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Prospecting, developing, and mining bentonite deposits

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PROSPECTING, DEVELOPING, and MINING BENTONITE DEPOSITS

BY

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THESIS

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INTRODUCTION

Clay and clay-like minerals are mined in many localities for a large number of uses. Most of these mines are small, seasonal operations. Common practice in these types of pits is to strip and mine clay from shallow overburden depths without the aid of careful prospecting and developing, and with little or no engineering technique.

Bentonite deposits which must be continuously mined at tonnages from 5,000 to 7,500 tons per month require that the entire project be carefully planned and engineered so suitable equipment may be obtained and operational cost minimized.

This thesis is concerned with the prospecting, developing, and mining of large bentonite deposits according to the best known engineering practice for continuous operation under various climatic conditions.

CONTENTS

LIST OF ILLUSTRATIONS

PART I. GEOLOGY AND DEPOSITION OF BENTONITE

Definition of Bentonite

A concise and exact mineralogic definition of bentonite has not yet been established. The name "bentonite" was derived from a clay-like substance found near Fort Benton, Wyoming. This clay was observed to swell to a large volume when wetted with water and from this designation the term bentonite has been assigned to various clays and clay-like substances found in other localities over the country. At the present time a commonly accepted definition of bentonite is a clay-like rock derived from volcanic ash of which the principal constituent is either the mineral montmorillonite or beidellite. A further classification[1] of bentonite has been assigned by the Bureau of Mines to differentiate between the so-called "swelling" bentonites that swell enormously when wetted with water, and the so-called "sub-bentonite" which refers to bentonites that do not swell more than ordinary plastic clays. More recently investigators have found that the so-called swelling-type bentonite is largely a sodium bentonite; whereas the sub-bentonite is principally calcium bentonite. The reference to sodium and calcium-type bentonite defines the elements in the base exchange position of the montmorillonite lattice structure.

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1. U. S. Bureau of Mines. Minerals Yearbook, 1937. p. 1256

Because bentonites are derived from volcanic ash, identification by chemical analysis is of little practical value. It is entirely possible to have a chemical analysis of a typical bentonite similar to that of volcanic ash or tuff. The identification of bentonite in the field is entirely limited to physical properties. Samples are gathered by promising physical properties and sent to the laboratory for evaluations according to the commercial use for which the bentonite is intended. Following is a chemical analysis of several typical Western bentonites together with an analysis of a typical volcanic ash and lava.

Chemical Analysis of Western Bentonites

	*California Bentonite	*Arizona Bentonite	[2] Nevada Perlite
SiO_2	66.94	66.03	65.13
Al_2O_3	24.45	21.17	15.73
Fe_2O_3	3.73	4.04	2.24
FeO	-	-	1.86
CaO	1.29	3.74	3.62
MgO	3.60	5.86	1.42
K_2O	-	-	3.69
Na_2O	-	trace	2.93
H_2O	-	-	2.43

* - Analysis on Volatile Free Basis 1700° F.

2 - Kemp, James F. Handbook of Rocks. Van Nostrand 1927. p. 25.

<u>Origin and Deposition</u>

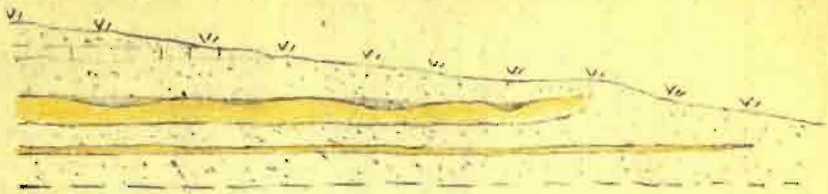
Bentonites are formed by the alteration of volcanic ash, such alteration may have occurred as a result of continental or aquatic deposition. In the continental types of deposition, the bentonites are limited in quantity and quality and are not of commercial importance within the scope of this thesis.

The aquatic type is the most wide spread in occurrence and includes marine, barred basin, and lacustrine classes of deposition (See Fig. 1).

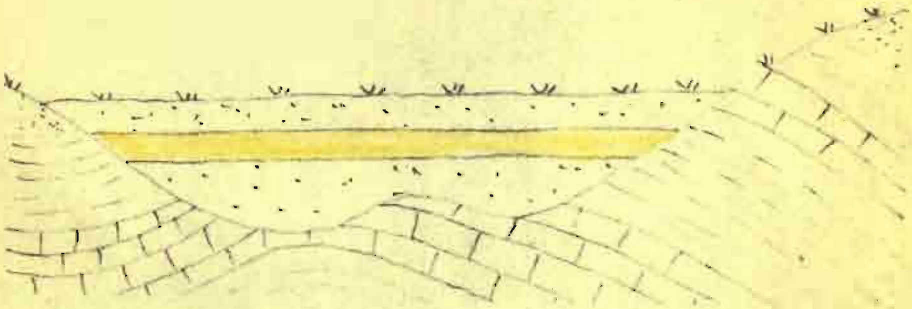
The marine depositions occurred where volcanic ash fell in estuaries or large shallow embayments of the open sea. Such deposits are typical of those occurrences along the Gulf coastal regions in the United States. Fossil shell remains are common in the Miocene bentonite deposits of central Mississippi.

Deposits of barred or semi-closed basins, but related to the open seas, are exemplified by occurrences in eastern Arizona and northwestern Oklahoma. Ash fell in to these basins during Cretaceous time (northwestern Oklahoma) and Upper Triassic time (eastern Arizona) in sufficient volumes to produce sizable bentonite beds. It is likewise possible the ash falls in the basins were associated with evaporites which salts aided in the alteration of the ash.

The lacustrine depositions include those occurrences where ash fell into ancient continental lakes. Occurrences



Marine Deposition (California)



Lacustrine Deposition (Nevada)

FIG. 1 - TYPICAL SECTIONS OF BENTONITE DEPOSITION

of this type are limited to the Western United States and are found in northern Nevada and Utah. Other occurrences have been noted in eastern California. In one California locality fossil remains of very large mammals have been found in the unaltered portions of the bentonite deposit.

The alteration of volcanic ash to bentonite has been fully substantiated by field examinations. Numerous occurrences have been found, notably in eastern Arizona, where a gradual gradation from soft waxy bentonite into hard unaltered ash occur in the same bed over a lateral distance of several hundred feet. In other localities, principally in the Mojave Desert regions of California, this similar occurrence can be noted in the vicinity of faults and folding of some continental volcanic ash beds. Invariably the hard ash is altered to a soft waxy bentonite adjacent to the fault plains and at the apex of sharp folds.

General Geology

Most commercial bentonite deposits occur in flat-lying sedimentary beds. The ash falls, which cause the deposits of bentonite, extend over large areas. A typical example of this wide spread deposition is the bentonite beds associated with the Miocene sediments along the Gulf Coast and commercial deposits of bentonite have been found in various localities from western Alabama through Mississippi, Louisiana and Texas to the Rio Grande. The important commercial deposits of bentonite are usually associated with sand, sandstone and limestone. Existing commercial deposits along the Gulf Coast and in Oklahoma are thought to be outlyers which are erosion remnants, such outlyers have existed because of relatively hard formations above the bentonite beds. Mississippi bentonites occur under beds of limestone and sandy clay; however, in localities where the limestone has been eroded, bentonite still remains without the overlying limestone and such deposits are amenable to strip mining methods. Typical overburden above commercial bentonite deposits consists of sand and unconsolidated sandstone containing some volcanic ash and glass shards. This type of overburden is representative of deposits in eastern Arizona and southwestern California.

Bentonite has very little resistance to weathering and this particular feature practically eliminates outcrops. In many commercial areas no outcrops can be found. Where bentonite beds occur near the surface of the ground around the edge of hills or other prominent features, the surface of the ground above the bentonite usually heaves and becomes spongy. This feature is a result of the admixture of bentonite with top soil which causes a "creep" when alternately wetted and dried. Deposits of this nature can be readily seen at bentonite occurrences in southwestern California and it is possible to visually trace the bentonite beds from the "creep". Areal photographs of this particular area show a lack of vegetation along the "creep" zone which is readily distinguishable from the adjacent foliage. In sandy areas like the occurrence in northeastern Oklahoma and eastern Arizona, practically no outcrops exist because these localities are arid and no "creep" zone is possible. Prospects are limited to road cuts, animal borings and water well drillings.

Development of the bentonite deposits by drilling often shows some post-depositional erosion and this is particularly noticeable in localities where the overburden is quite shallow. In a large deposit in eastern Arizona, uncovered bentonite reveals two systems of post-depositional erosion which can easily be seen after the bentonite has been uncovered and cleaned. The most common type of post-depositional erosion is that of small channels in the bentonite where the average bed thickness may be about 5 feet and the erosion channels cut the bentonite to a depth of from 2 to 4-1/2 feet.

Generally the flat lying type of bentonite beds show very little change in elevation over several miles of occurrence and these deposits are the most advantageous for commercial exploitation. Localized minor dips are common within a single mining block and present drainage problems in the individual pits. In the central Mississippi deposits undulation of the beds is quite common which again presents not only drainage problems but an additional amount of clean-up work before mining the uncovered bentonite.

Some bentonite deposits such as those in the Gulf Costal Area contain a gradual gradation from the sandy overburden to pure bentonite on the top and bottom of the bentonite beds. Deposits typical of eastern Arizona and arid regions have no such gradation and the sand and bentonite contact is very sharp, this penetration of sand in the bentonite bed being less than one-half inch in most cases. The hanging and footwall contacts of the beds are of economic importance because of the limitations of equipment which can be used to mine uncovered bentonite.

The most common diluent in bentonite occurrences is that of sand and lime. The lime usually occurs as gypsum in nodules or veinlets. In the arid regions of the south and southwest, gypsum contamination is quite noticeable particularly in areas where the overburden is shallow. Bentonite occurrences in northwestern Oklahoma contain lenses of sand within the beds which sand dilution makes them undesirable for economic extraction. However, these sand lenses are usually not very extensive laterally and the development of these deposits usually shows areas where no sand contamination occurs after the deposit has been thoroughly drilled.

PART II.

PROSPECTING AND DEVELOPMENT OF BENTONITE DEPOSITS

The prospecting and development of bentonite deposits discussed in this thesis is confined to those deposits from which bentonite can be economically extracted by strip mining methods. The following discussion relates to the sequence of the work involved in the prospecting and development of a typical commercial bentonite deposit.

Obtaining an Economic Interest in the Property

Bentonite prospects have been discovered by field reconnaissance but more often through the presentation of samples by a land owner or agent. If a cursory field examination shows that the prospect might be a commercial deposit and the property is favorably located with respect to transportation, an economic interest should be taken in the property or properties before any development work begins.

The economic interest may be in the form of an option to prospect for a definite period usually from 60 to 90 days. This option should contain provisions for conversion to a lease with terms of royalty, annual rental and also, if possible, a provision for the purchase of the property in fee. The provisions of the prospect option should be given careful consideration as it must be assumed that the property may prove to be extensive and sufficient latitude in the contract should be available for any future contingency which the operator might forsee.

The most common forms of economic interest in bentonite properties are those of purchase in fee simple or an annual-rental-plus-royalty type of lease. The latter type of interest is common when it is not anticipated that operations will begin immediately and the property under investigation will be held for future reserve. In this manner several properties may be developed with a minimum amount of capital investment. However, to offset the advantage of limiting capital investment, there is the expense of continual royalties when the leased property is mined. Most of the lease arrangements are written for a period of ten years and require only annual rental for continuation during the lease term.

Each individual district has its own peculiarities in negotiating for properties, however, the operator should be careful that the final arrangement for his economic interest is one that will be the most favorable for any forseeable contingency.

The instrument representing the operator's interest should be carefully reviewed by competent counsel and the transaction duly recorded in the county seat of the county in which the property is located.

The owner should understand that access for surveying and drilling will be readily available and that no prosecution for damage of crops or property can be assessed against the operator unless such damage is from carelessness or negligence. It is always desirable to have the confidence and respect of the property owner as it invariably assists the development work and the owner can be of material aid in furnishing labor and incidental services.

Organization of the Field Work

The prospecting programs and development of bentonite deposits are similar to field construction work and other engineering projects in which proper organization is essential to satisfactorily complete the work in minimum time and with the least expense.

A typical field crew for the development of a bentonite deposit with hand auger drilling equipment will consist of the following personnel.

Hand Auger Drilling Crew

a. Field Engineer

b. Instrument Man

c. Foreman

d. Chain and Rodmen

e. Drilling and Clearing Labor

The field engineer is in complete charge of the program and it is his responsibility to direct the work and make all of the decisions with respect to drilling locations, extent of survey and hiring of required personnel. It is likewise the field engineer's responsibility to see that all equipment and materials are at the location and sufficient labor is available to utilize this equipment to the fullest extent. The field engineer will record information gathered during the program and usually makes weekly progress reports to his immediate superior.

The instrument man is in charge of the surveying crew which usually consists of two chain or rodmen and several laborers for clearing lines. The instrument man operates with his helpers independently under the direction of the field engineer as his work is usually at some distance from the drilling crews. It is the responsibility of the instrument man to keep his lining crew in advance of contemplated drilling locations in order that a sufficient number of stakes are always set for drilling locations.

A drilling crew foreman is needed when more than four drilling crews are employed and this is especially true in shallow overburden deposits. The foreman supervises coring of the bentonite, takes the field notes on each hole drilled and keeps payroll time records of the labor under his direction. The foreman also sees that each crew is supplied with the necessary tools and materials in order to keep the work continuing as rapidly as possible.

Chainmen and rodmen are trained from local labor and it is particularly advantageous to train these local men if a subsequent mining operation is contemplated. There is a continual amount of engineering work required in a strip mining operation and it is, therefore, desirable to use local personnel. These men should be intelligent and willing workers as speed and accuracy are necessary requisites.

Hand auger drilling work can be performed satisfactorily by almost any class of common labor. However, in the case of each development program, the best labor available should be hired because it will be possible to draw future mine workers from these men.

The Survey for Drilling

The field engineering work for prospecting bentonite deposits is quite simple. A co-ordinate system is used as a base for drilling and the preparation of the development map. When beginning a survey, it is advisable to form the co-ordinate system parallel to land surveys within the area. The property owner usually knows where property corners are located and land lines should be used for the orientation of the co-ordinate system. The co-ordinates for strip mining are a system of 100 by 108 feet and multiples thereof. The 108 foot system is used as it facilitates the calculation of excavation measurements, and these lines are run at right angles to the contemplated length of the deposit or at right angles to the logical stripping sequence. The 108 foot lines are designated alphabetically and the 100 foot lines numerically.

The initial survey is made by running lines of 100 by 108 feet and a stake set at each corner of the system. The field engineer will estimate the probable area of commercial bentonite and direct the surveying crew over this area. A temporary base line is run through the center of the estimated commercial clay area so that offset lines over the clay area can be run as rapidly as possible. Each stake is marked with its co-ordinate for proper orientation of the drilling crews and sample tag designation. As previously mentioned, it is of considerable importance that the lining crew complete its work in advance of the drilling crews, otherwise a delay will result by not having exact locations established for locating the drill holes.

Drilling Methods

Hand auger equipment is entirely satisfactory for sandy overburden from the outcrop to depths of 30 and

35 feet. Two men constitute a drilling crew and each crew has the following equipment.

<u>Drilling Equipment for Each Crew</u>

a. Eight lengths of three-quarter inch extra heavy pipe with couplings.

b. One length 2 feet extra heavy three-quarter inch pipe with coupling.

c. Two handles.

d. Two handle T's.

e. Two 16 inch pipe wrenches.

f. Two 3 inch Iwan earth augers.

g. One 2 inch chisel bit with coupling.

h. One cleaning knife.

i. One sample cutting cloth 18 by 18 inches.

j. One sample cloth 36 by 36 inches.

k. One dozen sample tags.

l. One-half dozen sample bags.

m. 25 feet heavy twine.

n. One 50 foot metallic tape measure.

o. One pipe pole 3 by 3 inches by 16 feet with one foot diameter hoop bolted at one end.

p. One post hole digger.

The equipment described above is satisfactory for drilling sandy or sand and clay overburden quite rapidly, yielding core samples of sufficient size and cleanliness for a 5 pound sample from a 3 foot bed of bentonite. The 4 foot lengths of pipe have been found to be the maximum satisfactory working lengths, however, a 2 foot length is provided for coring the bentonite so maximum pressure can be brought to bear when turning the auger. With the three inch Iwan type earth augers, it is possible to drill 3 to 5 inches in depth before pulling the cup to clean out the cuttings. For holes to a depth of approximately 24 feet, it is possible for a crew of two men to hold the lengths of pipe in a vertical position while cleaning the auger. However, for depths in excess of 24 feet, it is advisable to place a vertical pole at the side of the hole and the pipe can be run through a hoop at the top. This provides an adequate brace for lengths of pipe of approximately 32 feet. For hole depths in excess of 32 feet, the pipe should be disjointed after six or seven lengths have been pulled before the remaining lengths are drawn from the hole. This precaution is necessary in order that the long lengths of pipe will not break and cause injury to personnel.

After one or two holes have been drilled on the prospect, the depth of overburden in successive holes can be estimated within one foot by use of a hand level because the bentonite bed is usually level at the bottom contact. With this estimate the drilling crew is cautioned to drill carefully immediately above the estimated bentonite depth and as soon as the bentonite is reached with the auger a measurement is made for overburden depth. The coring of the bentonite requires a sharp auger and when bentonite is encountered in the hole, it is advisable to use a new auger and turn the auger slowly with as much pressure as possible. After the cored bentonite has been pulled to the surface, the top half of the auger is cleaned of all cuttings and the sides and bottom of the lower half of the auger are carefully cleaned to remove overburden contamination. At this point the auger is placed on the sample cutting cloth and the bottom half of the core is removed. The sample is then transferred to the sample cloth. This procedure continues until the hole passes through the bed of bentonite. Each core sample is placed in an individual pile on the sample cloth so that it can be carefully examined. The cuttings on the sample cloth are then thoroughly mixed and poured into a sample bag. The sample bag contains an inside and outside tag showing the station co-ordinates, overburden and bentonite thickness, together with any pertinent remarks for the information of the laboratory.

Records of each hole are kept by the field engineer in a level book and transferred each day to another book for permanent record. This system of double records insures against damage or loss to the field notes.

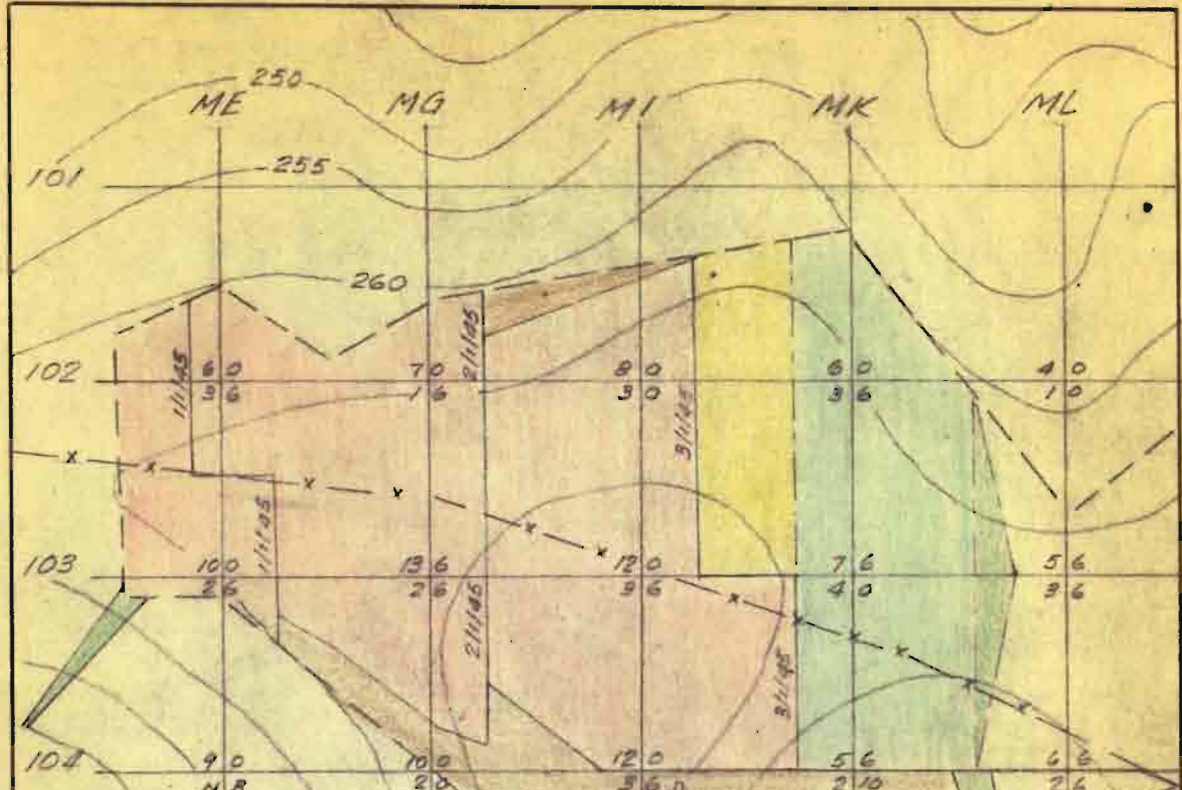
It is necessary for the field engineer to co-ordinate the drilling program so that the crews will always have stations ahead to be drilled and consideration is made of the assignment of holes. Too many deep holes assigned to one crew will keep them at a distance from the main working group and adequate supervision will not be possible. It is desirable to have either the foreman or field engineer present when samples are being taken so that the proper measurements and physical evaluations can be made at the time of sampling. The initial drilling on 100 by 108 foot co-ordinates is satisfactory for preliminary tonnage estimates, however, along the edge of the clay line it is often desirable to space holes on the 50 by 54 foot lines so that the inventory lines can be drawn with more accuracy.

Preparation of the Development Map

After the surveying crew has staked the area over the probable bentonite they then set a permanent base line well beyond the maximum overburden limit so it will not be disturbed by subsequent mining. This base line must be carefully staked with rot-resistant hub stakes and copper tacks. When this line has been completed, a closed level circuit is run over the entire length of line using either a ficticious datum or preferably datum from a known bench mark. The base line levels are carried along each 108 foot line and each 54 foot line in sufficient detail to prepare a profile map of a 5 foot contour interval. In addition to the level work all the surface features are carefully mapped so that the finished map will represent the topographic and surface features in detail.

The final development map is drawn on a 100 foot to the inch scale and should include as large an area as is practical for a working map (See Fig. 2). The finished development map should also include a monthly inventory record of bentonite mining and overburden removal which is kept currently at the close of each month's operation. In addition to the surface and topographic features the map should include property lines and overburden and bentonite measurements at each co-ordinate station. When the decision has been made as to the maximum overburden for an economic operation, a permanent inventory line is drawn on the map to form a basis for the estimate. These estimates should be concluded as final for the development work completed and if any change in inventory is established after further drilling, notations are made on the map at the time of such adjustments in inventory.

In computing the estimate for the inventory of commercial bentonite, a ratio is established between the number of cubic yards of overburden required to uncover one ton of bentonite and the inventory shown on the map



Mined Out
Uncovered
Inventory — — — —
Benched
Back Slopes & Drainage
Sub-standard Quality

FIG. 2 - PORTION OF A DEVELOPMENT MAP FOR OPERATING BENTONITE MINE (Mississippi)

should state this ratio. This ratio is of considerable importance in determining size and capacity of equipment necessary for mining which will be outlined in a subsequent discussion.

When a decision is made to operate the property, it is advisable that a "true" clay line be established along the edge of the deposit which requires drilling additional holes at close interval. The clay line drilling is usually completed on 25 by 27 foot co-ordinates and it is desirable to conclude this work before mining because bentonite under shallow overburden is often badly contaminated.

Samples from each individual co-ordinate are evaluated by the laboratories and a report of these evaluations given to the field engineer when the final map has been drawn so that all of the bentonite within the inventory lines can be substantiated as satisfactory quality.

PART III. MINING METHODS

General Considerations

When the field work and the finished map are completed, it is essential that a detailed analysis of the contemplated mining operation is made and a definite plan of mining formulated. It is assumed that the average monthly tonnage of bentonite required will be known prior to the development of the mine layout. Due consideration should then be given to drainage, transportation and general topographic features before the proper selection of equipment can be made. The prime factor in any strip mine operation is not merely a consideration of the initial opening of the property, but that of the anticipated condition of the mine when the last bentonite is removed from the deep overburden cuts. Improper consideration for overburden disposal, arrangement of mining cuts and placement of drainage will result in costly rehandling of overburden and possible flooding of the mine during the last stages of the operation. It is, therefore, necessary to anticipate and make proper allowance for adequate spoil placement and proper drainage for the entire property before the opening cuts are made. These considerations are even more important when a dragline type stripping operation is anticipated. The first consideration in the layout of the mine on the development map is that of determining the bottom elevation of the bentonite bed over the entire property so that a drainage system can be plotted prior to laying out individual cuts. It is advisable in the layout of the drainage pattern that two alternative outlets be provided in each mining block in the event one drainage channel becomes blocked by sliding of spoil piles or by a localized variation in the dip of the bentonite bed.

Overburden Operations

The selection of equipment and methods for removal of overburden will depend largely upon type and character of overburden, limitation in capital investment, estimated cost per unit of removal, climatic conditions and the overburden ratio.

There are several classes of equipment and combinations of this equipment that are commonly used in strip mining methods for bentonite deposits. These classes are:

Classes of Strip Mining Equipment

a. Dragline

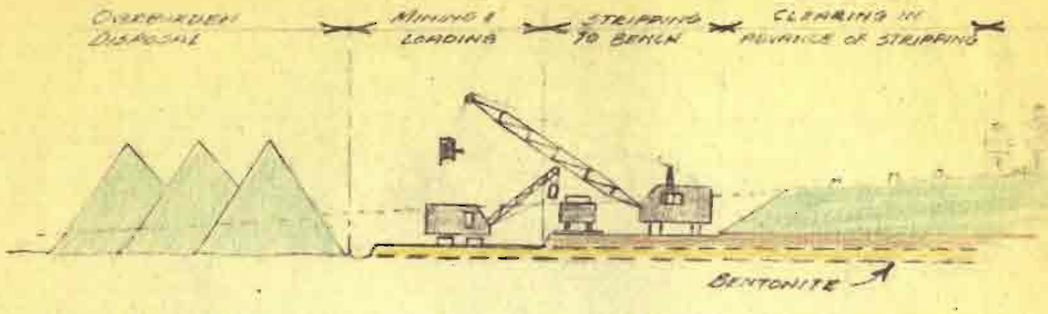
b. Crawler Tractor and Scraper

c. Pneumatic Tractor and Scraper

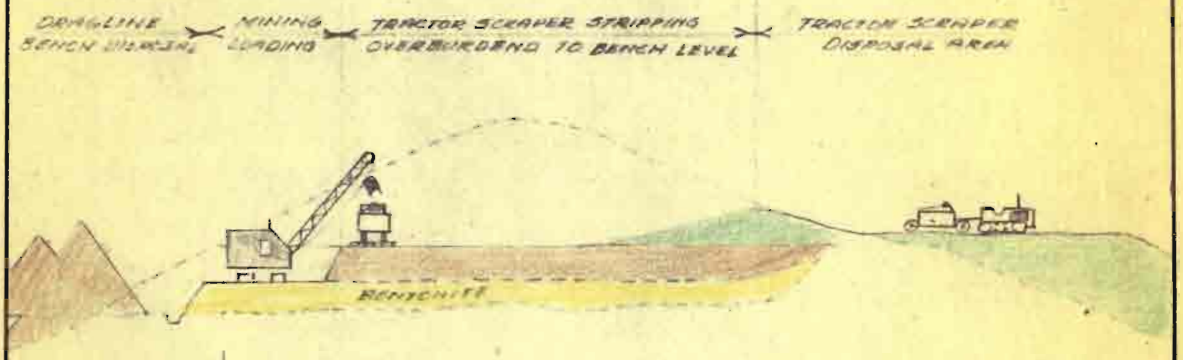
d. Shovel and Pneumatic Tractor and Trailer

This discussion will be limited to draglines and crawler tractor-scraper equipment or a combination of both. (See Fig. 3). A dragline machine is excellent equipment for strip mining, particularly where wet weather operations are necessary. A dragline machine operating continuously at its normal capacity will yield the lowest unit costs for overburden removed. However, the dragline operation limits the mine layout to relatively narrow successive cuts and continuous bentonite mining is required in order to make room for overburden disposal. This type of equipment is, therefore, limited to the location where disposal room is available in adjacent cuts before it can operate continuously. This system requires close supervision and excellent mine layouts to realize the low unit costs of overburden removal. A second limitation of the dragline is that of large capital investment for equipment to strip overburden in excess of 30 feet in depth without rehandling. When boom lengths exceed 80 feet, the dragline machines become heavy and costly.

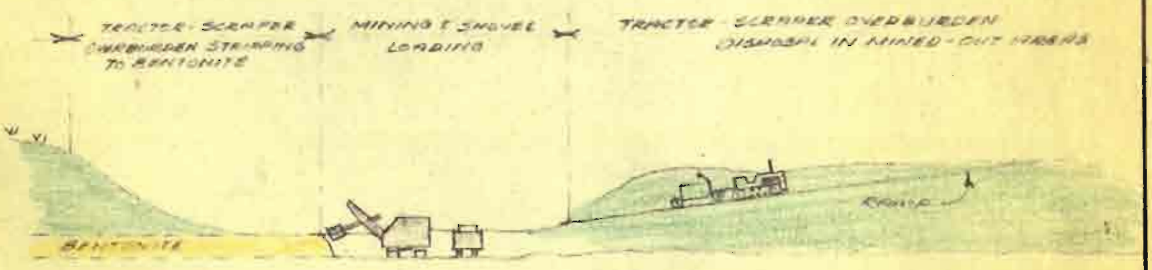
The crawler tractor and scraper equipment overcomes many of the limitations of the dragline machine. However, maintenance and repair cost per operating hour is much higher than draglines which invariably results in a higher unit cost per cubic yard removed. It is physically possible for this class of equipment to strip any depth of



Dragline Stripping - Dragline Mining & Loading



Crawler Tractor Stripping - Dragline Bench Removal, Mining, and Loading



Crawler Tractor Stripping - Shovel Mining & Loading

FIG. 3 - TYPICAL STRIPPING AND MINING METHODS

overburden, however, unless adequate spoilage disposal is available, unit costs will be unreasonably high because of the necessity for long hauls to suitable disposal areas. A wide degree of flexibility is offered by the tractor equipment as it is possible to strip far in advance of mining because the overburden may be hauled some distance to disposal and close back filling in the mined-out areas is unnecessary. A further limitation of crawler tractor equipment is that of operating in periods of wet weather because this equipment requires reasonably dry surfaces for movement.

The combination of the crawler tractor or pneumatic tire tractor and scraper with a dragline is entirely feasible for deposits having overburden depths in excess of 30 feet. With this combination, it is possible to bench the deep overburden areas to a level where the dragline can continuously handle the overburden from the surface of the bench to the top of the bentonite. This combination eliminates the excessive capital investment in an all-dragline operation and likewise decreases unit cost of overburden removed. Generally the tractors may handle less than 30 percent of the total overburden above the bentonite in this type operation. For deposits with deep overburden extending over a large area, the pneumatic-tired tractor-scraper is preferable as it is necessary to carry the overburden some distance for adequate disposal. The above factors for the acquisition of equipment should be given careful consideration because any change in mining plans after the operation has begun results in higher unit cost for overburden removal, particularly in stripping deep overburden sections of the property. It is customary for the engineer to assemble all these factors and present the equipment problem in the form of several combinations of equipment which considerations will show unit cost versus capital investment required. All equipment capacities should be conservatively estimated for unforseen contingencies.

After proper equipment has been selected, it will be advisable to have the overburden equipment placed into operation well in advance of contemplated bentonite mining because it will be necessary to have advanced overburden work completed prior to mining the uncovered bentonite. If dragline equipment has been decided upon, the mine layout should provide several adjoining working areas with disposal room so that some latitude may be possible in the event bentonite mining cannot be exactly co-ordinated with the stripping. It is likewise desirable to have these several areas available as the operation progresses, although the number of stripping areas usually diminishes as the property becomes exhausted. With either the tractor or dragline operation, it is desirable to strip the overburden to a bench above the bentonite so that the bench can be used to divert run-off water and provide a roadway for trucks hauling the mined-out bentonite. The height of the bench above the bentonite is determined by the character of the bentonite bed. The bench is also a consideration for the mining machine which may be used to take up the bench and clean off the bentonite before loading trucks. In most cases the bench will be from 2 to 5 feet in thickness which usually provides ample drainage facilities and support for trucking equipment.

Mining Operations

The selection of proper equipment for mining uncovered bentonite will depend largely upon the character of the bentonite deposition. In deposits where the bentonite contains a gradation of bentonite and overburden at the hanging wall and foot wall contacts or where the bentonite bed is pitted or undulating, a small dragline machine is the most satisfactory type of equipment. The dragline machine will permit "peeling" the mixed sand and bentonite from the top and bottom of the bed and also it is quite suitable for cleaning pockets and undulations where they exist. A further advantage of the dragline mining equipment is that it provides a satisfactory piece of equipment for carrying drainage ditches along with the mining operation.

In deposits where the bentonite bed is of uniform thickness and the contact with the overburden is sharp, a dragline is not feasible as this type of bentonite is usually hard and is not amenable to "peeling". In this type of occurrence hand cleaning at the top and bottom of the bentonite and mining with a power shovel is the most feasible type of equipment. (See Fig. 3). If the shovel-type mining operation is used in arid or semi-arid climates, it is possible to run the trucks on the bottom of the pit in the mined-out areas which eliminates the necessity of the bench system. If the dragline machine is used for mining, a further consideration is given to the estimated amount of bench and clean-up which will be necessary to remove so that the equipment will have adequate capacity for performing the clean-up operation and continuously load the hauling trucks. In most operations where 50 foot mining cuts are common, a three-quarter to one cubic yard dragline machine with a 30 to 35 foot boom is entirely satisfactory. When soft bentonite is handled and particularly where the bed is pitted, a smooth-lip bucket is preferable as it affords better mechanical cleaning and reduces the amount of hand labor necessary to mine bentonite without contamination.

Personnel and Organization

The principal divisions of organization for a strip mine operation are:

Divisions of Organization

a. Overburden Operation

b. Mining Operation

c. Engineering Work

A typical organization for a property continuously mining 3000 to 4000 tons per month from a deposit where 20,000 to 25,000 cubic yards of overburden per month are being continuously removed by a dragline is as follows:

Dragline Operation Organization

a. Superintendent

b. Overburden Dragline Operator

c. Relief Dragline Operator

d. Oiler

e. Mining Dragline Operator

f. Mining Dragline Oiler

g. Pit Labor

h. Instrument Man

i. Chain and Rodman

j. Watchman

Most bentonite operations are located in rather isolated communities and the most satisfactory personnel are always those who live in the immediate vicinity because they are the least likely to become transient workers. They are likewise most satisfied when it is possible to work in the immediate vicinity of their homes or farms. Quite often it is possible to select mining personnel from prospecting crews and the ability of the workers will be known prior to their employment.

The superintendent for this type of operation is usually a former dragline operator from another operating mine and the selection of the superintendent is of utmost importance because his ability for working men and for general organization of the work will directly affect the cost of the mined bentonite. A good superintendent will always have satisfied workers and greatly enhance the morale of the entire organization. In addition to the above qualifications the superintendent should have a good working knowledge of operating methods with mechanical ability as the maintenance of equipment is of the utmost importance. The superintendent transmits the general mining plans to actual operation, makes weekly reports, and is certain that adequate equipment and personnel are available for tonnage requirements.

The overburden dragline operator must be a skilled operator with previous experience in operating dragline equipment and preferably with the type and class of machine employed in the work. The capacity and utilization of the stripping dragline must be maintained by a satisfactory operator if the mining plans are to be properly realized. Improper spoilage disposal and poor maintenance may contribute to excessive costs. A skilled dragline operator is an essential personnel for a satisfactory operation.

A relief operator should be available for overtime operation and periods when the operator may not be available. This man may be trained from the best oiler and need not be as proficient as the operator. However, it is good practice to allow the relief operator to have some operating time at least once a week so that this man may eventually become proficient enough to relieve the operator in any case of emergency. The relief operator is utilized as an oiler during the normal course of operations.

The dragline oiler for both the stripping and mining machines, attends to the operating maintenance of the machine and also is utilized as a ground man for guiding the bucket when the machine is cutting banks, digging drainage ditches or grading bench. In the case of the mining dragline oiler the ground operation is confined to guiding the bucket during the bentonite cleaning operation. The oilers should be selected from common laborers who have mechanical ability and qualifications that may eventually make them satisfactory dragline operators. Through this system of organization, it is possible for each man to obtain better paying work by a steady training process. The oilers also assist the operator in repairing and overhauling work that may be required on the respective machines.

The mining dragline operator should also be a skilled operator, particularly where a considerable amount of clean-up is necessary before the bentonite can be mined and loaded. The greater part of mining machine time is required for loading trucks which operation requires skilful manipulation. In some organizations, it is desirable to exchange operators between stripping and mining equipment so they may familiarize themselves with both machines and likewise provide some relief from fatigue.

Pit labor is utilized to assist the mining and loading of the uncovered bentonite. These laborers hand clean the bentonite when machine cleaning is not possible. They also clean up spillage around the hauling trucks during the loading operation. These laborers are also utilized for clearing vegetation prior to stripping and for general utility work.

The instrument man performs the necessary engineering work for cross section measurements, uncovered bentonite estimates, staking cuts, and running levels for drainage ditches. He likewise prepares monthly reports of quantities handled during the month, makes out payrolls and bills railroad cars. The instrument man and his assistants are also available for part time prospecting and development of other areas in the immediate vicinity of the mining property.

The chain and rodman assist the engineer in his field work, drill and measure uncovered bentonite and establish bentonite depths under the benches to assist in the clean-up operations. These men are also used to assist the instrument man in any intermittent prospecting work in the immediate vicinity.

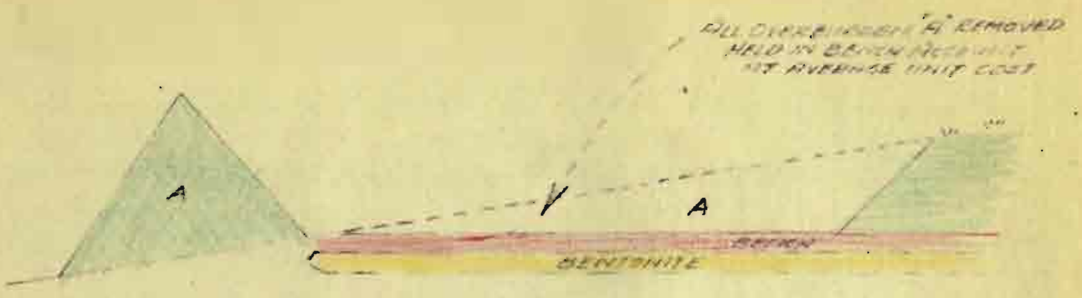
The watchmen, in addition to their regular duties, are also responsible for a certain amount of daily maintenance, particularly oiling and greasing of equipment during the night shift. These duties are of more importance where tractor-scraper equipment is used for overburden work as there is always more maintenance work to be performed on this class of equipment.

In operations where tractor-scrapers are used entirely for overburden work the oldest and most proficient operator is usually designated as a group leader or operating foreman to direct the tractor operation. This class of personnel is of benefit as the tractor stripping work is often some distance from the mining location and it is not possible for the superintendent to continuously supervise both operations.

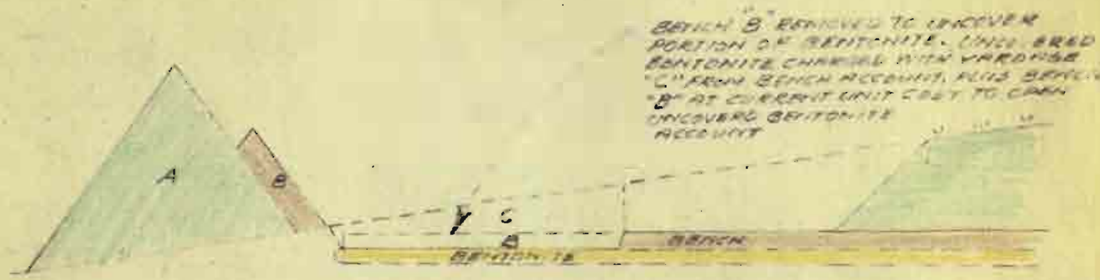
Provision is usually made for supplying personnel with wet-weather clothing in areas where operations are expected to be continuous during all seasons of the year. It is also a good plan to have a shower and change house available, particularly when tractors are used for stripping. Every reasonable convenience should be at the disposal of the personnel as it invariably increases the efficiency and productivity of the workers.

Cost Accounting and Operating Records

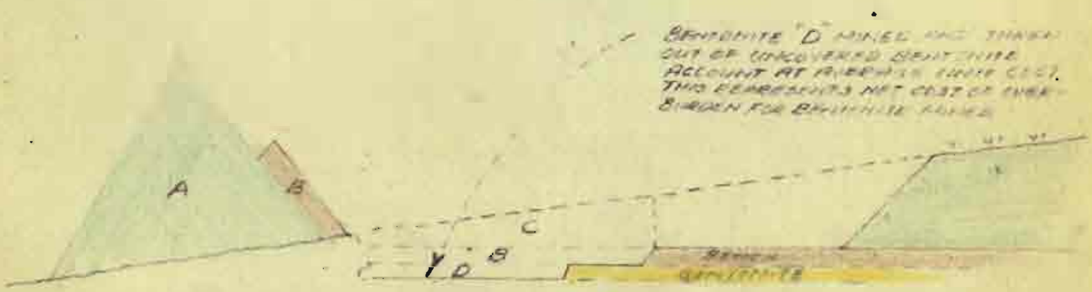
Cost accounting of a strip mining operation requires that proper distribution of costs can be accurately made at any particular time during this operation. It is customary to prepare cost statements for each month's operation. For this accounting, excavation measurements are made to account for overburden removed, railroad shipping weights are used for bentonite mining and estimates made in the field for bentonite uncovered. The most satisfactory method for this type of accounting is a system where three separate accounts are made for all the overburden and mining work during the month. At any one time during the operation there is always some bentonite uncovered, some overburden removed to the bench level and some overburden removed above the bench level. The proper distribution of overburden to be charged to uncovered bentonite is provided in two accounts. The first account is called the "bench account" and includes all of the overburden removed above the bentonite irrespective of the locality of such removal. The second account is called the "uncovered clay account" and contains proper charges for overburden removed directly above the bentonite uncovered. (See Fig. 4). When bentonite is uncovered ready for mining, an estimate is made of each block of the uncovered bentonite from the overburden cross sections. It is possible to estimate the exact number of cubic yards originally above this block of bentonite before it was uncovered. When this estimate is made, the equivalent number of cubic yards is taken out of the bench account at the average unit cost of this account and charged to the block of uncovered clay. A net cost for removing overburden for the bentonite mined during the month will, therefore, contain the proper distribution of yardage from any point on the property where the bentonite is mined and loaded. The yardage removed in back slopes and drainage ditches that does not directly uncover clay is charged to the uncovered bentonite adjacent to the slopes or drainage ditches so that after all of the bentonite has been mined the bench account will be reduced to zero. In



Overburden Removed - No Bentonite Uncovered



Bench Removed - Bentonite Uncovered



Bentonite Mined

FIG. 4 - ACCOUNTING METHODS FOR STRIP MINES

this manner a proper account can be made for the operation at any particular time in the course of stripping and mining.

The cost statements for the mining operation contain the following items:

Cost Items for Mining Operation

a. Net cost to remove overburden
b. Clean-up and mining
c. Hauling
d. Overhead at mine
e. Total cost at railroad loading point
f. Freight to Processing Plant
g. Total cost at Processing Plant

The cost statement shows the above account for the calendar month together with a cumulative accounting for the months preceeding during the calendar year. A third column shows the cumulative cost to and including the same month for the previous year.

Where a single machine such as the mining machine removes some overburden in addition to mining and loading, costs are distributed according to the number of hours of actual operations on each class of work. The average cost of operating the machine during the month is then properly aportioned to each class of work.

In addition to the cost statements, a further record is made of the cost of operating each machine with a detailed breakdown of total monthly costs. In addition to the costs, the record shows quantities handled during the month, operating conditions, notes on repair and maintenance and cumulative costs since the machine began operating on the property. These records are very useful for comparing different classes and models of equipment and also serve as a base for recommendation of replacement or estimates for costs of mining new properties.

INDEX