THE EXPERIMENTAL PREPARATION OF EARTH PIGMENTS OF DENTON COUNTY, TEXAS

THESIS

Presented to the Graduate Council of the North Texas State Teachers College in Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

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Denton, Texas

August, 1941

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CHAPTER I

INTRODUCTION

This study is a report of the results of a series of experiments, the purposes of which were to determine: (1) what natural pigments are available in Denton County, Texas, (2) the variety, quality, and quantity of the native pigments as compared with standard commercial pigments, and (3) the suitability of these native pigments for use in the preparation of artists' colors. Since the chief interest was in the specific hues, their quality and variety, the factor of commercial possibilities was not investigated.

The earth pigments were selected as the basis of the study, since, from the artist's viewpoint, they lend themselves particularly well to experimental production for the following reasons: (1) their preparation is much simpler than that of the pigments of chemical origin; (2) they are available in large quantities and are widely distributed throughout nature; (3) only simple equipment is required, thus making production inexpensive; (4) because of their valuable and stable qualities, they can be used as a standard for judging other pigments of different origins and properties; and (5) it was hoped, inasmuch as frequent variations in hue occur from source to source, that some subtle gradations in hue unattainable in commercial pigments could be produced.

The procedure of preparation and refining was kept as simple as possible, so that the operations could easily be duplicated by artists and teachers of art who are interested in performing similar experiments here or in other localities. With this thought in mind, the procedure involved in the preparation of these pigments is given in detail.

The samples of earth from which the pigments were to be prepared were labeled and sacked in paper bags, each bag containing three or four pounds, the approximate amount required for each experiment. Inasmuch as each specimen varied as to properties and composition, it was found that the amount of raw material required to make a given quantity of finished pigment varied from sample to sample. Certain types of ingredients tend to be washed out more than do others, thus leaving a smaller residue of pigment in relation to the bulk of the original unwashed earth than is left in the case of a specimen containing different types of ingredients. A sandy specimen, for instance, has more large particles which, when washed out, reduce the bulk of the sample more than does clay, which after washing retains a greater proportion of its original bulk; consequently, it was necessary to obtain quantities that often proved more than enough for the purpose of the experiments. Larger quantities would be advisable in the case of those wishing to carry their preparation of pigments beyond the experimental stage, that is, for purposes of painting. However, the larger the quantities prepared, the more cumbersome is the equipment required.

A cursory examination of the raw material to be used in the preparation of the pigment often fails to indicate the quality or appearance of the finished product. Only after the sample has been washed, refined sufficiently, and ground in the binding medium, is it possible to determine its behavior under the brush. The washing or elutriation, as it is called, not only changes the fineness of the particles making up the pigment, but also changes the proportions of all the various ingredients found in the sample, certain ones being more easily washed out than others. Calcination often changes the color of the pigment entirely, this being especially true of the yellow ochers.

In the experiments described in this paper, the two most important classes of binding media, oil and tempera, are used. The tempera binder is an egg emulsion and the oil binder is linseed oil (see Chapter V). In addition to these two experimental media, a third medium, casein, is used as the binder for the illustrative samples that are included within this paper. The reason for the use of this third medium is found in the fact that paper absorbs oil and is stained by it; consequently, for illustrative purposes, all oily binders and emulsions had to be eliminated in favor of the non-oily casein medium.

Mass tone and undertone, tinting strength, spreading power, opacity, and brushing quality are important qualities in determining the usefulness of pigments. These qualities are noted in the analysis of each pigment produced in the study, and the accompanying illustrations record them in so far as reproduction of them was possible.

The experiments are described in Chapter VI. The discussion of the experimental pigments is confined, on the whole, to those pigments which meet the minimum requirements of desirable painting qualities. However, a pigment which does not meet these minimum requirements is discussed whenever its inclusion serves to clarify a point or to illustrate a quality under consideration.

Of the twenty-seven native earths refined and tested in the experiments, it was found that approximately only a third of this number would make satisfactory paints. By eliminating all minor variations in hue and value, the number of pigments was further reduced to seven principal varieties, which constitute the group described in this paper. Each pigment is described as to the location of the sample, its appearance in the raw state, its various painting qualities, and any unusual procedural steps necessary in its preparation. Accompanying the text are samples of paint made from the various pigments, showing the mass tone and undertone of each and thus enabling easy comparison of the various hues.

It is hoped that this study will show how the available raw materials with which the artist comes into contact every day can be utilized to the utmost advantage. Not only is it possible to produce highly acceptable products for personal use, but these products prove to be economical to the user; and perhaps of more importance, their use helps him to become better acquainted with his material, thus enabling him to understand more thoroughly his craft and the possibilities and limitations entailed in its practice.

CHAPTER II

PIGMENTS--THEIR PROPERTIES AND CLASSIFICATION

Introduction

Pigments are insoluble mineral or organic bodies which color a substance, either by mechanical adhesion to its surface or by admixture with it. Because they are soluble in the vehicles used, dyes and stains are excluded by this definition. Properly, the term pigment should be restricted to the dry coloring matter which when mixed with a vehicle becomes paint; the terms are not interchangeable.

The Desirable Properties of a Pigment

To be useful to the painter, a pigment must fulfill certain requirements or possess certain desirable properties. These properties are: durability, insolubility, inertness, indifference to media, opacity, spreading or covering power, and ease of manipulation.

Durability.--There are several factors affecting the durability of a pigment, the chief of which are: light, atmosphere and moisture, chemicals (e.g., acids, alkalis, sulphur compounds), the vehicle or medium used, the associated pigments, and--in some cases--the painting ground. The ideal pigment would be proof against the action of all these agents; however, few possess such immunity. The extent to which any particular factor operates depends upon the use which is made of the pigment: thus, for fresco work, a pigment must be immune to the effects of alkali; or for ceramic use it must be proof against fire.

Many tests have been made by various persons in order to establish to what extent certain pigments are permanent. A typical experiment is that of Russel and Abney[1] who tested the effects of the action of light on water colors. The procedure of the experiment consisted in exposing washes painted on Whatman paper to the action of light and air for a period of nearly two years. Of the thirty-nine pigments tested, only thirteen remained unchanged. In this group of thirteen are six earth pigments. Only two earth pigments are classified among the twenty-six which were altered in one way or another by the prolonged exposure. These results indicate the permanence of most earth or mineral pigments.

Insolubility.--A satisfactory pigment must be insoluble in the vehicle or medium with which it is to be used. This insolubility applies to water, oils, and other neutral solvents or thinners. However, solubility in one of these media does not preclude its use in some other medium, although this condition necessarily limits the scope of the usefulness of a pigment. It is absolutely essential that the pigment be

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[1]W. J. Russel, W. de W. Abney, Report on the Action of Light on Water Colours, cited by Edward Thorpe, A Dictionary of Applied Chemistry, Vol. V, p. 302.

insoluble in water, as it has to be washed at some time during the process of manufacture.

Inertness.--An inert pigment has no effect on other pigments. It does not react chemically or otherwise alter in composition when in contact with these other pigments.

Indifference to media.--Since the vehicle, as well as the pigment, is an essential component of the paint film, the pigment must be indifferent to its complement, the medium. As the chemical and physical properties vary according to the medium used, it is possible that a pigment will be adversely affected by one medium while remaining unaffected by another. An illustration in point is found in the case of kaolin, which furnishes a serviceable white for water-color but which loses opacity in oil.

Opacity.--Opacity, or hiding power, is that characteristic of a pigment which enables it to conceal the surface on which it is painted. Gardner's explanation for opacity in a paint film is as follows:

> The fact that a layer of . . . paint can "hide" the basal material on which it is painted depends on the reflection of the light where it passes from vehicle to pigment, and from pigment to vehicle. For perfect "hiding" practically the whole of the light must be reflected before it reaches the material below the paint film. Thus--other things being equal--the pigments with the best covering power are those substances which have the highest refractive indices.[2] This may be seen from comparison of the values of the refractive index given below:--

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[2]H. A. Gardner, J. Ind. Eng. Chem. 8 (1916), 794, cited by Ulick R. Evans, Metals and Metallic Compounds, Vol. IV, p. 288.

Silica (quartz).	1.55
Barium sulphate.	1.6
Zinc oxide	1.94
White lead (basic carbonate)	2.0
Sublimed white lead (basic sulphate)	2.0
Zinc sulphide.	2.2 to 2.37

A paint-film consisting of silica in linseed oil will be practically transparent since the refractive index of silica is almost equal to that of the medium. On the other hand, a film of white lead in linseed oil will be opaque, and will have good covering power, owing to the high refractive index of lead compound.

But clearly the size of the pigment particles is also of importance. With small particles, the number of pigment-vehicle interfaces which the light must cross in penetrating a film of a given thickness will clearly be greater than with coarse particles. Thus, the covering power of a given pigment will be greater, the smaller the size of pigment-grains; this relation should hold good until the size of the pigment particles becomes so small as to be comparable to the wave-length of light.[3]

While opacity is a virtue, especially in the case of protective surface coatings, it is not to be thought of as an essential quality. Transparent water colors are valued because of their transparency. In water-color painting the color is applied in very thin layers so that all the light comes from the white background. For this reason the smallest amount of soluble binding medium possible is used with the pigment. While the desired transparency is generally obtained by spreading the very fine opaque particles of pigment over a large surface, it may be obtained also by using a pigment with a low refractive index. It can be seen, therefore, that a pigment which is unsuitable for opaque mediums such as oil

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[3] Ulick R. Evans, Metals and Metallic Compounds, Vol. IV, pp. 288-289.

and tempera because of a low refractive index may work very well in loosely bound water-color paints. On the other hand, pastose painting is well-nigh impossible with an excessively transparent pigment.

Spreading power.--The capacity of a pigment for being extended or spread over a large surface is known as its spreading or covering power. Spreading power may be determined by measuring the number of square centimeters of surface over which one gram of pigment can be satisfactorily spread. As in the case of opacity, spreading power increases with the decrease of the particle size.

Ease of manipulation.--Pigments mixed with a medium, such as oil, assume a set of properties which determine the ease with which the paint can be manipulated, both on the palette and on the surface to be coated. Behavior of the pigment under the brush may be described as smooth, sticky or tacky, or fluid. Of the three qualities, smoothness is the most desirable. A smooth paint spreads evenly and easily. Sticky or tacky describes a paint which is thick, viscous or rubbery, and difficult to apply. At the opposite extreme is the fluid paint, which flows too rapidly for correct handling.

The Classification of Pigments

Two types of classifications of pigments are used in this study. The first type classifies pigments according to their origin, the second according to their color. The first classification is general in nature, dividing all pigments on the basis of whether they are organic or inorganic in origin. The inorganic or mineral pigments include the native earths, both raw and calcined, and the artificially prepared mineral colors, such as, zinc oxide and cadmium yellow. The organic pigments include the artificially prepared organic colors as well as the vegetable and animal pigments. In addition to the first classification of pigments as to origin, a second classification as to hue is used because of the fact that the artist's utilization of a pigment must be determined not only by its chemical composition but also by its hue.

CHAPTER III

THE EARTH PIGMENTS OF DENTON COUNTY

Introduction

The colored earths, as a natural result of their widespread existence and their simplicity of refinement, were the first pigments used by man. Probably the first use of these pigments was in connection with the decoration of the body. This practice prevails among some contemporary primitive peoples. By no means is such decoration limited to the primitives, however; for, even civilized man, especially the female of the species, pigments his body with powder and rouges which contain colored earths in varying amounts. The earliest concrete records we have of the use of pigments are furnished by excavated bones and articles from the Cro-Magnon period, or earlier, which were stained with red ocher, indicating that this pigment was used in connection with burial ceremonies. The highest peak in the development of prehistoric art is found, however, in the cave paintings of France and Spain. In addition to the red, yellow, and brown ochers, a natural white and a charcoal black were added to the palette which was used to paint the pictures of animals and men depicted on the walls of the caves. These same pigments have continued to hold a dominant position as part of the materials of the artist down to the present day. Beginning with the historic period, additional pigments were added to the palette; these were lakes prepared from animal and vegetable sources, which, while more brilliant in hue than the colored earths, proved to be extremely fugitive. Although the number of pigments has grown from the nine or ten used during the period from the twelfth to the seventeenth centuries to two hundred and fifteen or more present-day pigments, there has not been a proportionate increase in the number of the known permanent pigments. Only fifteen of these two hundred and fifteen pigments are considered permanent. Of this group of fifteen, six or seven are earth pigments.

The earth pigments are well-distributed over the face of the globe, no locality possessing a monopoly on their source. However, because of a combination of environmental factors certain localities are more suited to the formation of colored earths than are others. As stated in the introduction to this thesis, one of the aims of the experiments which were performed in connection with the study was to determine the quality of the pigments in the Denton area and to compare them with the commercial products of other areas. In the following sections the environmental factors operating in Denton County are discussed and analyzed as to their probable effects on pigmental formation in this county.

Location of Denton County

Denton County is situated in the north-central part of the state of Texas, in the second tier of counties south of the Oklahoma line. It is forty miles northwest of Dallas and thirty-eight miles northeast of Fort Worth. The county is nearly square, being approximately thirty miles across and containing 941 square miles.[1]

Physiography of Denton County

The surface of Denton County is mainly an undulating to gently rolling prairie plain dissected by a number of small streams flowing in shallow valleys. Narrow belts of rough and hilly land are to be found. As shown in Figure 1 three physiographic divisions extend across the county from north

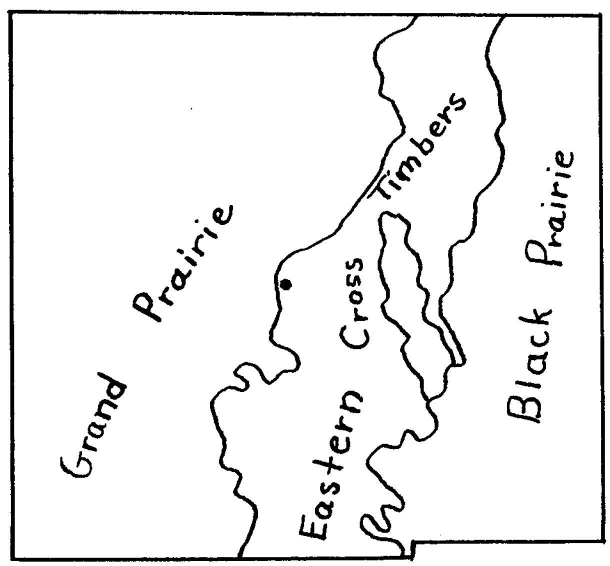

Fig. 1.--The physiographic divisions of Denton County

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[1]William T. Carter, Jr., M. W. Beck, Soil Survey of Denton County, Texas, p. 1.

to south: the Grand Prairie comprises the western half of the county; the Black Prairie the eastern one-fourth; and between these two there is a strip known as the Eastern Cross Timbers. The elevation ranges from approximately 500 feet to nearly 1000 feet above sea level, which fact insures good drainage and in some cases erosion.

Climate of Denton County

The winters in Denton County are short and characterized by sudden changes of temperature, caused by southern extension of blizzards or cold waves from the North and West. The summers are long and hot, the effects of the heat being somewhat ameliorated by the dry atmosphere. On the whole it may be said that Denton County has a mild climate, the mean annual temperature being 65° Fahrenheit. The rainfall is determined largely by the fact that the county is located between the most humid parts of the state and the drier sections. Rainfall is on the average rather evenly spaced throughout the year; however, great variability exists, there being periods of drought and periods of too abundant precipitation.

Soils of Denton County

The colors of soils are determined by environmental factors, such as topography, climate, and the nature of the parent rock.[2] The detrital mineral, in some cases, determines

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[2]Twenhofel gives the most influential land factors affecting colors as: "(a) the nature of the parent rocks, (b) the conditions under which they disintegrate or decompose, (c) the conditions at the place and time of deposition, and (d) diagenesis subsequent to deposition." (Treatise on Sedimentation, p. 775).

the color, but probably in most cases it is due to organic matter or iron--organic matter giving gray, blue, or black, and iron yielding browns, yellows, pinks, reds, blacks and greens, depending on the degree of oxidation and combination. High states of oxidation form colors ranging from yellow to red, and low states from gray to blue.[3]

The colors prevalent in Denton County, as in all warm temperate regions are greatly influenced by the factors of rainfall and drainage. When there is little or no frost action, as is the case in this region, the rocks are destroyed chiefly through decomposition. The detritals of these rocks tend to be brown to red, unless, as is often the case, there are thick growths of vegetation, the organic deposits of which tend to reduce the ferric oxides to gray. However, red and brown predominate as colors because, even though there is little frost action, the winters are severe enough to kill the vegetation; the sediments, thus retain their vivid colors after deposition. In cases where vegetation has produced a gray or black top soil, it is possible to reach the more brilliant colors by digging several inches below the surface soil. Good drainage of surface and subsurface materials tends to oxidize all the iron compounds to reds and browns; however, they turn gray when transported with organic matter. In consequence, gray colors instead of red are to be expected

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[3] *Ibid.*, p. 770.

in the sediments of stream valleys. Below the well-weathered red subsoils the material is bluish, because of imperfect weathering. In cases where the subsoil is poorly drained, thus remaining incompletely oxidized, it is mottled blue, yellow, and red in color. Figure 2 illustrates a typical cross section of a soil type, showing the different layers of color.

The reddish clays extend north and south across the central portion of the county, roughly following the physiographic division known as the Eastern Cross Timbers (see Figures 1 and 3). The yellow clays (usually subsoils) are found in the southern portion of the same division and also in the eastern section of the county known as the Black Prairie (see Figures 1 and 4). Overlapping of these two colors is to be found, both sometimes occuring in the same locality. The black and dark gray clays are an important component of the black soils of the western and eastern parts of the county, known as the Grand Prairie and the Black Prairie respectively (see Figure 1). These clays have little value as pigments, for reasons discussed later.

Summary

The annual average temperature of Denton County is high; freezing is rare; decomposition is rapid; and oxidation of the iron compounds in the soil is well advanced. Consequently, the subsoils are usually red or reddish. The color of the top soil, which depends upon the character of the native

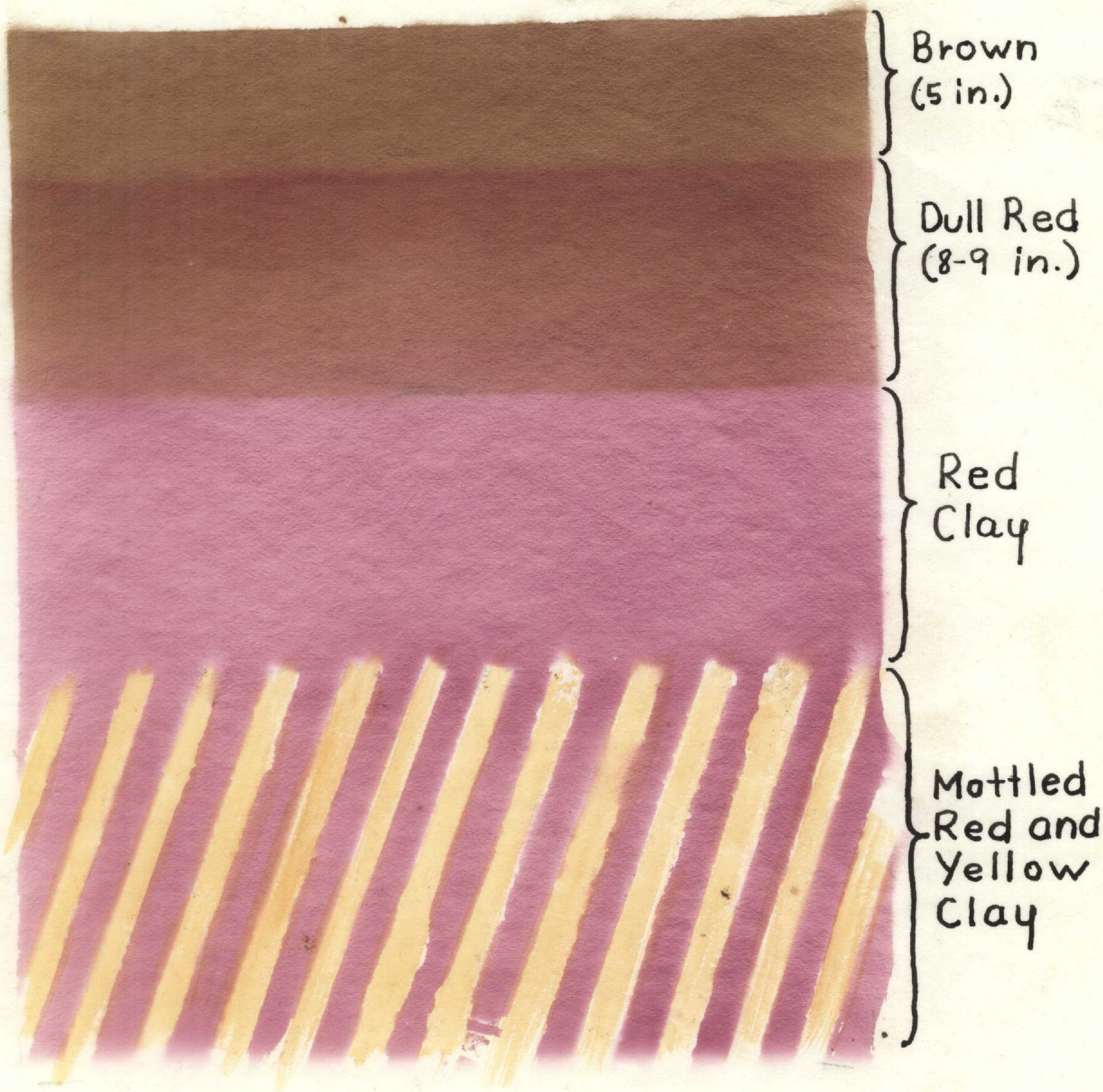

Fig. 2--A cross section of a typical Denton soil type

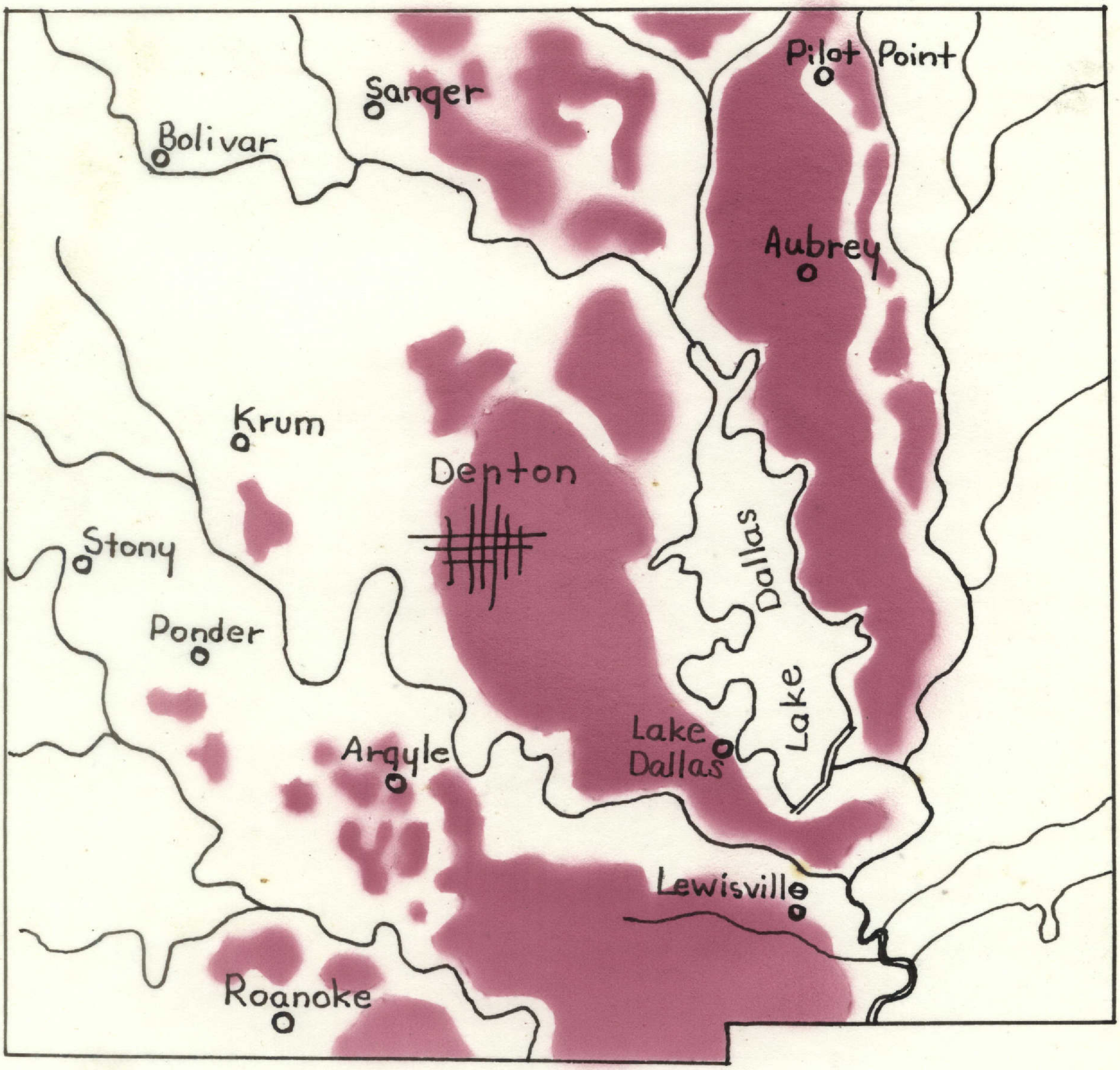

Fig. 3--The approximate locations of the red soils of Denton County.

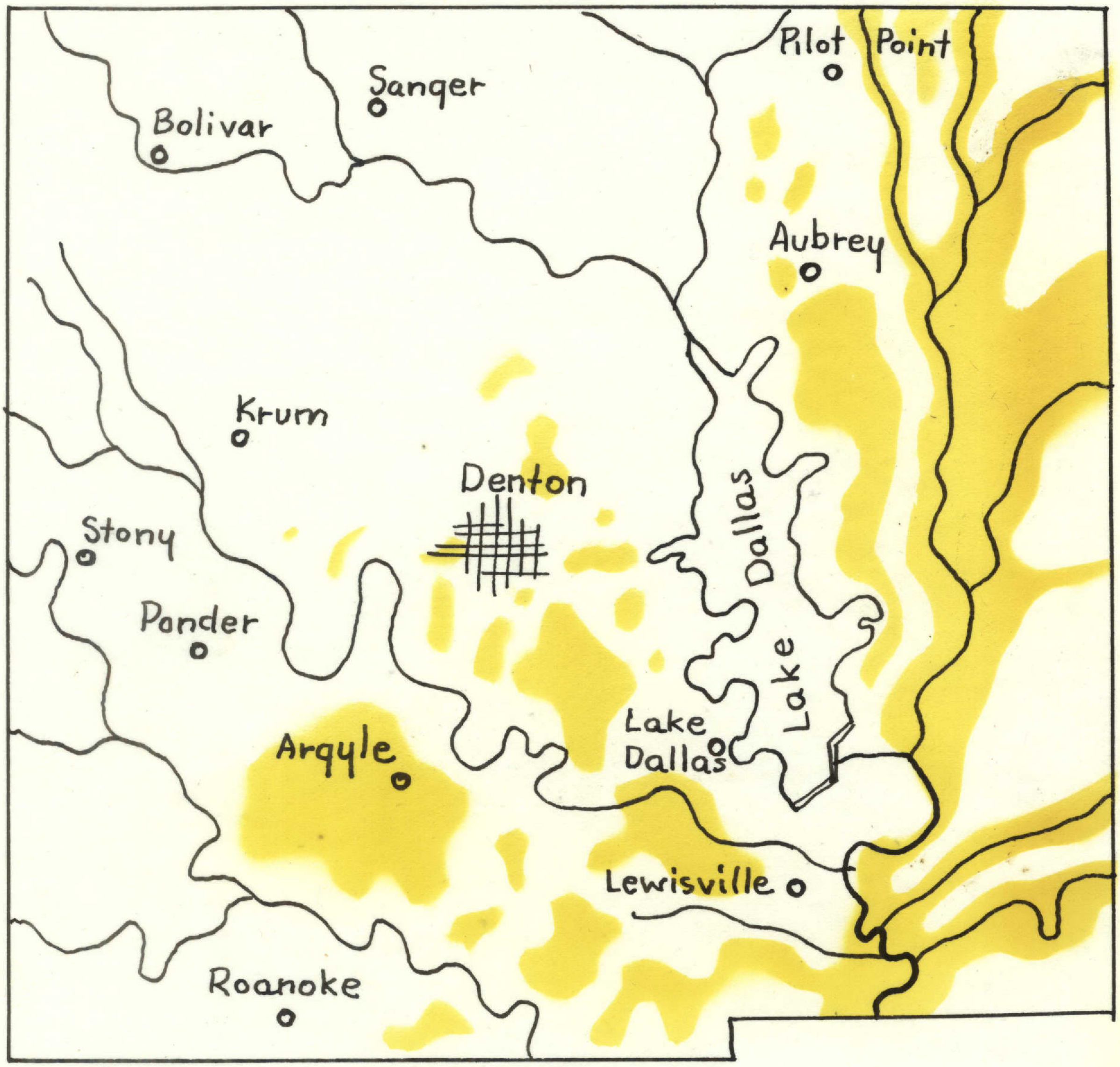

Fig. 4--The approximate locations of the yellow soils of Denton County.

vegetation, is usually dark gray, dark brown, or almost black. Below the well-weathered, red subsoils the materials are yellow or bluish, because of imperfect weathering.

CHAPTER IV

THE EXPERIMENTAL PREPARATION OF EARTH PIGMENTS

Introduction

In order to be suitable for painting purposes, the natural earths must first be purified; that is, all foreign matter possible and all coarse particles must be separated from the finer particles of clay which compose the pigment in question. The process of purification is simple, consisting chiefly of grinding and washing operations. After the pigment has been purified, a third operation is performed, the purpose of which is to determine whether or not the hue of the pigment is altered by heat; this process is known as calcination. The purpose of this chapter is to discuss these processes.

Obtaining the Sample

The most brilliant colors, particularly yellow, are more often found in the subsoils than in the surface materials; in consequence, it is better to select a location where erosion has exposed the sub-surface soils. In obtaining the samples for experimental purposes it is necessary to select them carefully. The quality of the samples varies within one deposit; consequently, care has to be exercised in separating the purer or brighter, and therefore desirable, veins of earth from those which are less pure or bright. For the experiments described in this paper, the samples were removed from the deposit either with a hoe or a broad spatula, sacked in paper or cloth bags, and labeled as to site and general description.

Grinding

After the sample is obtained, the first step in the preparation of the pigment consists of breaking up the lumps of raw material into a granular form which will facilitate washing. If the lumps are very hard, a mortar and pestle are useful. A mortar is essential for the grinding of a powdered pigment which has been calcined, because of the large conglomerations formed during the heating process.

Washing

After the large lumps of the raw specimens are broken up, the crushed or ground clay is churned up with water in a vat or similar vessel. For the quantities of earth used in the experiments, gallon buckets served satisfactorily as washing vessels. The churning causes all of the finer clay particles to be suspended in the water. The water containing these fine particles is then poured into another bucket, while the coarser grit remains at the bottom of the first container. In the second vessel a further quantity of comparatively coarse material sinks to the bottom. The water containing the finest particles is poured into a third container where the settling again takes place. This refining process may be carried further with a greater number of washings, thus obtaining a more finely divided pigment. Some specimens require more washings than do others before they reach a satisfactory consistency. After the pigment has settled to the bottom of the vessel, the water is decanted, carrying off all soluble impurities. After decantation the pigment will probably still be too liquid for use in making paint; in which case, the excess water must be allowed to evaporate. Heating will hasten evaporation; however, caution must be exercised, for, as in the cases of some of the yellow ochers, the hue might be altered by heating. In order to be safe it is best to take a small amount of the pigment and to heat it to see if there is any alteration. In some cases an ocher may be changed by only slight heating, while in others, only complete calcination will alter the hue; some of the red and brown ochers are not changed at all by calcination.

Calcination

The range of hues available in colored earths is greatly increased by calcining the natural specimens. Calcination consists of heating the pigment until the water of hydration is driven out. The lighter pigments, such as yellow ocher, sienna, and umber, contain this water of hydration, while the darker reds and browns are anhydrous and as a consequence are altered very little by calcination. The final shade of a calcined product is determined by the length of time it is heated. Some times after a very short period of initial heating, the color of the earth changes, producing the final shade. In other cases prolonged heating is required before the richest tint is obtained, the richness being directly proportionate to the length of burning time. Such is not always the case, however; sometimes the first deep shade will prove to be richer than those which are produced after prolonged heating. Figures 17 and 18 (see p. 51) show two different values of brown which were produced by heating a natural red ocher for two different lengths of time. The lighter value of brown (Figure 17) was produced by heating the raw earth for approximately twenty minutes. The darker shade (Figure 18) was produced by heating the specimen for thirty minutes or one hour, depending upon the quantity of earth heated at one time.

The equipment required for calcining small quantities of pigment consists only of a small enameled pan which will fit on a gas range, or, better still, on a bunsen burner. If the container is too large, it is difficult to obtain the red heat required in the burning of some of the ochers.

The raw earth is placed within this pan and heated until the desired change in hue has occurred. It is best to break the earth up into small lumps before heating begins, as large lumps do not change easily and require a much longer heating period.

After calcination, it is sometimes found that the earth has formed into hard lumps, in which case it is necessary to use a mortar and pestle in order to grind it fine enough so that it can be washed to the greatest advantage.

After the pigment has been washed, dried, and perhaps calcined and washed again, it is ready to be mixed with the vehicle or binder. Chapter V discusses the function of binding media and the processes used in their preparation.

CHAPTER V

THE PREPARATION OF BINDING MEDIA

Introduction

A powdered pigment, in order to adhere to a surface, must be combined with a medium which will act as a binder. This binding medium dries or hardens into an elastic solid skin which holds the pigment in its place. The ideal medium should: (1) dry into a permanent transparent film, (2) dry without changing greatly in color, and (3) retain its elasticity. Unfortunately no painting medium possesses all of these qualities. The artist's choice of medium, therefore, depends usually upon the qualities he considers most desirable. In the experiments described in this paper, the two most important classes of binding media, oil and tempera, are used. Tempera is the older of the two media, a greater number of paintings having been executed in it during its long history of use; however, oil is today much more commonly employed.

Tempera Media

Tempera media owe their distinct qualities to the fact that they are emulsions. An emulsion consists of very fine drops of one liquid suspended in another. There are many types of emulsions, both natural and artificial, the natural ones possessing better qualities than do the artificial ones. Among the natural emulsions are egg (either the yolk, or the white, or both), milk, and the milky juice of certain plants such as young sprouts of the fig tree, the dandelion, and the milkweed. The natural emulsions adhere to all grounds, fat as well as lean. With the passing of time a natural emulsion "sets"; that is, it becomes insoluble in water.

The artificial emulsions, such as gums and the emulsions which are formed by the saponification of oils, resins, fats, and waxes by alkalis, do not make as good tempera media as do the natural emulsions; they are sometimes used, however. They adhere only to grounds which are free from oil, and they never "set" as do the natural emulsions since they remain soluble in water.

Tempera, in contrast with oil, dries by evaporation rather than by oxidation; which causes rapid drying, a great advantage of this medium. The water evaporates, leaving the oil constituent of the emulsion in an elastic film on the painted surface.

A natural emulsion, such as egg, may be used as a medium without further preparation other than beating to mix the yolk and the white; however, an addition of oil to the egg is usually practiced in order to give more binding power. The fatty, drying oils are used principally in the preparation of the emulsions. Linseed oil, poppy oil, nut oil, sun-thickened oil, boiled oil, oil varnish, coach varnish, resin ethereal varnish, and also wax are especially good for this purpose. There are innumerable recipes for tempera emulsions. Some are good, but others are less satisfactory because of the inclusion of unnecessary ingredients which sometimes react unfavorably with the pigments or other components of the paint film. Consequently, those emulsions which contain the smallest number of ingredients often prove the most satisfactory. Two types of tempera, egg and casein, are used in the experimental preparation of the earth pigments described in this thesis.

Most tempera recipes are based upon the principle that an emulsion, such as egg, is capable of absorbing additional oil and water, this action being made possible by its possession of both of these substances in intimate suspension.

Egg Tempera.--Ingredients (from Doerner[1]):

1 egg
1 linseed oil
2 water

These ingredients may be mixed by shaking them together in a glass jar, or else beating them with a brush. First, beat the whole egg until it is well mixed; second, add the oil and beat again; last, add the water, beating again. The order of the addition of the ingredients is important, the oil always being added before the water. While painting,

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[1]Max Doerner, The Materials of the Artist and Their Use in Painting, pp. 213-214.

water may be added to the emulsion to thin it. The binding power can be further increased by adding a 5 per cent gelatin or glue solution to the emulsion in place of the water.

Casein Tempera.--Ingredients (from Doerner[2]):

40 gm. casein
¼ liter (250 cc.) moderately warm water
10 gm. ammonium carbonate

Doerner's procedure for preparing casein tempera is as follows:

> For easel paintings one had better use technically pure casein, insoluble in water but soluble in ammonia. This casein is a coarse powder made of artificially dried and ground curd. The powder should be fresh and dry and must not smell as if putrefied, otherwise the emulsion will spoil quickly.
>
> 40 gm. casein are first mixed with very little water, then ¼ liter (250 cc.) moderately warm water is added.
>
> In the meantime 10 gm. ammonium carbonate are dissolved in a few drops of water, and after all the lumps have been pressed out, the solution is poured into the casein. Promptly there is effervescence; the carbonic acid escapes. After a little stirring, as soon as there is no longer any foam, the casein solution is ready.
>
> The casein solution looks turbid and white like paste. Under no circumstances must casein be allowed to boil. If the water used is very hard, a white sediment forms at the bottom, carbonate of lime, which is harmless and removable. The ammonium carbonate should be very fresh, and, if so, will show a high degree of effervescence.

Oil Media

No preliminary preparation of the oil medium is necessary before grinding with the pigments as is the case with the

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[2]Ibid., p. 219.

tempera emulsions. In grinding the colors in linseed oil, the oil must be of a very pure grade, preferably cold-pressed linseed oil. Poppy oil is much used for grinding oil colors because it possesses a "buttery" quality, but it dries more slowly than does linseed. A combination of the two oils is often used. If poppy oil is available to the experimenter, it should be used; however, linseed oil alone is satisfactory. A more detailed discussion of the differences in appearance and painting quality between oil and tempera can be found in Doerner[3] and in Vytlacil.[4]

Grinding of Pigments in the Medium

Equipment:

sheet of plate glass, marble slab table top, or enamel sheet
muller, spatula, pestle, or marble block
pigment
medium

For grinding small amounts of color, a spatula will be satisfactory, but for larger amounts, the muller or marble block is preferable. Because of its weight the marble block grinds the colors thoroughly without the additional pressure that is required when a pestle is used--the marble block is used with the marble slab, the glass pestle with the plate glass.

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[3]Max Doerner, The Materials of the Artist and Their Use in Painting.

[4]Vaclav Vytlacil, R. D. Turnbull, Egg Tempera Painting, Tempera Underpainting, Oil Emulsion Painting.

At the beginning of the grinding process very little of the medium is added to the powdered pigment. The pigment and medium are mixed into a thick paste with the spatula. Under slight pressure and with a circular motion the paste is gradually spread over the surface of the plate or slab. After the thick paste is thoroughly ground, it may be thinned gradually until the desired consistency is reached. Consistency will probably vary with the medium used, the tempera possibly being thinner or more liquid than the oil. When oil colors are of a desired consistency they are "short;" that is, they will stand up when wiped on the edge of the plate with the spatula. Oil colors are made "short" chiefly through an economical use of oil; however, a 2 per cent solution of wax in turpentine helps give the oil color the desirable consistency and at the same time gives it an appearance of greater body and richness.

Varying amounts of oil will be required for the different colors; Doerner gives the approximate amounts of oil required for the different earth pigments as follows: light ocher, from 33 to 75 per cent; raw sienna, from 100 to 241 per cent; burnt ocher, about 40 per cent; iron oxides, about 40 per cent; green earths, about 80 per cent; umber, about 80 per cent; and burnt green earth, about 50 per cent.[5] It can be seen from the above figures that there is a marked degree

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[5]Doerner, _op. cit._, p. 144.

of variance; since the composition of the pigments varies, experimentation will largely have to determine the optimum amount required for each pigment. The powdered pigment to be mixed with oil should be thoroughly dry before the grinding begins, as the dry pigment will take up more oil and produce a more fluid color. Very slight heating will serve to drive out any free moisture present in the pigment.

Since tempera is an aqueous medium, it is not necessary that the pigment be dry before it is ground with the tempera vehicle. As a matter of fact, the powdered pigment may be ground in water only, being mixed with the emulsion on the palette with the brush just before it is painted upon the surface or ground. If the pigment is ground in the tempera emulsion, the same procedure of grinding or rubbing is followed as in the case of oil. The longer the pigments are ground the better they will be. Experience will show that certain ones will require more rubbing than do others. If the pigment is gritty, it should be thoroughly ground until it feels perfectly smooth. Much effort would be saved if as much of the grittiness as possible is removed in the earlier processes of washing the pigments.

The ground oil colors can be put into tubes by means of a spatula, the tube being rinsed out first with turpentine. The tempera colors may also be put into tubes, but a more convenient practice is to keep them in well-covered jars or glasses. Care should be taken to see that enough water is added from time to time to keep them from drying out.

The colors ground in egg emulsion will spoil if kept over a long period of time, especially in hot weather; however, they may be kept in satisfactory condition for about two or three weeks. Three or four drops of Oil of Cloves added to about one-fourth of a pint of paint will preserve them for a somewhat longer period.

CHAPTER VI

DESCRIPTION OF THE EXPERIMENTS

Introduction

The following chapter is devoted to a description of the experiments performed in connection with the preparation of the various pigments. Each pigment is described individually as to qualities displayed under actual painting conditions. Its behavior in each medium, tempera and oil, is discussed under the following headings: mass tone, undertone, tinting strength, spreading power, opacity, and brushing quality.[1] Figures show painted samples of each pigment discussed, with casein tempera as a binder. It was impossible to include illustrations of the pigments painted in the oil medium because of the stain produced by the oil on paper; however, the behavior and appearance of the pigment in oil is described completely. The painting qualities of each pigment are rated either poor, fair, or good. These ratings were judged by the author while comparing the several samples as they were washed, ground, and painted in the various media; it can be seen, therefore, that the rating is relative and is in no way intended to be arbitrary.

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[1]For a detailed description of these painting qualities see Chapter II.

As a rule a pigment should be classified as good in its various painting qualities before it is included on the artist's palette. However, a rating of fair or even poor may be offset by other good qualities. For example, a pigment may be low or poor in hiding power; in other words, it may be transparent, but this fact does not preclude its use in certain techniques, so long as it fulfills other requirements. Such transparency, indeed, is sometimes much sought after in water colors.

The painting qualities are often changed when a pigment is mixed with another pigment. This point was often illustrated in the experiments when white was added to the specimen pigment in order to determine its undertone. In these instances, the pigment frequently had a tendency to become opaque, its spreading power increased, and, even more frequently, its brushing qualities improved. A paint which was sticky or tacky in brushing quality became more smooth upon the addition of the white pigment. Whenever any of these changes in quality are noted, they are mentioned in the discussion of the pigment affected.

In addition to the usual pigment name there is, for purposes of more accurate identification, the name of the hue as given in A Dictionary of Color.[2] This aid is especially useful in the case of those pigments ground in oil.

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[2] A. Maerz, M. Rea Paul, A Dictionary of Color.

As explained previously, it was impossible to incorporate the samples of oil paints within the body of the thesis; consequently, the Dictionary furnishes an authentic basis for identifying the hues of these colors for the reader. It will be found, for instance, that the pigments ground in oil are darker and richer in value and tone than are the same pigments when they have a tempera binding medium. For example, the yellow ocher sample illustrated in Figure 5 is matched most nearly by the hue called golden yellow in the Color Dictionary. On the other hand, the sample of the same pigment with an oil binder is most nearly matched by the hue known as raw sienna.

Yellow Ocher

There are many yellow ochers, some of which are known by the following trade names: Roman ocher, Oxford ocher, mineral yellow, and Chinese yellow; they vary in hue and properties, depending upon their sources. They are all silicious and argillaceous earths containing such impurities as lime and barium. The yellow color is due to presence of hydrated ferric oxide. These colors are permanent and inert, being unaffected by other pigments, any painting medium, light, or impure atmosphere. Most ochers possess fair hiding power, although this quality varies from sample to sample. Different qualities of ocher may be obtained from different portions of the same deposit. The texture and grain size or the amount of clay or carbonaceous matter present may vary; as a result, careful selection is necessary. Certain French ochers are more brilliant than the American ochers which have been placed on the market.

Location of the Experimental Sample

The particular specimen illustrated in Figure 5 was obtained in the City of Denton in the 900 block of South Elm Street. This section of the street runs up a fairly steep hill, the soil of which is conspicuously red with occasional yellow streaks. The specimen was obtained from a clay bank on the side of the street.

Description of the Sample

The unrefined specimen was a silicious yellow earth, containing clay. It was crumbly in nature, lacking the high percentage of sticky clay found in some of the other yellow samples obtained in other sections of the county.

Reaction in Tempera

Mass tone.--The mass tone is illustrated in Figure 5. The Color Dictionary designates this hue as golden yellow[3]; the sample therein illustrated as yellow ocher contains more orange than the ocher illustrated in Figure 5.

Undertone.--The undertone of this specimen of yellow pigment is illustrated in Figure 6. This particular value of ocher is designated as sunset in the Dictionary.[4]

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[3]A. Maerz, M. Rea Paul, A Dictionary of Color, Pl. 10 L 7, p.43

[4]Ibid., Pl. 10 C 4, p. 43.

Fig. 5.--The mass tone of the native yellow ocher casein paint.

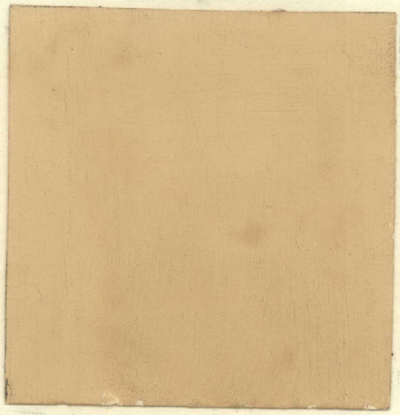

Fig. 6.--The undertone and tinting strength of the native yellow ocher casein paint.

Tinting strength.--The tinting strength is fair.

Opacity.--The hiding power ranges from fair to good.

Spreading power.--The spreading power is good.

Brushing quality.--The pigment brushes smoothly over the painting surface.

Reaction to Oil

Mass tone.--As is to be expected, the oil color possesses a darker and richer mass tone than the tempera ocher illustrated in Figure 5. The Color Dictionary designates this hue as raw sienna.[5] It would be accurate, therefore, to name the oil color produced in this experiment raw sienna although the tempera is correctly designated as a yellow ocher.

Other qualities.--The painting qualities of ocher in oil

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[5] *Ibid.*, Pl. 13 L 10, p. 49.

are similar to those described in the discussion of the tempera binder.

Burnt Ocher

By calcining the yellow ocher it is possible to obtain an additional hue. The heating serves the purpose of driving off the water of hydration--the ferrous salt of the ocher is turned to ferric salt. Some of the most brilliant reds are obtained in this way, the red of the burnt product often being more intense than the natural red ocher. The final color of the calcined product is influenced by the length of heating and the rate of cooling--the longer the calcination, the more purple is the product. The color is also influenced by the nature or color of the raw ocher--the best yellows do not always produce the best reds. The burnt ochers cover solidly and are quite permanent.

Location of the Experimental Sample

This specimen in the raw state is from the same site as the yellow ocher described just previously.

Description of the Sample

The appearance of this sample in the raw state is described in the preceding section (see p. 38).

Calcination.--The raw yellow ocher was broken up and heated in a pan; it gradually became deep violet in color. Upon cooling it lost its violet tint and became the hue illustrated in Figure 7. Another noteworthy change was noticed when the calcined product was washed. The pigment appeared to exist in much finer particles than were found in the raw ocher sample. Whereas the particles of yellow ocher settled to the bottom of the container within a few hours, the fine particles of the burnt ocher had not settled completely after a period of two weeks. This fine division of the pigment may explain its greater tinting power, opacity, and generally improved working qualities over those of the raw yellow earth.

Reaction in Tempera

Mass tone.--Figure 7 illustrates the mass tone of this specimen. The Dictionary describes this hue as Spanish cedar.[6]

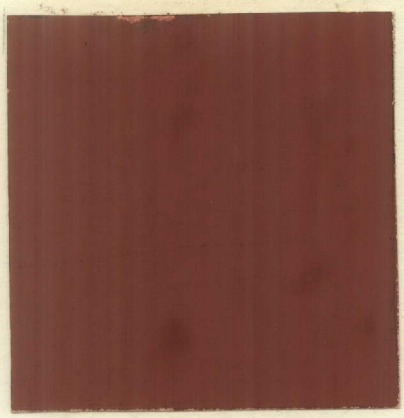

Fig. 7.--The mass tone of the native burnt ocher casein paint.

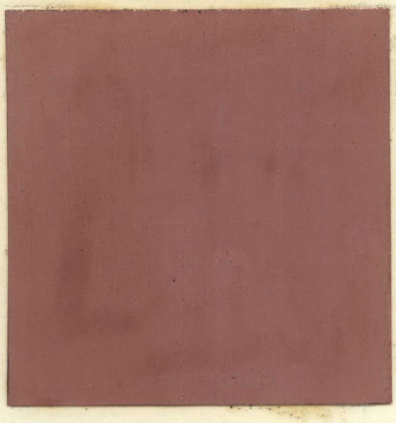

Fig. 8.--The undertone and tinting strength of the native burnt ocher casein paint.

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[6] *Ibid.*, Pl. 6 J 10, p. 35.

Undertone.--This hue is classified between _roseglow_ and _faded rose_.[7] It should be noted that it is colder in hue than is the mass tone.

Tinting strength.--The tinting strength is strong, being greater than that of any of the other pigments prepared.

Spreading power.--The spreading power is good.

Opacity.--The hiding power is good, being better than that of the unlevigated product (yellow ocher).

Brushing quality.--The brushing quality is smooth.

Reaction in Oil

The reaction of this pigment in oil is in most respects as satisfactory as its reaction in tempera. The chief difference was found in the usual effect of oil on the hue. The burnt ocher ground in oil was most closely approximated by _kettledrum_ or _Moro red_.[8]

Green Earth

Green earth or terre verte is one of the most ancient of pigments used by artists. It was commonly used by medieval and early Renaissance artists as underpainting for flesh tones. This pigment is permanent and is an alkaline and magnesian ferrous silicate. It is dull in intensity and ranges from warm to cold in hue. Its chief fault is its deficiency of covering power.

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[7] _Ibid_., Pl. 5 F 9, p. 33.

[8] _Ibid_., Pl. 7 L 10, p. 37.

Location of the Experimental Sample

This particular earth is located a quarter of a mile east of the spillway at Lake Dallas. The area is rocky, with outcroppings of grayish-green sandstone. There are also a few pools of standing water scattered over this area.

Description of the Sample

The soil is greenish-gray, sandy and crumbly, possessing the qualities of sandstone rather than those of clay. In a wet state it appears brighter than it does when it is dry.

Reaction in Tempera

Mass tone.--The Color Dictionary classifies this hue (see Figure 9) as bronze clair.[9]

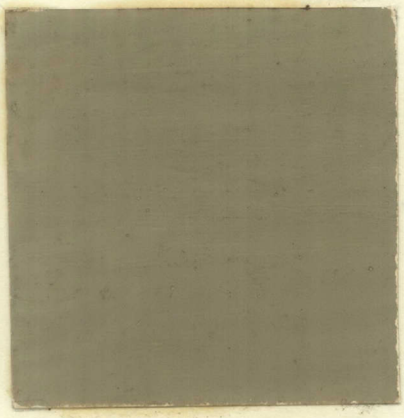

Fig. 9.--The mass tone of the native green earth casein paint.

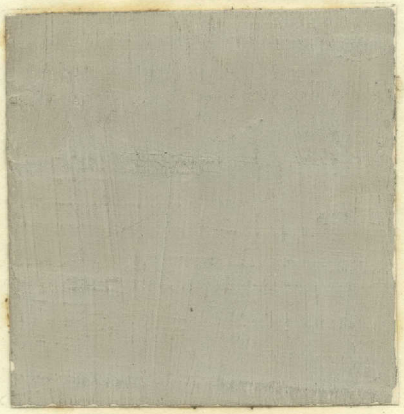

Fig. 10.--The undertone and tinting strength of the native green earth casein paint.

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[9] Ibid., Pl. 13 D 2., p. 49.

Undertone.--The undertone, illustrated in Figure 10, is shown as new silver in the Dictionary.[10]

Tinting strength.--The tinting strength is fair (see Figure 10).

Opacity.--The hiding power is fair.

Spreading power.--The spreading power is fair.

Brushing quality.--The brushing quality is smooth.

Reaction in Oil

Mass tone.--The mass tone is much darker and richer than that found in the tempera sample, approximating a dark olive-green. The Color Dictionary lists this hue as olive brown or bronze nude.[11]

Undertone.--While there is no name given to this particular hue in the Dictionary, it would fall between A 1 and B 1 on Plate 12.[12]

Other qualities.--In most respects this green earth forms an oil paint which is as satisfactory as the tempera paint, with the exception that there is an increased tendency toward transparency.

Calcination.--Upon calcination, the green earth became a dull brown. This change in hue is typical of the ferruginous earths, indicating that the green color is due to iron rather

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[10] Ibid., Pl. 11 B 1, p. 45.

[11] Ibid., Pl. 15 H 7, p. 53.

[12] Ibid., Pl. 12 A-B 1, p. 47.

than to organic coloring matter. If organic matter had been present, it would have burned, leaving a black residue rather than the anhydrous brown earth which was left.

Since other brown pigments of superior color were obtained in other experiments, the brown produced by burning the green earth was not made into a paint.

Yellow Ocher (Light)

Location of the Experimental Sample

This sample was obtained several feet below the earth's surface from an excavation for a telephone pole at the corner of South Elm and Highland Streets in Denton.

Description of the Sample

This specimen is a pale yellow clay with a slight greenish tint. On close examination the sample appeared to be a mixture of very sticky yellow and gray clays.

Reaction in Tempera

Mass tone.--This sample (see Figure 11) is yellow-cream in hue. The Color Dictionary classifies the hue between leghorn and nankeen.[13]

Undertone.--The undertone (Figure 12) of this pigment is classified between polar bear and cream (slightly less yellow) in the Dictionary.[14]

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[13] *Ibid.*, Pl. 10 E 3, p. 43.

[14] *Ibid.*, Pl. 9 B 2, p. 41.

Fig. 11.--The mass tone of the native yellow ocher (light) casein paint.

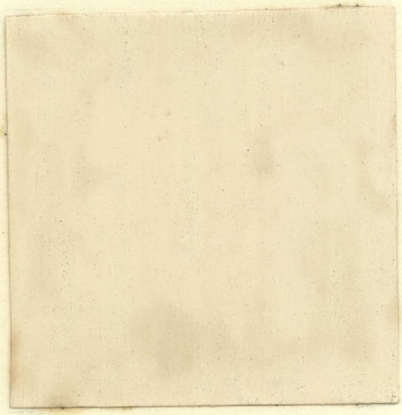

Fig. 12.--The undertone and tinting strength of the native yellow ocher (light) casein paint.

Tinting strength.--The tinting strength, as seen in Figure 12, is poor.

Opacity.--The hiding power is poor and uneven.

Spreading power.--The spreading power is average.

Brushing quality.--When the paint is thick or pastose it is sticky or tacky, which causes it to be difficult to handle and apply in an even coat. It spreads more smoothly in the form of a transparent wash.

Reaction in Oil

This specimen of pigment behaved even less satisfactorily in oil than in the tempera medium. In addition to the tacky quality, it became transparent since its hiding power is very poor.

Burnt Ocher (Light)

Calcination.--The light yellow ocher described above was calcined in the usual way. After a much longer heating period than had been required by the other earths, it became a light pink-brown in color. While darker than the original raw color, it was still light and pastel-like in value. As noticed in previous instances of calcination, many of the painting qualities of the burned product are superior to the qualities possessed by the raw product.

Reaction in Tempera

Mass tone.--The mass tone, illustrated in Figure 13, is browner in hue than the pale yellow of the raw ocher. The Color Dictionary describes this hue as golden wheat.[15]

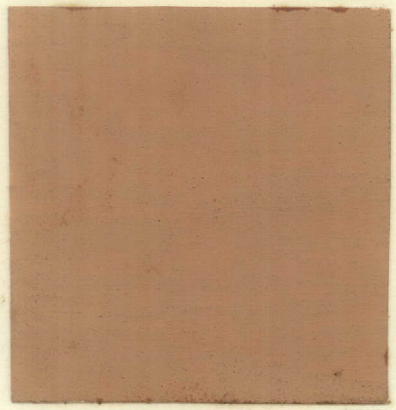

Fig. 13.--The mass tone of the native burnt yellow ocher (light) casein paint.

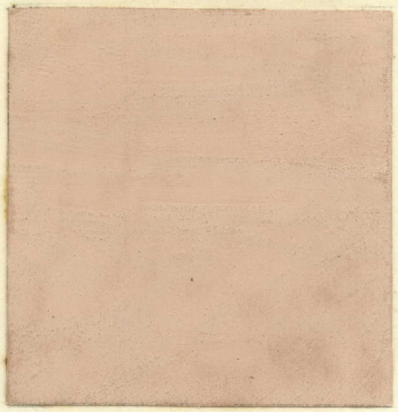

Fig. 14.--The undertone and tinting strength of the native burnt yellow ocher (light) casein paint.

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[15] Ibid., Pl. 11 D 7, p. 45.

Undertone.--The undertone seems to possess less yellow than does the mass tone, tending toward a light pink. The sample, Figure 14, matches more nearly burnous in the Color Dictionary, the experimental sample containing less yellow than does the hue illustrated in the color chart of the Dictionary.[16]

Tinting strength.--The tinting strength, although below average, is greater than that of the raw ocher.

Opacity.--The hiding power of the burnt ocher is much better than that of the raw ocher, being classified as fair.

Spreading power.--The spreading power is fair.

Brushing quality.--As in many of the other painting qualities, the brushing quality of the pigment was improved by calcining. The tacky consistency was eliminated.

Reaction in Oil

The reaction of this pigment with an oil binder is not so favorable as it is with tempera since it results in a tendency toward transparency.

Mass tone.--The mass tone in oil is much darker than the tempera mass tone, tending to be more brown than yellow. It no longer has the delicate quality of a pastel. It is a brown with more red and less heaviness than the brown illustrated in Figure 17. It is shown as burnt sienna in the Color Dictionary.[17]

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[16] *Ibid.*, Pl. 9 B 4, p. 41.

[17] *Ibid.*, Pl. 5 F 12, p. 33.

Undertone.--The undertone, instead of being brown as is the mass tone, is a somewhat darker pink than the pink of the tempera sample.

Opacity.--The hiding power of the oil paint is less than that of the tempera paint. It is classified as less than fair.

Brushing quality.--The brushing quality is uneven. It is not quite so good as it is in the tempera medium.

Natural Red Ocher

Denton County has many red earths which vary from red sands and rocks to red clay. Several experiments were conducted with these sands and clays, but in every instance the product failed to come up to the standards of opacity and brushing quality required of a good pigment. For that reason no natural red is included in the pigments described in this thesis. Figures 15 and 16 are included, however, in order to illustrate the poor hiding power of two types of red earths.

Figure 15 illustrates a paint made from a red sand which proved to be the best of the several red earths used in experimentation. Figure 16 is the typical appearance of a paint made from a red clay. It can readily be seen from the figures that the paint made from the red sand is not so transparent as that made from red clay; moreover, although both are uneven in hiding power, the clay sample is in this respect also inferior. The best red pigments are obtained by calcining the yellow ochers.

Fig. 15.--The mass tone of a native red earth (sand) tempera paint.

Fig. 16.--The mass tone of a native red earth (clay) tempera paint.

Brown

By calcining the red clay illustrated in Figure 16, it was possible to obtain a new pigment, possessing different qualities from the natural red ocher. Often a red earth fails to change upon heating; however, the process changed this particular red clay to a deep brown.

Location of the Experimental Sample

The red clay which was calcined was obtained from the hill at the end of South Elm Street in Denton.

Description of the Sample

This particular specimen of red clay was crumbly in nature, especially when dry. Figure 16 illustrates the mass tone of this clay, with the exception that the clay is a darker red (the white paper showing through the painted sample makes the pigment more orange than it actually is). Upon heating, the clay became a velvety brown. Prolonged heating darkened the color. Figure 18 illustrates the shade of brown obtained by heating the clay for 45 minutes. It can be compared with Figure 17, which shows paint made from pigment which was heated for 20 minutes.

Mass tone.--The mass tone illustrated in Figure 17 is classified in the Dictionary between mango and sorrel.[18]

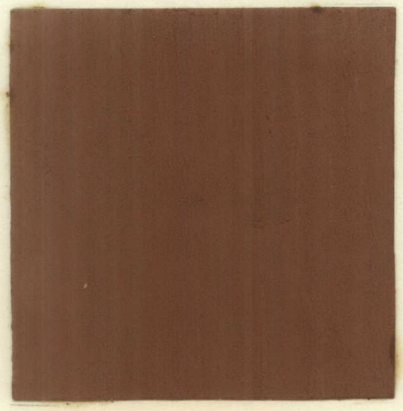

Fig. 17.--The mass tone of brown pigment produced by calcining a native red clay for 20 minutes (casein binder).

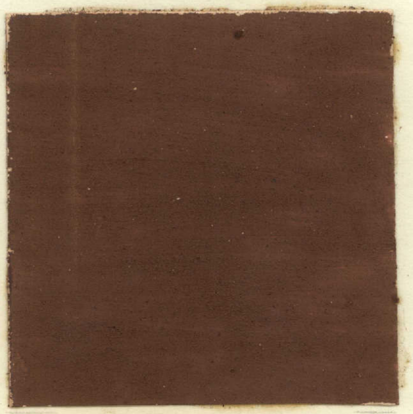

Fig. 18.--The mass tone of brown pigment produced by calcining a native red clay for 45 minutes (casein binder).

Undertone.--The undertone may be classified as sundown or Yosemite (Figure 19).[19]

Tinting strength.--The tinting strength is fair.

Opacity.--The hiding power is fair, being much greater

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[18]Ibid., Pl. 13 F 11, p. 49.

[19]Ibid., Pl. 11 B 6, p. 45.

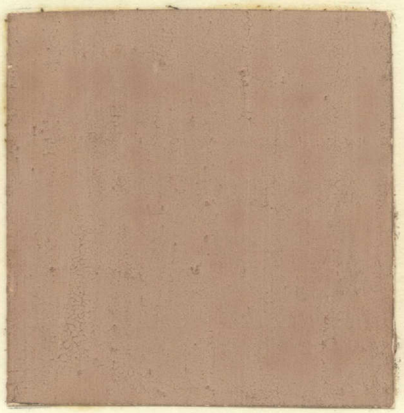

Fig. 19.--The undertone and tinting strength of brown pigment produced by calcining a native red clay for 20 minutes (casein binder).

than that of the natural red clay.

Spreading power.--The spreading power is greater than that of the natural product, ranging from fair to good. The explanation may be found in the fact that the fine particles no longer adhere to each other as they do in the clays.

Brushing quality.--The brushing quality is smooth in comparison with the sticky and tacky natural red clay.

Reaction in Oil

The chief difference between the tempera and the oil brown is one of value. The oil paint is very much darker than the tempera brown. *A Dictionary of Color* does not illustrate this hue, the closest approximation being 1 L on Plate 56.[20] The experimental pigment contains less violet

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[20] *Ibid.*, Pl. 56 L 1, p. 135.

than the one illustrated in the Dictionary. The appearance of the color in this particular instance was altered more by the oil medium than any of the other pigments. The difference between the values of the undertones of the oil and the tempera brown is not so great as that existing between the mass tones.

Gray

From ancient times black and gray pigments have been obtained from deposits of graphite, shales, peats, and coals. They are forms of carbon, graphite being almost a pure form. They vary greatly in their suitability for painting purposes; graphite is good because it is inert and permanent in all media, while some of the others make poor pigments because they dry slowly, if at all, and lack body. By burning these organic products, it is possible to obtain a pure carbon which makes a valuable black. Since the emphasis in these experiments was centered on the mineral or inorganic pigments, none of the organic blacks was prepared. Of the neutral hues, only grays were secured in the inorganic form.

Location of the Experimental Sample

The specimen of gray illustrated in Figure 20 was obtained in the stream bed below the dam at Lake Dallas.

Description of the Sample

The specimen was moist and almost black; but after it had dried, it was a considerably lighter gray. The gray material on the stream bed appeared to be a fine sediment which had hardened into cohesive lumps. The material was extraordinarily pure in that there were no other colors or earths discernably mixed with it. In all probability, the sediment is powdered shale which has been eaten from the sides of the stream's banks by the extreme force with which the water sometimes pours through the dam.

Reaction in Tempera

Mass tone.--The mass tone, illustrated in Figure 20, is classified as slate gray by the Color Dictionary.[21]

Fig. 20.--The mass tone of the native gray casein paint.

Fig. 21.--The undertone and tinting strength of the native gray casein paint.

Undertone.--The undertone is illustrated in Figure 21. The Color Dictionary does not illustrate this particular gray. It is warmer than any of the grays on the color charts.

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[21] Ibid., Pl. 14 A 2, p. 51.

Tinting strength.--The tinting strength is fair.

Opacity.--The hiding power is poor to average.

Spreading power.--The spreading power is poor to average.

Brushing quality.--The brushing quality is not quite smooth; it has a tendency to be tacky.

Reaction in Oil

Mass tone.--The oil mass tone is darker than it is in tempera; that is, it is light black rather than gray.

Undertone.--The undertone is gray, but slightly darker than the tempera gray.

Tinting strength.--The tinting strength is fair; that is, it is of the same quality as that exhibited by the tempera.

Opacity.--Oil destroyed the opaqueness that this pigment exhibited in tempera. The hiding power is low.

Spreading power.--The spreading power is fair.

Brushing quality.--The brushing quality tends to be tacky.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Denton County as a Source of Earth Pigments

The annual average temperature of Denton County is high; freezing is rare; decomposition is rapid; and oxidation of the iron compounds in the soil is well advanced. Consequently, the subsoils are usually red or reddish. The color of the top soil, which depends upon the character of the native vegetation, is usually grayish, brownish, or almost black. Below the well-weathered, red subsoils the materials are yellow or bluish, because of imperfect weathering.

The weather conditions described above fulfill the environmental requirements for the production of brilliant and vari-colored earths. Indeed, this study revealed extensive areas of red and yellow clays and sands, and, what is more, a rarer green earth of very dull hue. Other colors, such as black, gray, and some browns, were also observed, although because of defects, such as transparency, they often proved useless for pigmental purposes.

Preparing the Pigments

In obtaining the specimens of earth required for the experiments, careful selection had to be exercised in order to obtain the purest and brightest hues. Some of the colors especially yellow, were found below the surface soils, which were usually red or brown. On the other hand, the green and red earths were exposed to the atmosphere.

Washing revealed the following differences between specimens composed chiefly of sand and specimens composed chiefly of clay: (1) samples composed predominantly of clay leave a larger residue in proportion to the amount of original unwashed material than is left by the predominantly sandy samples; (2) specimens composed of sticky clay particles settle to the bottom of the washing vessel faster than do the fine particles left after several washings of sand specimens; (3) clay settles en masse, leaving a clear-cut division line between the residue and the washing water, while minute particles of the sandy specimen tend to remain suspended and dispersed throughout the water after the main bulk of the pigment or residue has settled; and (4) clay is sticky or cohesive, not dispersing as readily throughout the washing water as does sand.

The explanation of the differences of behavior between clay and sand can readily be seen when the nature of the two materials is understood. Both are detritals of rock material, the difference primarily being one of particle size. If, by definition, clay is composed of particles .005 mm. or less in diameter, and sand is composed of particles of 1/20 to 2 mm. in diameter, there evidently would be no sand particles left in a pigment after thorough washing; only an impalpable powder would remain. Consequently, a specimen composed chiefly of sandy particles would possess much less bulk after washing had removed the coarse particles. The small particles which remain in the wash water are probably, therefore, clay. But these clay particles of the sandy specimen appear to be different from the clay comprised in the specimen which in its natural state had little extraneous material. The particles do not seem to be plastic or sticky, which fact suggests an explanation for reactions (2), (3), and (4) (see p. 57). The particles of the clay sample, because of their stickiness, adhere to one another; consequently, they resist even dispersion, tend to settle _en masse_, and, because of their collective mass, settle quickly. Clays vary in plasticity and stickiness. The less sticky a clay is, the easier it can be washed; and what is more important, the smoother will be its painting quality. Sticky clays make sticky paints.

Calcination has some very definite effects upon some of the earth pigments. The changes which occur hinge upon the important fact that heating drives out the water of hydration, if such is present. The loss of the water of hydration (1) changes the yellow and green hues to red or brown and (2) reduces the plasticity of clay. The latter change may affect the painting quality of the pigment in several ways, of which the two most important are: (1) the loss of cohesion, which enables the particles to be dispersed more finely throughout the washing solution, and eliminates _en masse_ settling; and (2) the elimination of the tacky or sticky behavior of the pigment when ground in the medium, which causes it to paint smoothly. The second change suggests calcination as a special treatment for pigments which are tacky but which will not be altered otherwise by the heating. A specific illustration is the calcination of a sticky or tacky red ocher. In most cases, the heating of a red ocher does not alter its hue but reduces its plasticity. The reduction in plasticity makes possible a finer degree of washing and improves the painting qualities.

In grinding the pigment in the binding medium, only enough of the latter should be mixed with the pigment to bind it thoroughly. This is particularly true of oil because any excess medium will have a deleterious effect. The amount of medium required for each pigment varies and must, therefore, be determined by experience. The oil color should be short; that is, it should have a buttery and firm quality which will allow it to stand up when it is piled with the palette knife. The consistency of tempera color need not be stiff, since excess moisture of this acqueous medium evaporates. A pigment is too gritty and coarse if in the process of grinding it scratches the surface of the plate on which it is ground. Colors ground in the tempera media of egg and casein will spoil rather quickly; consequently, only quantities sufficient for a few days supply should be mixed. The oil colors, if sealed adequately, will keep for an indefinite period.

An Evaluation of the Experimental Pigments

In order to obtain an evaluation of the experimental pigments, they were rated from two standpoints: (1) their appearance, i. e., their hue and value; and (2) their painting qualities, e.g., smoothness and opaqueness.

In obtaining an evaluation of the appearance of the experimental pigments, they were compared with commercially prepared pigments of the same type and with the hues illustrated in A Dictionary of Color.[1] In order to obtain an exact comparison between the experimental and the commercial paints they must both be ground in the same type of medium. As most commercial tempera paints have a different type of binding medium (usually gum) than is used in the experiments, comparison of pigments ground in the tempera media was difficult. The difference in appearance of paints ground in various tempera media is illustrated by the egg tempera and the casein tempera paints produced as a result of the experiments. Because of the oil present in the egg emulsion, the egg tempera paints are darker than the corresponding casein paints. Oil colors are not so difficult to compare as are the tempera colors because an identical medium is used in the preparation of the commercial and the experimental paints described here. The following facts are revealed by the comparison of the experimental pigments with the same types of commercial pigments: (1) the yellow ocher and the green

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[1] A. Maerz, M. Rea Paul, A Dictionary of Color.

earth[2] are not so brilliant in hue as are the commercial colors, the ocher being a less pure yellow and the green duller in the native colors; (2) the burnt ocher exceeds any commercial type in clarity of tone and beauty of hue; (3) hues equivalent to the experimental yellow ocher (light), and the burnt yellow ocher (light) were not found in any of the commercially prepared pigments; and (4) all hues, other than those mentioned above, produced in the experiments can be obtained from commercial sources.

In addition to the rating based upon appearance, the experimental pigments are evaluated from the standpoint of painting quality. The painting quality, as much as the appearance of a pigment, determines its usefulness. Most of the properties and painting qualities of a pigment can be observed and determined during its preparation and use. For example, the desirable qualities of insolubility, indifference to media, opacity, spreading power, and ease of manipulation can be observed as each pigment is washed, ground, and painted upon the surface. The two properties of durability and inertness, however, can not be determined under the same conditions. These last two properties are controlled by a set of factors different from those which existed in the set-up of this particular experiment. Therefore, because of the time element and the additional equipment

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[2]Maerz states that it is impossible to obtain an average color for green earth, in view of the fact that samples from different manufacturers vary so widely. (A Dictionary of Color, p. 184).

required for determining these qualities, the author refers to the extensive and reliable tests performed by other experimenters as to the durability and inertness of the earth pigments. Briefly, the earth pigments produced in these experiments are, as a whole, durable, inert, and insoluble. The effect of the media on the pigment varied from specimen to specimen, as did also the qualities of opacity, spreading power, and ease of manipulation.

Russel and Abney have indicated the durability of earth pigments in their tests[3] which are described briefly in Chapter II (see p. 7) of this thesis. The quality of inertness of earth pigments is illustrated again and again in numerous paintings hundreds and even thousands of years old. During these long periods of time these pigments have remained intermixed with others without reacting with them.

The property of insolubility (in water) is illustrated in every instance when the pigments are washed, an essential step in their preparation. An illustration of the varied effects of a medium on various pigments is found in the effect of transparency produced by oil on pigments which are opaque in an acqueous medium. Oil tends to make some pigments more transparent than they would be in an acqueous medium.

Generally, it can be said that the more fatty oils a medium contains, the darker the pigment ground in it will appear. For example, the casein binder, which contains no

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[3] Russel, Abney, *op.*, *cit.*, Vol. V, p. 302.

fatty oils, produces a lighter paint than any of the other media; the egg tempera emulsion which contains fatty oils, as well as water, produces a paint darker in value than the casein paint, but at the same time lighter in value than the paint produced by grinding the pigment in linseed oil.

Transparency of paints, in so far as it is influenced by the oily content of the binding medium, is likewise manifested in different degrees by the different media. Judged from the standpoint of opacity, casein ranks first in the number of opaque paints produced when it is mixed with the experimental pigments; egg tempera ranks second and linseed oil third in this respect.

Because transparency is not a desirable quality in oil color, the following pigments produced in this study are classed as unsuitable oil colors: burnt ocher (light); yellow ocher (light); gray; and the natural red ocher. Of these, the natural red ocher has an unfavorable reaction in tempera also. The yellow ocher (light) and the gray have doubtful value as opaque water-colors; however, they, as well as the red ocher, may be valuable for making transparent water-colors.

Table 1 shows the pigments produced in the experiments and summarizes their painting qualities. They are rated, according to the author's judgement, in the order of their suitability for artists' pigments. The score is derived by giving 25 points for each <u>good</u> or <u>smooth</u> rating of painting quality and 12.5 points for each <u>fair</u> rating of painting

TABLE 1

THE RATING OF THE EXPERIMENTAL PIGMENTS ACCORDING TO THEIR PAINTING QUALITIES

Pigment	Type of Soil	Tinting Strength	Hiding Power (Opacity)	Spreading Power	Brushing Quality	Score
Burnt ocher	Sand-clay	Good	Good	Good	Smooth	100.0
Yellow ocher	Sand-clay	Fair	Fair-good	Good	Smooth	81.2
Green earth	Sand	Fair	Fair	Fair	Smooth	62.5
Burnt ocher (light)	Clay*	Fair	Fair	Fair	Smooth	62.5
Brown (burnt red ocher)	Clay*	Fair	Fair	Fair	Tacky-smooth	50.0
Gray	Clay	Fair	Poor	Fair	Tacky-smooth	39.5
Yellow ocher (light)	Clay	Poor	Poor	Fair	Tacky	12.5
Red ocher (natural)	Clay	Poor	Poor	Fair	Tacky	12.5

*Before calcination

quality and 0 points for each poor or tacky painting quality.

All pigments having a score of 50 or above are usable for most purposes. Those with a score lower than 50 are to be included inadvisably on the artist's palette, except in certain instances when particular effects are desired in a special technique, as in transparent water color.

The total score of a pigment must not be allowed to obscure the importance of any particular item or quality. For his particular purposes a painter may value a specific quality more highly than he does others. Therefore, this quality, rather than a total score, may determine his choice of a pigment.

Several implications valuable for the artist and the teacher of art are indicated by these experiments. First, there is the economic aspect of cheaper production of paints. Second, while there are pigments which can be produced at home, there are others which are best left to the commercial producers. Third, and most important, the home production of paints gives the artist an understanding of the possibilities and limitations of the earth pigments, their composition, and their behavior under certain conditions, thus enabling him to have better control of his art and craft.

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