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Efficient field methods for the petroleum geologist

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EFFICIENT FIELD METHODS FOR THE PETROLEUM GEOLOGIST.

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A

THESIS

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Approved by G. H. Cox
Professor of Geology & Mineralogy.

Illustrations

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Contents.

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-------OO-------

Introduction.

The methods and systems suggested for the use of the petroleum geologist in the following manuscript are intended not only as subject matter for a thesis but also, I sincerely wish, that they may be of some use and help to those of The Missouri School of Mines who are planning to take up petroleum geology as a profession, but have not yet had the opportunity to study the practical or field end of this work.

The average graduate entering into his profession is handicapped by his lack of practical experience and his lack of knowledge of the short cuts, systems, and methods which make the work of the experienced professional so much easier and quicker than that of the beginner. This lack of practical experience often, when conditions are adverse, retards his progress to such an extent that by the time he has worked out these points for himself, and has attained a responsible position, he has forgotten most of the fine theory that is the basis of all clear and logical thinking in his profession.

With this in view, I have set down some practical systems, pointers, and methods which I have found to be of value to the petroleum geologist, in that they insure accuracy, ease of operation, and speed in his work,- in other words, efficiency.

The company who maintains a geological department values it according to the results it produces; and if it cannot produce results which are at least equivalent to its cost, it is eliminated. Thus it is readily seen that efficiency is highly essential to the geological profession as well as to any other; and its continuity and growth depend primarily upon the rapid development and efficiency of the beginners.

This article is by no means intended as a text; the principal object being, as previously stated, to offer a few systems, methods, and practical pointers which may help the beginner to develop more rapidly into a valuable professional. Those theories or portions of theories stated here are known to the student of geology; and my purpose in stating them has been to show more clearly why these methods and systems are the logical and efficient ways of carrying on the work.

With continued wishes for success and prosperity to the Faculty and the Student Body of the Missouri School of Mines, I am

Sincerely yours,

(Signed) Phil B. Dolman.

Reconnaissance.

The reconnaissance survey in petroleum work is the preliminary looking over of the territory by the geologist; the object being to discover, locate and describe the structural geology of the region. The location, size, shape, and extent of any structure of interest or economic importance are indicated within the limits of accuracy attainable and without actually surveying and mapping the area.

Reconnaissance methods are to be used when it is desired to cover a great amount of territory in a short time, when finely detailed information is not necessary, when an immediate report is wanted, and when detail is impracticable or impossible.

The accuracy of reconnaissance work depends wholly upon two closely related things: first, the ability of the geologist to see the structure, and second, the clearness with which the geology expresses itself.

Rapid Reconnaissance.

In rapid reconnaissance the object is to cover the area in question with the least expenditure of time; observing the major structural features. Such items as direction of regional dip, nature of outcropping beds and their extent, and stratigraphic relationships, relief, and proportion of timbered to open country. In general, rapid reconnaissance is to be used as a basis for future work in new or "wildcat" territories.

The only instruments necessary are a Brunton compass, and a speedometer. In case the country is such that a car cannot be used, the latter is, of course, out of the question, and some other means for measuring distance must be procured.

In this work, it is highly essential that the geologist be well trained and experienced, for structures are to be observed, not measured, and the relative size, shape, and extent is to be estimated.

The questions before the geologist should be:-

Are any sands exposed whose physical characteristics would permit oil saturation and migration, and if so,

have they an impervious capping?,

how thick is the capping?,

how thick is the sand?,

What is the direction of regional dip, and what is the approximate average rate of dip?

Is there any folding down the dip, and if so

is it far enough down from the sand outcrop to place that sand at a sufficient depth below the probable zone of oxidation, and how deep would this sand lie here?

Is it sharp or gentle folding?

Is there much faulting, very intense folding, metamorphism, or intrusion in this area of folding or relatively close to it, down the dip, that would destroy oil possibilities in this area, or would tend to divert the oil migration around it from the down-dip sides?

Is there any general area of weakness suggested by an isolated area of folding?

How about transportation facilities?

Is there sufficient water for drilling purposes?

Is detailing possible?

The preceding order is the order in which these questions should present themselves and be answered or taken up, for it is the order of importance, and is believed to be the best, quickest, and easiest way to arrive at the desired conclusions: namely, of what economic importance is the area from an oil and gas standpoint?

As for methods for seeing or observing structures accurately, no definite rules can be suggested; for structural folds express themselves to the eye in a multitude of ways varying with and depending upon the degree of folding, age of folding, relation of period of folding to period of uplift and erosion, degree of relief, presence or absence of resistant beds, relation of resistant beds and nonresistant beds to surface of erosion, type of topography, or regional age in the erosion cycle, etc.

However, in the petroleum fields of the Mid-Continent field a general relation between folding and topography holds true, not only to major structural features but to single small folds as well.

Here, it seems, the period of most active folding occurred prior to the major uplift and the beginning of erósion:- thus structural features were the primary features in controlling topography, in that synclinal flexures in the first resistant strata presented natural drainage lines and channels along which the most active erosion began; so that structural "highs" are most commonly high points topographically, and synclines are almost invariably occupied by drainage channels.

Thus topography in this region and in most regions of gently dipping strata is of invaluable aid in pointing out to the geologist structural dips and folds. I wish to emphasize, however, that all drainage channels are not synclines, and topographic "highs" are not all anticlines.

Another topographic relationship which is quite a help in determining structure in sharply eroded areas is as follows:- When an escarpment is on the up-dip side of a ridge, it will be much more sharp and abrupt than on the down-dip side; for example,- when the dip is west the east side of a bluff will nearly always be much more sharp and steep than the west side. This is not infallable by any means, but has been found to be a great help to the geologist where definite and distinct outcrops are lacking.

Dip-Slopes are "half the battle" in reconnaissance. Many producing structures have been located upon the strength of dip-slope geology, where no distinct or definite beds are exposed; and, in my opinion, a great deal of future production, especially in the central and south-west will be based upon the location of "apparent structures" in regions where resistant outcrops are lacking.

The Dip-Slope is a topographic feature representing in appearance a smooth, dipping, or flexed surface whose major erosional breaks are parallel to the strike of the plane. These topographic surfaces show very accurately the dip of the strata; for - on the even surface of a stratum of even texture and equal resistive qualities, erosion will not be localized or concentrated in any one line, and as a result erosion will be uniform over the entire surface till meteoric waters become united in sufficient quantities to cut through the stratum and seek an outlet in some other direction.

It will be seen, as previously stated, that reconnaissance, especially the rapid variety, requires a geologist of considerable experience; for in order to see geology as it is generally expressed, one must be familiar with the signs and indications nature has afforded, and these can only be learned through repeated and continuous observation in the field.

Detailed Reconnaissance.

In detailed reconnaissance, the object is to determine and indicate as closely as possible, without accurately mapping the area, the structural details of probable economic importance. Very often acreage is bought, and test wells are located upon recommendation from this type of work; thus it will be seen that the results obtained must be of an accurate and definite character in regard to size, shape, and extent of folds.

This type of work is desired when,-

A working report is wanted in the shortest possible time,

When detailing is impracticalbe or impossible,

When topographic conditions are such that corallation of beds over the area is impossible, when folding is so sharp, or other conditions are such that detailing would be unnecessary.

The instruments found to be of the greatest benefit in working under the conditions stated are:-

Brunton Compass.

Pocket transit of the type having (% grade) indicator. K&E.

Hand level with stadia-hairs.

Note book with note and section sheets.

Light stadia rod.

Speedometer on car, in case car is used.

Two methods are suggested below: both efficient in that they produce the desired results in the quickest and easiest ways. The first may be applied where the geologist works alone, the second where the geologist has an assistant. The first is the most commonly used in practice, but is not the most accurate.

The geologist first locates the highest structural point or points. From here he is able to observe the various breaks in rate and direction of dip on all sides,- in the case of wooded country, he has lost nothing by starting at the top.

The second step in either case is to drive or walk over the structure in question, placing bench marks (anything that can be recognized or attract the eye) at advantageous points on such breaks in dip.

Third, these points are located, direction from point to point taken, distance between points driven or paced, and direction of strike and percentage of dip observed. All are tabulated in the notes, and points and map data are plotted in the office or at home, for it is unnecessary to do this work in the field. The most efficient worker while in the field, does only that which cannot be done in the office.

In the office, points are plotted to scale upon the coordinate sheet, and dip arrows with their numerical values inserted. The finished results are transferred to a township plat sheet; synclinal and anticlinal axes are shown with a contour or two sketched in where needed to indicate the general shape of the structure.

A more finely detailed reconnaissance may be executed by method two. The instruments found to be of greatest benefit when working under conditions stated in this second method are:-

Brunton.

Hand level with stadia hairs.

"Pocket Transit" which indicates per cent grade.

Stadia rod,- See description under "Detail".

Note book - as in preceding first method.

The method of procedure is in general the same as described under the first. The rodman is placed at a conspicuous point preferably at the crest of the structure. The geologist locates the breaks in dip, backsighting upon the rod, thus determining direction, angle, and distance. Results are tabulated in the notes.

This method serves as an approximate detail, for relative elevations of points may be determined, intervals observed with fair accuracy, and the structure contoured roughly. Final results are transferred to township plat sheet or detail sheet as in first method.

Upon reading this article, some may wonder why I have not mentioned the Aneroid as an instrument to be used in reconnaissance work.

The Aneroid has been used quite a little in petroleum work in the past, and very poor and misleading results have been attained. In my experience, I have found that the Aneroid is very erratic when used in the ordinary way; and I have also found that the only method for obtaining dependable results from it is as follows: - Measure distance and direction from point to point, take the time at which each reading was taken, and check at starting point at regular intervals not greater than one hour apart. After field work is done the increasing or decreasing error each hour is plotted upon coordinate paper, and an error curve constructed. From this all elevations must be adjusted. This consumes so much time and energy, and is such an inefficient method for obtaining results that I do not consider the Aneroid worth using in any case.

In a good many cases it is found that a combination of rapid reconnaissance with detailed reconnaissance may be used to advantage, depending upon the degree of accuracy required.

Detail.

Detail is the accurate surveying and mapping of the geological structure. Such work is carried on by the use of the plane table and telescopic alidade with the stadia rod. The party is composed of at least two men,- the geologist and the instrument man. In some cases a rodman is employed to follow the geologist, but this is considered unnecessary.

Detail is used when accurate data upon structural folds of economic importance are desired; when one wishes to show the relation of structures in an area; and when the relation of surface to underground structure in a drilled area is desired.

The instruments to be used in this work, as previously stated, are plane table with tripod, telescopic alidade, and stadia rod.

Besides these the instrument man should have a scale, one side of which is graduated to scale 2000 feet to the mile and the other 1000 feet per mile; a note book with leather case with compartments for pencils, scale, and reflector; a small hand level; and a reflector. The latter is to be used in signaling the geologist or attracting his attention when conditions are such that the instrument man is not in plain view. A metal trench mirror has been found to be about the best thing for this use.

The geologist should carry (besides the rod) a Brunton compass and a small hand level. The Brunton may be used as a relfector when necessary.

The tripod, plane table and alidade described below are considered standard for this general type of work, in that they have given in practice the most efficient results and all-around service.

Tripod - Socket Head.

Plane table - 18" x 24"

Alidade - A Gurley, series 17000 to 18000, with Stebinger Drum and Beamann Arc.

A leather washer about 5" wide and 1/4" thick should be screwed upon the tripod head to eliminate wind vibration.

The 18x24 plane table is preferable to the square 18x18 or larger, in that it will hold a full township map scaled 2000 feet to the inch, and permit of a large enough margin on the right side for a legend column; and yet it is not so large as to be cumbersome, or to permit undue wind vibration. The 18x18 board leaves no margin for the legend.

The Gurley alidade - model (   ) has a long barrel, enlarged optic end, together with good general lens characteristics. These give a clear vision. It also has a wide vertical angle range which give it more flexibility than some of the other makes.

The instrument is small, light, and easily carried, the container being about 5" sqmare and 12" in length.

A standard rod is much meeded in petroleum work.

One sees a great variety of designs, colors, lengths, weights, and widths in rods used in this work, and in my opinion the great majority are very inefficient, basicly.

It is or should be a well known fact that ease, accuracy, and speed of instrument observations depend to a very great extent upon the type of rod design and coloring.

The rod illustrated and described below has been found in my experience to be the most efficient under all general conditions.

Stadia Rod.

Specifications.

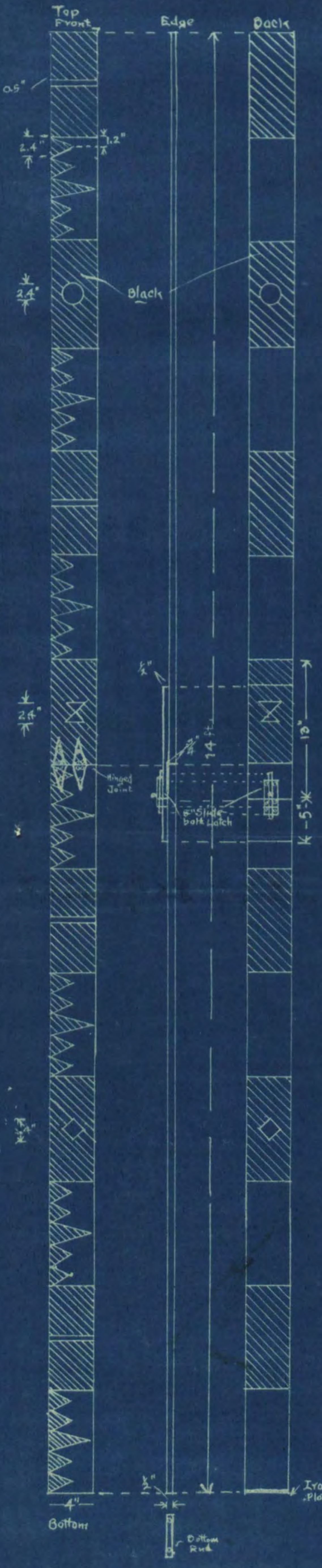
Lumber - White pine, Cedar, or some light weight material.

Paint - Flat white and flat black. - Not glossy.

Miscellaneous - Eight 1 3/4 inch stove bolts, one 1/4 inch iron plate for bottom as indicated, two dozen 3/4 inch wood-screws, one 5 inch slide-bolt latch.

Dimensions of the rod and its design are indicated on the drawing.

STADIA-ROD
(For Plane-table work.)



Specified materials:
Lumber- white pine, or cedar.
Paint- flat black and flat white

Merits.

The rod is light yet strong enough to withstand rough usage, and will not bend at the joint in the wind: the latter point is effected by the overlap joint connection,- see drawing.

It is easily taken down and put up: this is effected by the slide bolt on the joint connection which is strong enough to hold the rod together, and at the same time is very quickly slid in place or apart.

There are no loose parts, everything is together so that nothing will be lost out in transit.

The iron plate at the bottom eliminates wear and will not catch on things and get torn off as would a tin capping.

There is no liability of error due to the stadia rod being set upside down, for if it is not set on the right end, the latch will slide apart, and the upper end will come down.

Color Design.

Flat white and flat black are chosen as best because they offer the best contrast, are most read-

readily distinguished at long distances as well as at short distances. Flat colors are used because they do not reflect the sunlight. Glossy paint reflects the light making the rod hard to read; and at long distances reflection causes the white portions to appear longer than they really are. Flat paint does not peel off readily, dirt does not stick to it. Flat paint dries readily thus saving time when repainting the rod.

The design is simple and easily executed in any paint shop. The tenths are easily seen and accurately read at long distances. Every other foot on the front is solid except for the half foot mark,- the latter is easily distinguished at long distances. Three designs are painted at the centre of the 4, 8, and 12 foot blocks.

The solid blocks make the different divisions more readily distinguished at long distances, also eliminate unnecessary painting. Small figures giving the foot number cannot be read except on short shots. The designs at 4, 8, and 12 serve this purpose; for all shots (except very short ones) at least one of these comes within the range of vision, and the position on the rod is quickly determined from any one of them. Intervals can always be read accurately with this design, and thus it is not necessary to have the whole rod divided into tenths; for in instrument work one cross hair is set on an even or a half foot mark, the interval being read above or below this. Thus it is seen that by setting the first on an even or half foot mark, one of the others is sure to cross a foot which is divided into tenths.

The back may be painted solid black and white, as indicated, with very little trouble, and on long shots where the sun is not on the face of the rod, this is often quite an advantage, for the solid blocks appear more distinct than those marked in tenths in these instances.

Field Notes.

Foreword.

The following system of notes, in my opinion, is preferable to many other systems used, in that it eliminates a great deal of memory work and figuring in the field. In the field, the instrument man is usually kept busy keeping track of the rodman and thus is unable to concentrate his attention upon the note figuring, and usually makes mathematical mistakes that require checking after hours. Computing notes and elevations in the field, I believe, is unnecessary, and takes a good deal of time that might be spent in actual field work.

Explanation.

Sheet #1 represents a set of field notes, and has upon it all that is necessary to be taken while running the traverse.

Sheet #2 is a duplicate of 1, and is the second stage. The B.S. and F.S. are figures and tabulated as shown whenever the instrument man finds time to work on them undisturbed. Notation in the "remark" column pertaining to bed numbers and descriptions is given by the geologist upon his return to the plane table; also such notation as the (14+5) in the "dist." column opposite #22 on sheet 2 is given at this time.

Sheet 3 is a second duplicate of 1, and represents the completed notes, the third stage. This final work may be done at home after hours, or at any convenient time when the instrument man's mind is not distracted by other things. In this way he is able to do the most efficient field work while in the field, and can figure the notes with much greater ease, rapidity, and dependable accuracy than by trying to do both at the same time in the field.

The instrument man while in the field is obliged only to take notes as indicated on sheet #1; to figure the B.S. and F.S. as indicated on sheet #2 at times when it is convenient; and to plot the points on the map, giving them each a number corresponding to that in the notes.

The geologist, upon his return to the table, gives any other data that may be essential, and sketches the traces of the outcrops through their respective points on the map.

Description of Terms, Symbols and Field Methods.

▽ represents a triangulation point, B.M. means that the point has been marked for future reference, A indicates that an elevation has been obtained upon a standard rig without the use of the

T26N, R 11 E
Nov 1, 1919.

Sheet-1.

Sta & Dist	Angle	B.S.	Elev.	F.S.	Remarks.
—	—	—	900.0	—	U.S.B.M. □ S 36|31 / 1|6
Δ 8.	+1 3.5				1
⊙ 10.0	−2 7.0				2
Δ 7.5	+½ 5.2				3
x 12.0	−3 14.0				4
x 3.	+2 12.0				5
⊙ 7.4	−1½ 5.3				6
Δ 11.5	0.0 4.0				7
⊙ 5.	0.0 7.0				8 BM
Δ 2.5	+3 3.0				9
x 16.	0.0 60.0				10 A ⊙ #1
x( )	+1½ 0.0				11 ∇ Top Windmill
x 14.	+1 0.0				12 BM.
—	—	—		—	8
Δ 6.	0.0 1.5				13
x 8.	0.0 3.8				14
x 12.	0.0 0.0				15
x( )	+1 0.0				16 ∇ Top Wm. Check (11)
x 12.	−½ 72.0				17 A ● #2
⊙ 2.	+1½ 10.0				18
Δ 8.	−½ 4.5				19
⊙ 4.5					20 Check (12)
Δ 5.2	+1 0.0				21
x (14+)	0.0 1.0				22
x 5.	−3½ 14.0				23
x 10.	+2 5.5				24

T26N, R 11 E.
Nov 1, 1919.

Sheet-2

Sta & Dist	Angle	B.S.	Elev.	F.S.	Remarks.
—	—	—	900.0	—	U.S.B.M. □ S 36|31 / 1|6
Δ 1600 8.	+1 3.5	−12.5			1
⊙ 2000 10.	−2 7.0			+47.0	2 (IS#1)
Δ 1500 7.5	+½ 5.2	−2.3			3
x 2400 12.	−3 14.0			+86.0	4 (IS#1)
x 600 3.	+2 12.0			0.0	5 (SS#1)
⊙ 1480 7.4	−1½ 5.3			+27.5	6 (IS#1)
Δ 2300 11.5	0.0 4.0	+4.0			7
⊙ 1000 5	0.0 7.0			+7.0	8 BM (SS#1)
Δ 500 2.5	+3 3.0	−12.0			9
x 3200 16.	0.0 60.0			+60.0	10 A ⊙ #1
x (4000)	+1½ 0.0			−60.0	11 ∇ Top Windmill
x 2800 14.	+1 0.0			−28.0	12 B.M. (SS#1)
—	—	—		—	8
Δ 1200 6	0.0 1.5	+1.5			13
x 1600 8.	0.0 3.8			+3.8	14 (IS#1)
x 2400 12.	0.0 0.0			0.0	15 (IS#1)
x (4650)	+1 0.0			−46.5	16 ∇ Top. Wm. Check (11)
x 2400 12.	−½ 72.0			+84.0	17 A ● #2
⊙ 400 2.	+1½ 10.0			+4.0	18 (SS#1)
Δ 1600 8.	−½ 4.5	+12.5			19
⊙ 900 4.5	+1 3.0			−6.0	20 Check (12)
Δ 1040 5.2	+1 0.0	−10.4			21
x 3800 (14+5)	0.0 1.0			+1.0	22 (IS#1)
x 1000 5.	−3½ 14.0			+49.0	23 (SS#1)
x 2000 10.	+2 5.5			−34.5	24 (SS#1)

T26 N, R 11 E.
Nov. 1, 1919.

Sheet-3

Sta & Dist	Angle	B.S.	Elev.	F.S.	Remarks.
—	—	—	900.0	—	U.S.B.M. □ S 36|31 / 1|6
Δ 1600 8.	+1. 3.5	−12.5	887.5		1
⊙ 2000 10.	−2 7.0		840.5	+47.0	2 (IS#1)
Δ 1500 7.5	+½ 5.2	−2.3	838.2		3
x 2400 12.	−3 14.0		752.2	+86.0	4 (IS#1)
x 600 3.	+2 12.0		838.2	0.0	5 (SS#1)
⊙ 1480 7.4	−1½ 5.3		810.7	+27.5	6 (IS#1)
Δ 2300 11.5	0.0 4.0	+4.0	814.7		7
⊙ 1000 5.	0.0 7.0		807.7	+7.0	8 BM (SS#1)
Δ 500 2.5	+3 3.0	−12.0	795.7		9
x 3200 16.	0.0 60.0		735.7	+60.0	10 A ⊙ #1
x (4000)	+1½ 0.0		855.7	−60.0	11 ∇ Top Windmill
x 2800 14.	+1. 0.0		823.7	−28.0	12 BM (SS#1)
—	—	—	807.7	—	8
Δ 1200 6.	0.0 1.5	+1.5	809.3		13
x 1600 8.	0.0 3.8		805.4	+3.8	14 (IS#1)
x 2400 12.	0.0 0.0		809.2	0.0	15 (IS#1)
x (4650)	+1 0.0		855.7	−46.5	16 ∇ Top. Wm. Check (11)
x 2400 12.	−½ 72.0		725.2	+84.0	17 A ● #2
⊙ 400 2.	+1½ 10.0		805.2	+4.0	18 (SS#1)
Δ 1600 8.	−½ 4.5	+12.5	817.7		19
⊙ 900 4.5	+1 3.0		823.7	−6.0	20 Check (12)
Δ 1040 5.2	+1. 0.0	−10.4	813.3		21
x 3800 (14+5)	0.0 1.0		812.3	+1.0	22 (IS#1)
x 1000 5.	−3½ 14.0		764.3	+49.0	23 (SS#1)
x 2000 10.	+2 5.5		847.8	−34.5	24 (SS#1)

rod, ⊙ any foresight which is a turning point, × a side-shot, △ a back-sight, ⊙, ×, and △ must be indicated in the "dist". column, ⏟ in the "elev" column indicates that it is the elevation of a side-shot which must be figured from the elevation of the first preceding instrument station and not figured in the regular traverse.

System and Method of Computation.

It has been found that the most logical order in which to take the readings is as follows:
First, angle - up is plus, and down is minus; this is the top figure in the angle column.
Second, rod reading; this is the lower figure in the angle column.
Third, the half-interval; this is the small figure in the upper right hand corner of the distance column.

The angle may be read accurately up to 1/2 stadia angle when one has only a Beaman arc on the instrument: read the top or bottom hair instead of the centre hair and add 1/2 to the number of Beaman arc divisions actually turned,- for instance, suppose the instrument was turned up 2 divisions and the top hair read 3 feet, then the rod reading may be taken as 3, and the angle is 2 1/2 divisions. This works the same on down turns using the lower hair.

Multiplying the half interval by 200 in all cases gives the distance. Some prefer to read the half interval in all cases, for if a half interval is read in one case and a full interval in another, one is liable to forget and make mistakes.

On sheet 2 in the distance column opposite #22 it will be observed that a half interval of 19 feet has been obtained. This of course can not be done on a 14 foot rod, without a Stebinger Drum attachment, except in the following manner: The geologist can usually tell when he is over 2800 feet from the instrument, and in such cases will take pains to set the rod upon some open or prominent point so that the bottom can be clearly seen,- the instrument man sets one hair on the bottom of the rod and motions for the rod to be raised slowly, when the top reaches the next cross-hair the instrument man motions to that effect, and the geologist measures the height raised. This value is tabluated upon his return to the plane table, as indicated on sheet 2. In this case, a 14 foot rod was raised 5 feet.

The principal of figuring is based upon an algebraic principal which holds true in all cases, and may be resolved into four simple rules as follows:

1) Multiply the angle reading by the distance divided by 100; the product is *always* considered plus.

2) If the sign on the angle is plus, *subtract* the rod-reading from this product; if the angle is minus, *add* the rod-reading.

In order to illustrate the 3rd rule, consider this *second* answer with its sign in a parenthesis.

3) If the sign of the angle is plus, the sign of the 3rd quantity is *algebraically minus*, and if the sign of the angle is minus, the sign of this quantity is *algebraically plus*. For instance, in the case of #1 on sheet 2:

1x16=(+16), 16-3.5=(+12.5), the sign of this is -(+12.5)= -12.5 or in the case 18 on on sheet 2, 1 1/2x4=(+6), 6-10=(-4), the sign of this is -(-4)= 4.

4) In adding or subtracting back-sights or fore-sights in order to obtain the elevations of the respective points, add algebraically all back-sights, and subtract algebraically all fore-sights.

The advantages of this method of notes and figuring lies in the fact that the rules always hold true, so that the instrument man need never become confused upon peculiar or unusual shots; the notes taken are no more than necessary, and yet are all that is needed in any case; and are so arranged that no time is lost in taking them down or finding their column; also when they are closely arranged in this manner, note-figuring is much easier and more quickly done; and again the volume of notes is much less.

Short Method for Determining the Elevation of any Desired Point and of Checking Addition.

Suppose the geologist wants the elevation (in the field) of numbers 8, 12, and 24 without figuring through the whole traverse.

Put all plus back-sights and minus fore-sights in a B.S. column, and put all plus fore-sights and minus back-sights in a F.S. column in the order in which they come, and omitting all side-shots as illustrated in the following:

```
   U.S.B.M.    8 to 12.                                     No. 8 to 24.
     B.S.       F.S.                                         B.S.    F.S.
      4.0       12.5                 -96.3                    1.5     4.0
 +4.0 28.0      47.0                 + 4.0                   12.5    10.0
     +32.0       2.3                 -92.3                    6.0   -14.0
                27.5                 900.0                   34.5
  -108.3         7.0                 -92.3                  +54.5
  + 32.0        12.0  -96.3          807.7= El.8            -14.0
  - 76.3      -108.3                                        +40.1

  900.0                                                     807.7
  -76.3                                                     +40.1
  823.7= El.12                                              847.8= El.24
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Foot Note.

Two brackets may be noted in the distance column on sheet 1 opposite triangulation point 11, and check point on 11 at 16. The distance is obtained in both cases after the second set-up from which it was observed, by measuring the distances on the map from each set-up to the point of intersection. The distances obtained are inserted in the distance column, and the elevations of that point computed. Such work in triangulation without the rod is most readily done with the Stebinger Drum attachment on the instrument, but may often be done with only the Beaman Arc. If the work has been carried accurately, the two elevations of point 11 should check.

This method of triangulation on various points may be used in different stages of the traverse as a check upon the work, thus eliminating the necessity of tieing in by special traverses, and thereby eliminating a good deal of unproductive work and time spent. And again, if such observations are taken at fairly frequent intervals, any field error can be definitely limited to a short portion of the traverse.

In detail as in reconnaissance, it is impossible to suggest set rules or definite geological field methods for working out the structure in the most efficient manner. Yet a few general rules and methods in such work may be set down as applicable in the majority of cases, and if followed consistently, will eliminate a great deal of unnecessary work, worry, and chance for error, thus inducing greater efficiency and ease of operation.

In beginning work two different cases present themselves:- The area to be covered may be large or small; in other words, is the object to map a given territory, or to map one particular structure of importance?

The methods of carrying out the work will vary according to which of these two is the case.

We will consider first the large territory to be detailed in general; and in this instance the following questions will arise:-

What is the direction of regional dip?

Is the region rough and broken, or is it gently rolling, and is it open or timbered generally?

Is the region generally accessible by roads, or are there isolated parts which are hard to get at;if the latter is the case, where are such isolated portions?

It is presumed that reconnaissance - rapid, detailed, or both has been done over the area in question, and from such reports the geologist may be able to obtain this information.

We will take the case of an average territory: It is partly timbered, partly open, partly rough and broken, and partly gently rolling, the dip regionally is west.

From experience, it has been found that the logical place to begin upon such a territory is on the down dip side. In this instance, work will be started on the western extremity of the region to be detailed, and will be carried to the east. Thus the work will follow in the natural order, for the youngest beds will lie on the west extremity, and the oldest on the eastern extremity; we are beginning with the highest, and ending with the lowest; the stratigraphic column will begin at the top, and end at the bottom; the first area covered will belong to the highest series, and the next to the next lower series; intervals will always be taken from a higher bed to a lower; dip-slopes will (except in the case of a fold) be gently up, and topographic breaks abruptly down. In this way it may be seen that any reversal of the last two conditions will at once attract the attention of the geologist, for it is a departure from the general rule, and logically suggests a structure. When a structure is spotted more care must be exercised in taking points; so that it may be shown accurately. And again, while working up the dip the geologist will be warned in the case of a fold by variations on the flank, thus will be prepared for any reversal, and the chance of missing slight folds will be eliminated.

High points should constant objectives of the instrument man, for it is from these that the greatest area is covered and the most rapid work done.

The open portion should be worked first, if possible, until timbered or broken spots have been surrounded. By working around these difficult portions in this manner one lets the geology within them work itself out in a major sense, so that later a short traverse or two through them will supply all the necessary data with comparatively little expenditure of time or energy. The same procedure is recommended for any difficult portion where corallation is uncertain, or where the geologist becomes confused in any way.

For the greatest ease and speed, the geologist should cover as much area as possible with the car or whatever conveyance he has, and in order to show the structure definitely and completely (especially in the case of sandstones) he should take points upon all definite ledges which he may expect to use in his work and which are exposed to the view of the instrument man, the distance being governed by the limits of accuracy of the instrument. Thus if a certain bed is absent or cut away over a portion of the area, points to show the structure may be taken on another; and again, if one bed is lensing or erratic, the others will show this fact and give dependable results; in addition to this, points taken upon different members of a series, when favorably exposed, will give an average interval that will tend to eliminate structural error due to a wrong interval measurement, and such errors will be taken up and graded out at the time of contouring.

In order to obtain efficient results, the detail geologist should be able to see structure.

Ideally, points should be only taken at the breaks in rate or direction of structural dips, at the lowest and highest points structurally, and at bed contacts and scarp extremities (the latter for determining average intervals).

All the area (within the limits of instrumental accuracy) exposed from each set-up should be covered at that time by the geologist and points should be marked frequently along the unjoined edges of that area. The latter points are established as future check or turning points to future work.

In the case of a small area to be worked, such as the single known structural fold, the object should be to establish the plane table at the highest structural point, or the highest topographic point upon the axis of the fold, in case both do not coincide.

From here the geologist as well as the instrument man is usually able to see over the greater portion of the fold, and can see where and in which order the points are to be taken. With the larger and more complex structures, of course, it may be necessary to carry a traverse along the axis, or in the manner indicated in the preceding description of methods for large areas.

By working the flank which is on the regional dip side, first the geologist becomes familiar with the bed series, and therefore is less liable to make an error in the reversal, which is naturally the most important part of the fold, yet often the most difficult to work out.

When working with sandstones, the geologist must depend a good deal upon mentally projected structural lines and curves and upon the series of intervals for corallation, rather than upon lithologic characteristics and similarities; for sands all look a great deal alike, and change a great deal in texture and appearance over comparatively short distances.

In my experience, considerable changes in the intervals of one series due to thickening, thinning, or introduction of new members is comparatively rare, and where such does occur it is usually so apparent or extends over so great an area that the geologist readily recognizes the conditions. In this case, an actual or theoretical convergence sheet is constructed to correct the contours over the area in question.

Two sandstones often merge into one, producing an apparent thickening which is equal to the sum of their thicknesses. They usually separate again, however, and retain their original intervals.

With sandstones, especially when the geologist becomes confused, the best policy is to work around the questionable portion. Nine times out of ten the difficulty will work itself out, saving the geologist much time and worry.

Map Work.

The following methods and order for carrying out the map work has been found to give the most efficient results:

First,- at the end of each week, points on the checked portion of the traverses, their numbers, and the traverse lines are inked in in black. The point number being placed at the top and to the right of the point.

Second,- the outcrop traces are inked in in different colors with a number on each different trace, the highest being No. 1.

Third,- point elevations are inked in in the color of the bed upon which they were taken. In case the point is not on a bed, use black. The ground or crop elevations are placed at the bottom and to the right of the point.

Unless copies of portions of the structure are desired before the area is completed, the datum elevations and contouring are left till the field work has been finished, for not until then will the geologist know which will be the best datum horizon.

Fourth,-when the area is completed, construct the vertical stratigraphic column, and choose the datum bed (which should be either the best, most prominent, easily recognized, or the one which covers the greatest territory in that area.

Fifth,- reduce the bed elevations to datum, placing this datum elevation directly above the bed elevation of that point.

Sixth,- the map may be cleaned and the contouring begun. Contours are first traced in pencil. In starting, begin with the structural highs or the crests of folds. When these are contoured, other intervening structure is easily contoured, for this latter will tend to conform with the trend of dip and strike on the folds. In case any point causes a sharp irregularity, not observed in the field, either throw it out or reexamine that portion in the area. Contours should be smooth curves, except of course in the case of faulting, for structural folds are seldom sharp or jagged.

Contours are now inked in some transparent color - carmine, for instance. Some color should be used that will not obliterate points and numbers on the map. In case contours show a fold or dip not observed in the field, it is safest to reexamine that territory.

Conclusions.

In drawing conclusions, one must take into consideration quite a number of factors besides structure alone.

The principal factors affecting one's conclusions are described below in the order in which they should present themselves.

The first question should be does the area lie in or near a producing region or in a "Wild Cat" undrilled territory.

In the case of the wild cat country, of course, the best structures are uncertain from an oil standpoint, unless - extensive sands are exposed up the regional dip which are of suitable texture and thickness to produce favorable oil carriers in this region. Even then one does not know certainly that they retain these characteristics at depth under the region examined. And again, in the case of an unconformity up the regional dip, one has no way of knowing at what depth the unconformable surface lies in this area.

In producing or drilled territory, a great deal of this uncertainty is eliminated, and one has recourse to definite information concerning conditions at depth from well logs and drilling reports. In this case, equal attention should be paid to such information and to surface structure. A few of the major points are taken up in the following:-

Sand conditions are of first importance, so the first question under this should be -

What is the producing sand? and is it a true sand? If so, steady and even production may be expected with a steady rate of decline. Gas may be expected upon the highest portions of a structure, oil occurring farther down on the flank which is on the down-regional-dip side.

Is the oil carrier a lime? If so, production may be expected to be erratic and wells may vary greatly in capacity. The field may be "spotted". The structure may be barren altogether; and the fundamental reason for these conditions is that a lime is basicly irregular in porosity. Thus one may get a

10,000 barrel well surrounded by 5 barrel wells, or a dry hole surrounded by good producers.

Is the oil carrier a conglomerate? If so, the same conditions apply as in the case of the lime, except to a much greater extent. The conglomerate is the most uncertain oil horizon of them all.

Do drilling records show that the oil "sand" varies greatly in thickness or lenses out altogether in places? Has production been obtained upon straight long regional dip where the underground structure shows the same? If so, local lensing-out of the sand may be expected most anywhere, adding to the uncertainty in future drilling upon structural folds.

Is the sand thick or thin? The thicker the sand, the steadier will be the production, and the longer will be the life of the wells with resultant slow rate of decline. In general very thin sands are short lived oil producers.

Is the sand hard and dense, or soft and porous? In the case of a hard and a soft producing sands of the same thickness, the hard sand will give a long lived, slow production, while the soft sand will give short lived but big initial production.

Does the sand carry water, or is it a "dry" sand? If it is water bearing, as is the usual case, oil will be found upon anticlinal folds according to the anticlinal theory. If the sand is dry, oil may be expected to lie in the synclines, the anticlines will probably be dry. Such a sand is seldom a good producer.

How deep does the oil horizon lie? Drilling costs increase very rapidly at depth; so if the producing horizon lies at a great depth, drilling should be confined to the best structural folds until the area has been proven.

Having investigated these points thoroughly, the geologist turns his attention to the surface structure as mapped or indicated in field work,- and the following questions arise:-

What is the regional dip? Knowing this, he knows in which direction the oil will migrate (up the dip), and on which side of the fold the oil will accumulate in the greatest quantities and over the greatest extent (this is of course the side which lies down the regional dip.

What is the size of the fold? (laterally) The greater area covered by it, the greater will be the area of probable production if sand conditions are normal, naturally.

What is the amount of reversal or complete closure of the fold? The greater the reversal and the greater the complete closure, the greater the resistance there will be offered to stop and hold the migrating oil, and thus the better are the chances for accumulation on the flank which lies on the down regional dip side.

What is the trend of the axis of the fold? A fold whose axis is normal to the regional dip (parallel to the regional strike) is much more favorable to oil accumulation than one which has its axis normal to the regional strike, in that the former presents a longer line of resistance to oil migration than the latter.

What is the shape of the fold? Is it an anticline, dome, terrace nose, or a combination of two or more of these? The student of structural geology will readily understand which of these, taking size into consideration are relatively the most favorable to oil accumulation. Also, does the axis curve against the direction of oil migration or with it? In the case of the former the greatest resistance is offered, naturally.

Is the fold symmetrical or asymmetrical? The axial plane of a fold is a surface which is the locus of all points on the sides of that fold, thus it is readily understood that in the case of the symmetrical fold, the axial plane will be vertical, and the axis at the depth of the oil horizon will be directly under that of the fold at the surface. However, in the case of the asymmetrical fold, the plane will be inclined in the direction of the more gently dipping flank, and the axis of the fold at depth will lie away from the axis at the surface and in the direction of the more gently dipping flank. This lateral distance may be computed approximately when the depth of the oil horizon from the surface is known. In the case of sharp crested folds of the asymmetrical type, the axial plane may be expected to curve back to some extent, thus lessening the lateral distance of "axis migration".

Axis migration is a rather important point to consider when locating tests upon asymmetrical undrilled folds.

The preceding system and order used in considering the factors which are influential in drawing conclusions has been found in practice to be the most logical, natural, and easy to follow consistently, and offers a simple system that may be used to quite an advantage in the work of the petroleum geologist.

The Report.

In petroleum work, the report should be just as concise and short as possible, yet include all points which may be of present or future importance. It is desirable that the separate subjects should be arranged in a standard order, so that any desired information relating to any one of these subjects may be found readily and quickly in future reference to the report.

The following order is suggested:-

Heading

General Description

Production

Geology

Beds

Structure

Recommendations.

The heading is printed in capitals, and indicates the location and type of work done,- such as --

REPORT ON THE GEOLOGY OF T 18 N, R 5 E, PAYNE COUNTY, OKLA.

(DETAIL)

The general description should include - relief, timbered or open, presence or absence of water for drilling purposes, condition of roads, and distance from shipping point on RR.

Production should include description of producing wells, their capacity and depth on or near the area examined. Dry holes, locations, rigs, or drilling operations should be reported here.

Geology is divided into two topics:-

First, a description of the beds worked with.

Second, a detailed description of structures of economic importance.

Recommendations come last, as is their natural order.

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*"Practical Oil Geology"--------------- Hager.

"Oil and Gas Production"-----Johnson, Huntley.

"Popular Oil Geology"--------- Victor Ziegler.

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Index

Index

Index

Index