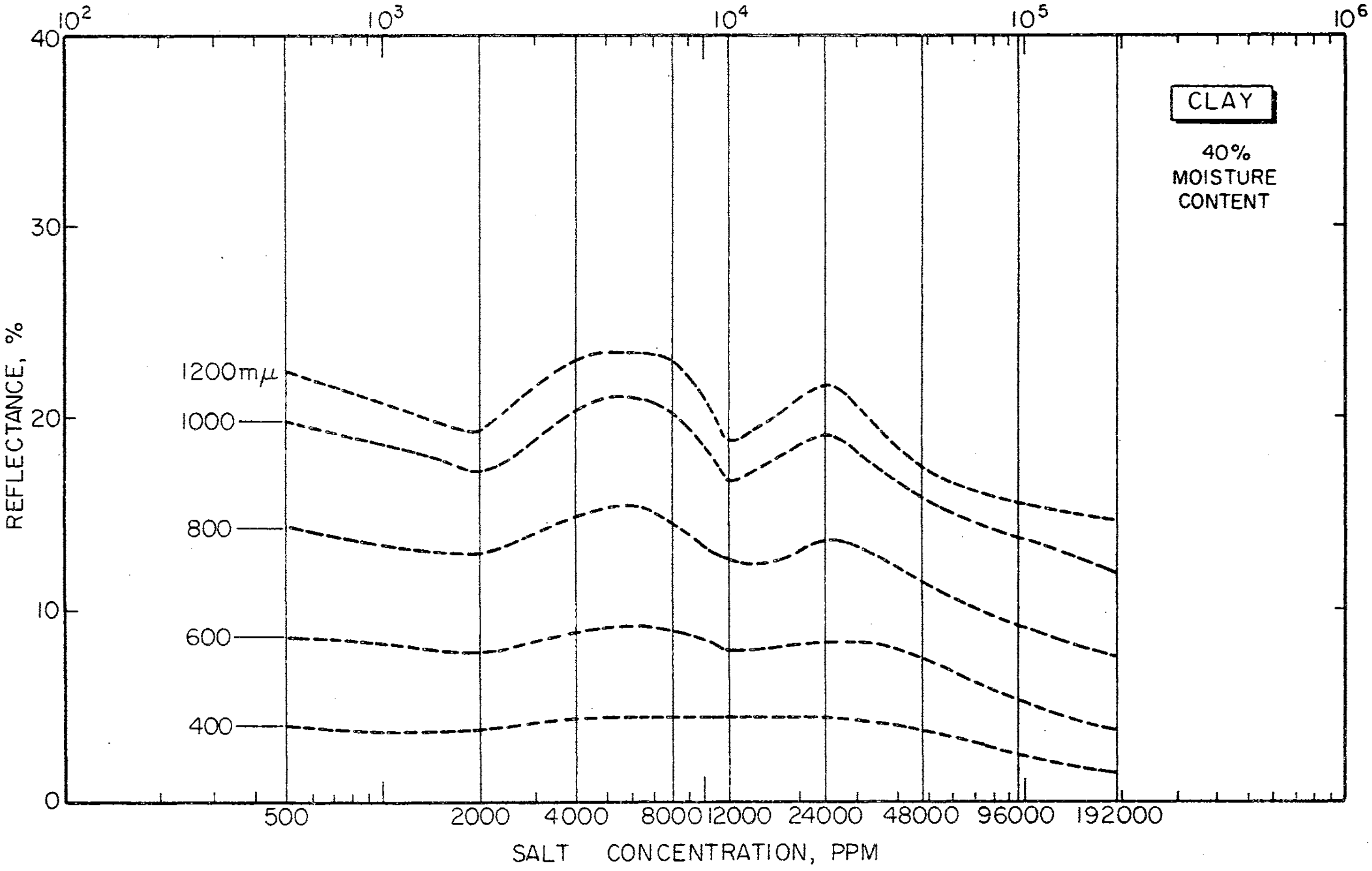


Figure 39. Effect of Salt on Reflectance of Clay at Forty Percent Moisture Content

with the increase in salt concentration.

At 80 percent moisture content (Figure 40) however, the spectral reflectivity seemed to be nearly inversely proportional to the salt concentration. The maximum reflectance value was noted at the lowest salt concentration (500 ppm) and the minimum value at the highest salt concentration (192,000 ppm). In addition, at 400 millimicrons wavelength, the reflectance values at the three different moisture levels, for all salt concentrations, were practically the same.

From this behavior, no definite conclusion can be drawn as there seems to be no particular explanation. Higher reflectance at higher moisture contents could be attributed to the presence of impurities or other organic matter such as actinomycetes or bacteria or mold which could have floated to the surface and effected the reflective quality of the soil.

Lastly, it can be stated that in clay, there was no single general fixed pattern. However, several interesting conclusions can be drawn from the results. First, at any specific salt concentration, reflectivity was lower at higher moisture contents. Secondly reflectance did not always increase with the increase of salt concentrations, on the other hand, and especially with higher moisture content, reflectivity remained constant or even decreased gradually with the increase of salt content.

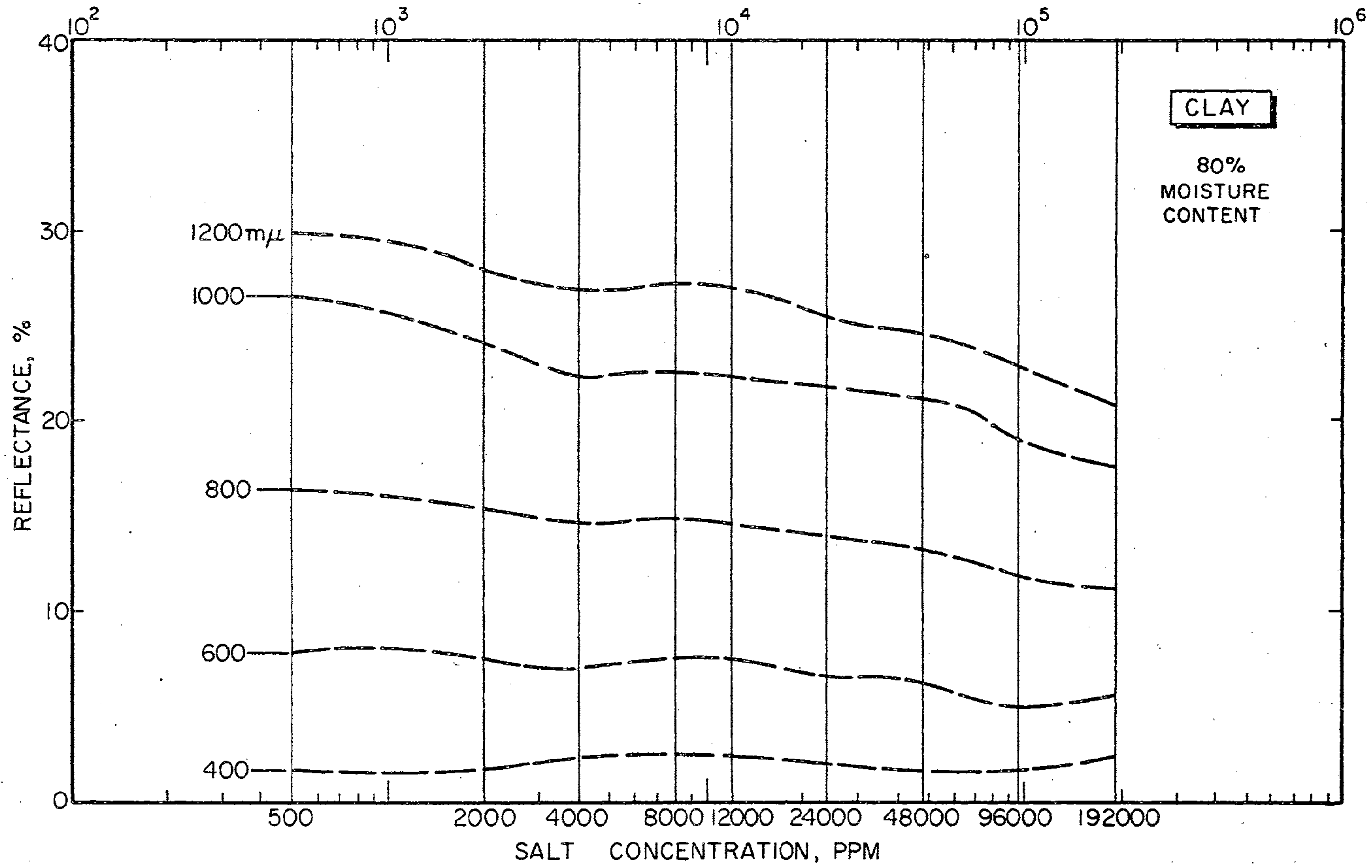


Figure 40. Effect of Salt on Reflectance of Clay at Eighty Percent Moisture Content

CHAPTER VII

CONCLUSIONS

This investigation was a part of a study of reflectance qualities of sand and clay with varying salt concentrations and moisture contents. The main object of this research was to evaluate in which portion of the electromagnetic spectrum exists the maximum differences in the levels of reflectance of the two soils under various conditions.

From the analysis of the data discussed in the preceeding pages and taking into consideration the method and means that were available, the following conclusions can be drawn:

1. Maximum difference in reflectivity between dry sand and clay with no salt treatment exists in the red and infrared range of the spectrum.

2. In all cases investigated reflectivity increased with the increase of wavelength.

3. For dry clay soils with various amounts of salt concentration, no consistent pattern of reflectivity was observed. Maximum reflectivity in this case was observed at relatively lower salt concentrations ≈ 4,000 ppm and at very high concentrations, above 96,000 ppm. Lowest reflectivity was associated with salt concentration in the range of 12,000 ppm. Maximum differences between the highest and lowest reflectivity with the change of salt concentration were observed in the near infrared range.

4. No irregular pattern of reflectivity was noted in case of dry sandy soils with various amounts of salt concentration as that obtained with dry clay soils. Reflectivity increased consistently with the increase in salt content and at all wavelengths. Photographs taken at any wave band for dry sandy soils would be expected to exhibit lighter tone with increasing amount of salt. As there was little change in reflectance with variations of salt concentrations between 0 to 8000 ppm, no noticeable change in tone on photographs would be expected when varying salt concentrations between these limits.

5. In wet sandy soils with no salt content, reflectivity decreased with the increase of moisture content and at all wavelengths. It was significant, however, to note that the change in reflectivity with moisture content was much sharper in the red and infrared regions of the spectrum. Film-filter combinations sensitive in the range of 600-900 millimicrons are therefore recommended for mapping sandy soils to detect variations in water content.

6. In case of wet clay soils a sharp increase in reflectivity was noted when dry soil was wetted to the hygroscopic level. This was followed by an irregular pattern of reflectivity with the increase of moisture content, some of which could not be explained. Effect of mold, soil bacteria and other organic impurities that could have floated to the surface at higher moisture levels could have been responsible for increase in reflectivity noted at these moisture levels.

Results also indicated that best wave bands to show variations in moisture content in clay soils is in the red and near infrared regions of the spectrum. Tonal differences recorded on photographs in this case should be interpreted with great care because of the non-uniform pattern which was observed in reflectivity studies.

7. When studying the effect of varying both salt and moisture contents on reflectivity of sandy and clayey soils, it was noted that there was no one general pattern by which the behavior of samples could be described. It appeared that after a certain point, the effects of salt on spectral reflectivity diminished and the changes produced were primarily due to the increase in moisture. It was also very interesting to note that the increase in salt concentration did not always result in an increase in reflectance, except at lower moisture levels and when present in very high concentrations. In mixtures with higher moisture content, the increase in salt concentrations even resulted in some cases, in gradual decrease in reflectivity.

8. Because of the irregular pattern of reflectivity observed in many instances, multispectral sensing seems to offer a good possibility for interpreting the ground conditions. Photographs taken at several wave bands should be compared using the results of this investigation and with the help of ground truth data so that best results can be obtained.

9. Results indicated that sensing in the red and infrared regions of the spectrum offer definite advantages in specific situations.

CHAPTER VIII

RECOMMENDATIONS FOR FUTURE RESEARCH

The following are suggestions for further research:

1. A further investigation using a more sophisticated equipment such as a double beam spectrophotometer will provide more accurate data.

2. Different kinds of clay and sandy soils should be examined at the various conditions of moisture contents and salt concentrations.

3. In nature soils exist as sand, silt, and clay and as combinations of these three basic types. Research should be carried out to determine the reflectance qualities of sand, silt, and clay in various proportions and under different conditions similar to those in this investigation.

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APPENDIX

REFLECTANCE READINGS

Treatment No.	Salt Concentration
T1	0 ppm
T2	500
T3	2,000
T4	4,000
T5	8,000
T6	12,000
T7	24,000
T8	48,000
T9	96,000
T10	192,000

Reflectance Readings of Sand Samples

% W	T_{10}	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	
O	40.3	25.2	17.6	9.5	8.6	7.9	8.2	8.3	8.3	8.0	Wavelength 200 mμ
H	45.8	16.3	16.1	11.4	10.4	9.1	9.2	9.1	8.9	9.7	
20	24.7	11.2	9.2	8.3	7.2	6.5	6.7	6.1	5.5	5.9	
40	14.2	10.6	9.0	7.4	6.9	7.0	6.8	6.3	5.6	6.3	
60	10.6	13.2	10.0	8.2	7.4	7.7	7.5	7.8	7.5	7.1	
80	2.4	13.1	11.9	10.5	9.9	9.8	9.4	9.6	9.5	8.6	
100	13.0	12.3	9.7	10.1	9.5	11.2	10.6	9.0	8.0	8.7	
O	41.8	22.4	17.3	10.1	8.9	8.0	8.1	7.5	9.1	9.5	Wavelength 300 mμ
H	38.5	15.5	15.4	10.7	9.7	8.1	8.9	9.0	9.0	9.4	
20	24.0	11.4	6.5	6.0	5.6	4.9	5.3	5.2	4.9	5.4	
40	13.4	6.2	5.5	5.2	5.3	5.6	5.0	5.2	5.0	5.1	
60	8.1	6.9	6.2	5.5	5.4	5.3	5.5	5.9	5.5	5.5	
80	2.1	7.0	6.8	6.5	6.6	6.4	6.1	6.2	6.2	6.3	
100	7.2	6.3	6.0	6.5	6.1	6.5	6.3	6.0	6.0	6.2	
O	39.6	23.6	19.2	13.2	12.3	10.7	10.2	10.6	11.7	12.3	Wavelength 400 mμ
H	38.6	18.0	18.4	14.0	13.4	11.5	11.6	12.3	12.1	12.8	
20	23.7	15.6	7.3	7.3	7.1	6.5	6.5	6.8	7.3	7.6	
40	13.7	6.9	6.0	6.6	7.0	7.5	6.8	6.9	6.6	7.4	
60	9.9	6.5	6.5	6.5	6.2	6.6	6.7	7.0	7.0	7.3	
80	3.0	6.4	7.0	6.8	7.1	7.1	7.1	7.2	7.3	6.5	
100	6.8	6.0	5.9	6.4	6.9	6.9	7.0	6.5	6.2	6.7	
O	44.8	30.2	25.7	18.7	18.0	16.1	15.35	15.6	16.8	18.4	Wavelength 500 mμ
H	48.3	23.9	24.9	21.1	20.75	18.15	18.25	19.0	18.4	20.0	
20	30.7	22.7	11.7	11.0	11.1	11.0	10.3	11.1	11.7	13.4	
40	18.6	10.5	9.05	10.5	11.25	12.2	11.0	11.6	11.0	11.8	
60	14.4	8.5	9.1	9.3	9.5	10.2	10.6	10.6	10.8	10.7	
80	5.5	8.7	10.3	9.3	10.2	10.1	10.5	10.2	10.5	9.4	
100	9.2	8.4	7.8	9.3	9.7	11.0	10.0	9.7	9.4	9.7	
O	52.9	42.4	38.0	30.6	28.8	26.3	25.2	25.2	27.1	31.9	Wavelength 600 mμ
H	58.6	36.7	36.6	34.1	32.8	29.8	30.0	31.2	29.5	31.5	
20	42.3	34.9	21.3	19.8	21.8	20.5	18.7	21.1	21.3	23.6	
40	27.6	19.2	16.4	19.2	21.3	22.2	20.8	21.0	20.1	21.9	
60	24.0	15.0	16.8	16.9	17.7	19.4	19.5	19.7	19.5	20.1	
80	12.1	14.8	18.2	16.8	18.4	17.8	18.8	18.5	18.5	17.4	
100	16.4	15.3	14.5	17.0	17.9	19.2	18.3	17.8	17.1	17.2	
O	57.4	48.9	45.2	37.0	36.0	32.3	32.0	30.8	33.0	32.9	Wavelength 700 mμ
H	61.4	42.5	42.6	40.0	38.8	34.8	35.0	37.3	36.1	36.4	
20	46.8	41.6	25.9	24.9	27.0	25.6	22.6	26.5	26.5	28.5	
40	31.8	23.6	20.3	23.7	26.0	27.0	25.6	25.6	24.4	26.0	
60	28.4	18.0	20.7	21.2	22.2	23.0	23.7	24.1	24.5	24.55	
80	14.6	17.5	21.7	20.3	21.9	22.1	23.2	22.1	22.8	21.3	
100	19.0	18.4	18.0	20.8	21.9	22.6	22.7	22.1	21.8	27.3	

Sand

%W	T_{10}	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	
O	68.7	53.9	50.3	41.4	40.5	38.1	36.0	35.5	38.5	44.4	
H	68.1	48.0	47.3	45.0	43.7	40.6	40.3	41.7	40.9	41.3	
20	51.6	47.0	29.8	29.0	31.7	29.8	26.1	30.4	30.6	33.0	Wave-
40	35.6	27.0	23.5	27.1	29.8	31.2	29.4	29.7	28.2	30.1	length
60	32.1	20.6	23.9	24.2	25.6	26.1	27.2	27.6	28.2	28.3	800 mμ
80	17.1	20.0	24.6	22.6	25.0	25.2	26.3	25.4	26.1	24.4	
100	21.8	21.0	20.8	24.1	24.6	25.8	26.0	25.1	24.4	24.4	
O	62.2	56.4	52.3	42.2	42.4	38.8	38.3	37.4	40.3	45.9	
H	67.0	49.9	49.4	47.0	45.2	43.3	42.0	44.1	42.4	43.7	
20	54.0	49.6	31.1	30.5	32.8	31.0	27.5	31.6	32.1	34.7	Wave-
40	36.7	27.9	24.6	28.4	31.0	32.8	30.9	31.1	29.5	31.5	length
60	33.7	21.2	24.6	25.2	26.4	27.0	28.2	28.7	29.2	29.3	900 mμ
80	18.4	20.5	25.3	23.6	25.7	26.1	27.1	26.4	27.0	25.2	
100	22.3	21.5	21.8	24.5	25.5	26.4	26.7	26.1	25.4	25.1	
O	64.0	60.3	56.0	45.5	44.7	41.7	40.9	41.5	43.0	51.3	
H	70.4	52.6	52.4	50.0	48.6	46.4	45.5	47.2	46.3	46.2	
20	57.0	52.5	33.6	33.5	35.9	34.3	29.8	34.3	34.9	37.8	Wave-
40	38.3	30.0	26.7	30.6	33.5	35.3	33.6	38.4	32.6	34.3	length
60	35.6	22.5	26.4	27.3	28.6	28.9	30.4	31.0	31.45	31.5	1000 mμ
80	19.1	21.6	26.7	25.1	27.6	28.2	29.0	28.0	28.9	26.7	
100	23.3	22.9	23.5	26.0	27.1	28.1	28.6	27.8	27.0	26.7	
O	65.3	62.2	58.1	48.0	46.9	44.1	43.9	43.3	45.6	52.9	
H	75.4	55.0	54.7	52.2	50.9	49.2	48.5	49.6	48.4		
20	60.4	55.9	36.5	36.0	38.8	36.4	32.4	37.0	37.5	40.6	Wave-
40	41.3	32.7	28.8	33.2	36.1	37.9	36.3	36.3	34.7	37.1	length
60	38.5	24.4	29.0	30.0	31.5	31.1	33.2	33.7	33.7	34.1	1100 mμ
80	21.3	23.6	29.1	27.4	30.0	31.0	31.5	30.5	31.0	29.6	
100	25.7	25.5	26.0	28.7	29.9	30.5	31.2	30.1	29.3	29.3	
O	66.5	63.6	57.8	49.5	48.5	45.8	46.1	45.2	47.6	54.5	
H	76.1	57.8	55.4	54.4	52.2	51.3	50.2	51.4	51.3	50.9	
20	61.2	57.9	37.5	37.3	39.9	37.9	33.5	38.5	38.8	41.5	Wave-
40	42.1	35.1	29.3	33.8	36.9	38.7	37.0	37.4	35.4	38.1	length
60	38.5	24.6	29.0	30.2	32.0	31.2	33.5	33.8	34.3	33.0	1200 mμ
80	20.4	23.2	28.4	27.7	29.8	30.8	31.3	30.4	30.8	29.6	
100	24.6	24.9	26.0	28.1	29.5	30.1	30.3	29.8	29.5	29.4	

H = Hygroscopic Moisture .13%

Reflectance Readings of Clay Samples

%W	T_{10}	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	
O	24.6	16.3	8.0	5.0	4.3	4.0	4.4	4.2	3.8	4.0	
H	25.0	9.2	7.1	4.9	4.8	4.6	4.1	4.3	4.8	24.6	Wave-length 200 mμ
20	4.1	6.0	4.2	4.6	3.6	3.8	3.7	3.8	3.6	3.3	
40	1.9	4.4	8.2	9.4	9.1	8.8	7.9	6.1	6.4	7.1	
60	0.7	0.6	1.0	1.0	1.0	1.1	1.1	1.5	1.6	1.5	
80	1.6	1.3	1.6	1.6	2.4	2.0	2.3	2.2	2.4	1.8	
O	20.9	12.1	6.1	4.0	3.3	3.0	3.2	3.1	3.0	3.1	
H	19.4	6.8	6.0	3.6	3.6	3.2	2.3	3.0	3.0	2.1	Wave-length 300 mμ
20	2.6	3.3	2.5	2.4	2.3	2.2	2.4	2.5	2.3	2.0	
40	1.4	2.5	4.5	5.2	5.2	5.0	4.8	4.0	4.1	4.4	
60	0.6	0.9	1.2	1.4	1.3	1.3	1.2	1.5	1.6	1.4	
80	1.9	1.5	1.5	1.5	2.3	2.5	2.0	1.8	1.9	1.0	
O	16.2	9.6	6.3	3.9	3.4	3.0	3.6	3.4	3.4	3.6	
H	15.7	6.0	5.0	3.8	3.4	3.8	4.2	3.5	3.7	3.6	Wave-length 400 mμ
20	2.8	2.5	2.2	2.4	2.1	2.4	2.3	2.3	2.2	2.2	
40	1.4	2.4	3.8	4.5	4.5	4.4	4.4	3.9	4.0	3.9	
60	1.1	1.3	1.6	1.8	1.8	1.9	1.8	2.1	2.2	2.2	
80	2.6	1.7	1.9	2.0	2.2	2.5	2.2	1.9	1.8	1.8	
O	18.0	11.2	7.6	5.2	4.6	4.5	5.8	5.0	4.8	5.4	
H	18.0	7.8	7.4	6.0	5.5	5.6	6.0	6.2	5.4	5.4	Wave-length 500 mμ
20	4.5	3.2	3.3	3.4	3.3	3.6	3.9	3.9	3.6	3.6	
40	2.0	3.1	4.9	5.5	5.3	5.5	5.4	5.0	5.2	5.1	
60	1.8	2.4	2.9	3.2	3.4	3.5	3.5	3.9	4.1	4.0	
80	3.8	2.8	3.0	3.4	3.7	3.9	3.2	3.3	3.6	3.7	
O	21.7	15.8	10.5	9.2	5.2	8.0	11.5	8.9	8.6	8.9	
H	23.5	11.9	12.2	11.4	11.2	10.5	12.6	11.8	10.7	10.2	Wave-length 600 mμ
20	9.1	5.6	6.4	7.3	7.6	7.9	8.6	8.6	7.9	8.1	
40	3.5	5.2	7.4	8.4	7.9	8.8	8.8	7.7	8.5	8.4	
60	4.2	5.1	6.4	7.1	7.4	8.0	7.5	8.4	8.5	8.7	
80	5.8	5.1	6.2	6.6	7.3	7.5	6.9	7.8	8.0	8.0	
O	25.5	20.4	14.6	13.7	12.7	11.5	17.4	13.4	12.9	12.8	
H	27.7	17.6	16.8	16.5	16.2	15.0	17.2	16.6	15.7	14.3	Wave-length 700 mμ
20	14.3	8.4	10.5	11.4	12.0	12.5	13.6	14.2	12.6	12.6	
40	5.1	6.8	9.0	10.3	9.9	11.0	8.8	10.2	11.2	11.0	
60	6.1	7.6	9.6	10.2	11.0	11.1	11.2	12.0	12.3	12.5	
80	7.8	7.8	9.1	9.6	10.1	10.4	9.9	10.7	11.6	11.5	
O	31.4	28.5	19.6	19.2	16.4	15.9	23.8	17.7	16.5	17.2	
H	33.8	23.4	22.2	22.1	22.2	20.5	22.5	22.9	21.5	19.6	Wave-length 800 mμ
20	20.0	12.2	15.5	16.5	17.6	18.1	19.9	20.3	18.4	18.5	
40	7.4	9.1	11.3	13.5	12.5	14.5	14.8	12.7	14.2	14.4	
60	9.1	11.0	13.5	14.3	15.3	15.5	15.3	16.5	17.0	17.4	
80	11.4	11.6	13.3	13.8	14.6	15.0	14.5	15.4	16.6	16.4	

Clay

%W	T_{10}	T_9	T_8	T_7	T_6	T_5	T_4	T_3	T_2	T_1	
O	34.4	31.0	23.7	23.7	19.7	19.8	29.3	21.5	20.6	20.9	Wave-length 900 mμ
H	37.5	27.5	26.4	27.1	26.8	24.3	27.0	27.3	26.0	24.4	
20	2.5	18.1	20.1	21.2	22.7	23.1	25.2	25.6	23.6	23.3	
40	9.5	11.1	13.5	16.1	14.4	17.1	17.5	14.8	17.0	17.3	
60	12.0	13.9	16.9	17.6	18.8	19.0	18.8	20.2	20.8	21.3	
80	14.4	15.3	17.3	17.7	18.7	18.7	18.6	19.7	21.1	20.7	
O	38.8	36.8	27.8	29.4	23.0	23.7	34.9	25.0	24.7	24.6	Wave-length 1000 mμ
H	42.6	32.7	31.4	32.4	32.1	29.7	33.1	32.7	30.9	30.1	
20	30.6	20.0	25.0	26.1	27.8	28.4	30.6	30.9	28.3	28.8	
40	12.0	13.5	15.7	19.2	16.6	20.4	20.5	17.3	19.6	20.0	
60	15.0	17.1	21.9	21.2	22.4	22.9	22.3	23.9	24.5	25.6	
80	17.8	18.9	21.2	21.5	23.0	23.4	22.9	24.0	26.5	25.9	
O	40.7	41.3	30.4	33.2	26.0	26.3	38.9	28.3	27.7	28.0	Wave-length 1100 mμ
H	46.4	36.2	34.9	36.3	36.2	33.0	37.0	36.8	35.0	40.7	
20	34.2	23.1	28.5	29.6	31.6	32.0	34.4	34.8	31.9	32.2	
40	13.6	15.0	17.3	21.1	18.1	22.2	22.4	18.7	21.7	21.8	
60	17.5	19.3	22.9	23.6	25.1	25.7	24.8	26.5	27.1	28.5	
80	20.0	21.8	24.3	24.5	26.2	26.5	26.1	27.0	29.1	28.7	
O	42.3	42.8	32.1	35.2	27.1	28.1	41.0	29.4	29.2	29.3	Wave-length 1200 mμ
H	48.3	38.6	36.4	38.2	38.1	35.5	39.1	39.2	36.6	36.7	
20	36.0	24.8	30.1	31.2	33.4	33.9	36.5	36.7	33.8	34.2	
40	14.4	15.7	17.9	21.8	18.6	23.0	23.1	19.4	22.3	22.9	
60	18.4	20.1	23.4	24.4	26.2	26.9	25.8	27.1	28.0	29.3	
80	21.0	22.6	24.8	25.2	26.8	27.2	26.7	27.7	29.9	28.6	

H = Hygroscopic Moisture 2.38%

VITA

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