A REFRACTION PROGRAM IN NORTHEASTERN BRITISH COLUMBIA

by

A. A. DENSMORE
Texas Gulf Sulphur Company

ABSTRACT

A refraction program was conducted in the mountainous area of Northeast British Columbia during the summer of 1969. The layout of the program is thought to be unique to this part of the world. The object was to attempt to increase the resolving power of the refraction method by recording from all four quarters. The schematic layout of the program and the operational problems connected with collecting the data are described, although interpretation results are not given.

INTRODUCTION

Texas Gulf Sulphur Company has conducted geophysical operations in the mountains of Northeast British Columbia during the three years up to 1969.

The program conducted during 1969 was designed in an attempt to cope with the topographic conditions encountered and to increase the resolving power of the refraction method.

GENERAL GEOLOGICAL GEOPHYSICAL PROBLEM

Sour gas production has been obtained from the Upper Triassic Formation in the area. The Triassic has taken part in gross folding and faulting somewhat as shown in Figure 1. The wave length of the folds is usually 5 or 6 times amplitude with amplitudes typically several thousands of feet. Thrust faults in the Triassic on eschelon occur near the tops of the gross folds. These thrusts often have reversals in the order of 1,500 feet. The configuration of the deeper formations is presumed to be more gentle. Thrusting within the Cretaceous above the Triassic is much more complex.

Surface geology indicates the strike and general locations of the gross features at depth. However, more accurate estimates of the locations of these structures are necessary when a drill site is required.

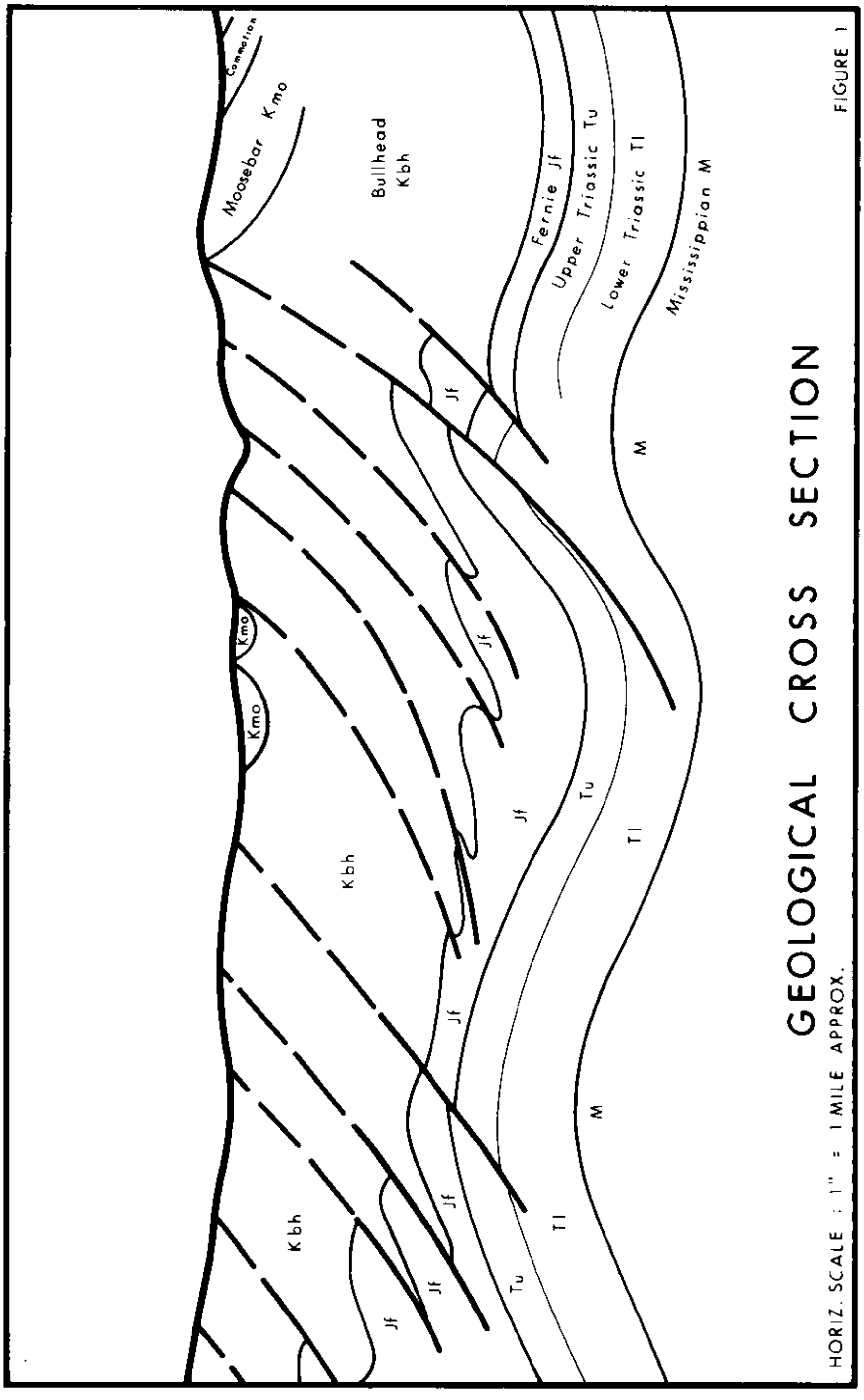


FIGURE 1

GEOLOGICAL CROSS SECTION

HORIZ. SCALE : 1" = 1 MILE APPROX.

GEOLOGICAL DESCRIPTION

Bullhead	5000' - 7000'	Interbedded shales, mudstones, coals, siltstones, sandstones, grits and conglomerates. The lower 2000' - 3000' contains a higher proportion of sandstones and quartzites and is generally not coal-bearing.
Fernie	850' - 2065'	Dark grey to brown and black shale, commonly sandy
Nordegg	50' - 200'	Black limestones and calcareous black shales with chert
Triassic		
Pardonnet	150' - 300'	Dark calcareous shales and siltstones with some limestone
Baldonnel	200' - 250'	Dolomite
Charlie Lake	1500' - 1700'	Dolomite and limestone with anhydrite. Also siltstone and sandstone
Halfway	1000' - 1600'	Sandstone, fine to medium grained, minor dolomite and dolomitic siltstone
Lower Triassic		
Toad - Grayling	1000' - 2700'?	Shales, siltstones, limestones, flagstones
Mississippian and Perma Penn	1000' - 1500'+	Limestone
Ordovician-Devonian	500' - 1000'	Shaley carbonates, calcareous, siltstone and shale

GEOPHYSICAL METHODS AVAILABLE

Reflection — Most of the accessible lines have been along river valleys and have produced poor reflection data because of the presence of alluvial fill. Good data has been recovered on one mountain trail and poor data on another. Sixty to 100 foot holes and charges of up to 200 pounds have been used. It was impractical to doze trails back into the mountains for access for conventional drills for reflection work.

Refraction — Our practice with this tool has been evolving. Initially conventional centre position broadside refraction techniques which outline the gross features were used. However, the resolution was limited so the techniques were modified. These modifications occurred at the same time that the program penetrated deeper into the wilderness of the mountains, essentially removed from roads and amenable topography.

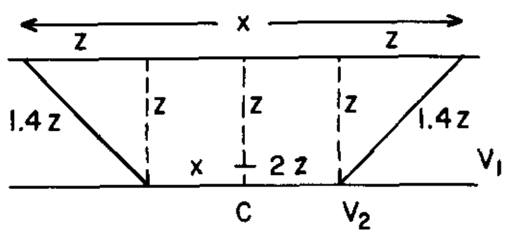
VELOCITY SURVEYS

Information from nearby wells indicated velocities in the Cretaceous of 14,000' to 16,000' per second down to top Nordegg. Below this the velocity is 20,000' per second. Essentially a two layer case exists, which gives a critical refraction angle close to 45°.

CONVENTIONAL CENTRE POSITION REFRACTION LAYOUT

R6	R5	R4	R3	R2	R1		
.	.	.	.	.	.		— Shooting Line
						C	— Middle Subsurface Position Line
. S5	. S4	. S3	. S2	. S1	.		— Spread Line

Spread S1 shot from R1 and R2
Spread S2 shot from R2 and R3 etc.



T—Total travel Time
V_1—14,000' per second
V_2—20,000' per second
i—45°

$$\text{Depth} = \frac{V_1 \left(T - \frac{x}{V_2}\right)}{2 \cos i}$$

$$\left(T - \frac{x}{V_2}\right) = \text{Delay time}$$

After suitable elevation corrections, the variation in depth z is proportional to the delay time $\left(T - \frac{x}{V_2}\right)$ and is plotted along the centre position line C.

OPTIMUM SHOOTING DISTANCE

The offset distance of the shooting line from the spread line must be estimated by anticipating the depths of the refractor in order to obtain second arrivals. Considering the topography and the mapped Triassic structures, the refractor depth varies from about 8,000 feet to about 16,000 feet. The minimum offset distance thus should be about 32,000 feet. Imposing the limitation of allowing the second arrival to approach no closer than .100 seconds to the first arrival, we have:

$$\frac{x}{15{,}000} + .100 = \frac{2.8z}{15{,}000} + \frac{x-2z}{20{,}000}$$

from which $x = 5.2z - 6000$

Thus, for the minimum expected refractor depth of 8,000, x = 5.2 x 8000 — 6000 = 35,600 feet. Therefore, the optimum shooting distance should lie between 32,000 and 35,600 feet. This is a very narrow range of shooting distances available for second arrival information. It was therefore hoped to be able to adapt to topographic conditions by shooting first arrival data.

LIMITS OF RESOLUTION IN MEASURING DEPTH USING REFRACTION

The gross outline of the large structures in the mountains can be mapped reasonably well. However, the accuracy involved in estimating plunge along any given thrust sheet from one broadside centre position refraction spread to another has been found to be only in the order of 10 to 15%.

The program was therefore designed to attempt to get a better idea of the plunge on a structure prior to locating a well.

LAYOUT OF REFRACTION PROGRAM

The layout of the program consisted of a set of pairs of parallel lines as shown in Figure 2. The members of each pair were spaced at the expected horizontal emergent distance of the refracted energy. The sets of pairs were spaced at twice the expected horizontal emergent energy distance. (Also see figure 3).

All lines were recorded from four quarters; two broadside and two in-line. The major advantages expected from this technique were:

1. Resolution for the refraction technique would be increased. For example, along strike the delay times line to line from a particular broadside shotpoint give a measure of the plunge of a structure. With the old method of single broadside lines and centre position estimates of depth to the refractor, the uncertainties from centre position to centre position line to line are the normal uncertainties attached to refraction measurements of depth — namely something in the order of 10 to 15%.

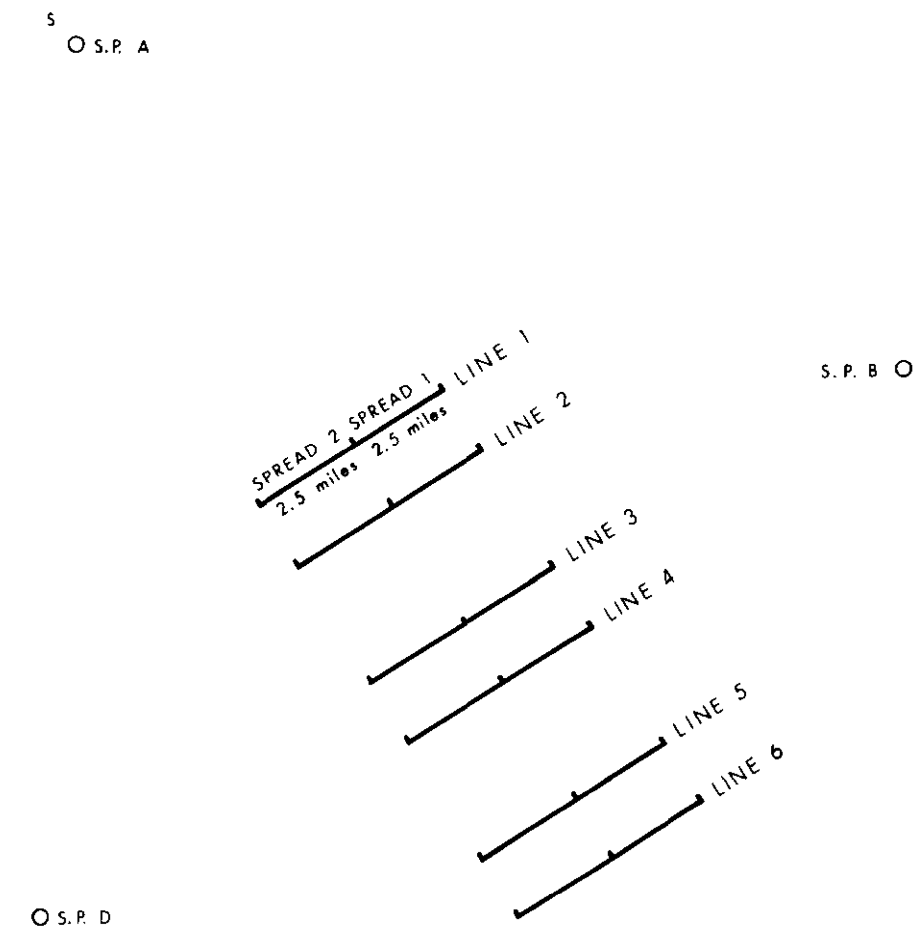
2. The advantages of being able to view a structure from four different sides.

3. The emergent data in effect yields greater subsurface coverage.

SPREAD AND HELIPORT CONFIGURATION

Initially 24 trace spreads of 600 foot interval were used with two trace overlap from spread to spread. Heliports were cut at intervals of 3,300 feet, as shown, such that at each heliport two linemen could be dropped in, each laying out 3 stations of the spread in either direction. The recorder was located at Stations 12, 34, 56, etc.

LAYOUT OF PROGRAM DESIGNED TO IMPROVE LIMITS OF RESOLUTION AND PROVIDE ITERATIVE DATA FROM FOUR QUARTERS



S.P. C

Broadsides from shot points A and C
In lines from shot points B and D
Shot points either mountain sloughs or drilled holes.

FIGURE 2

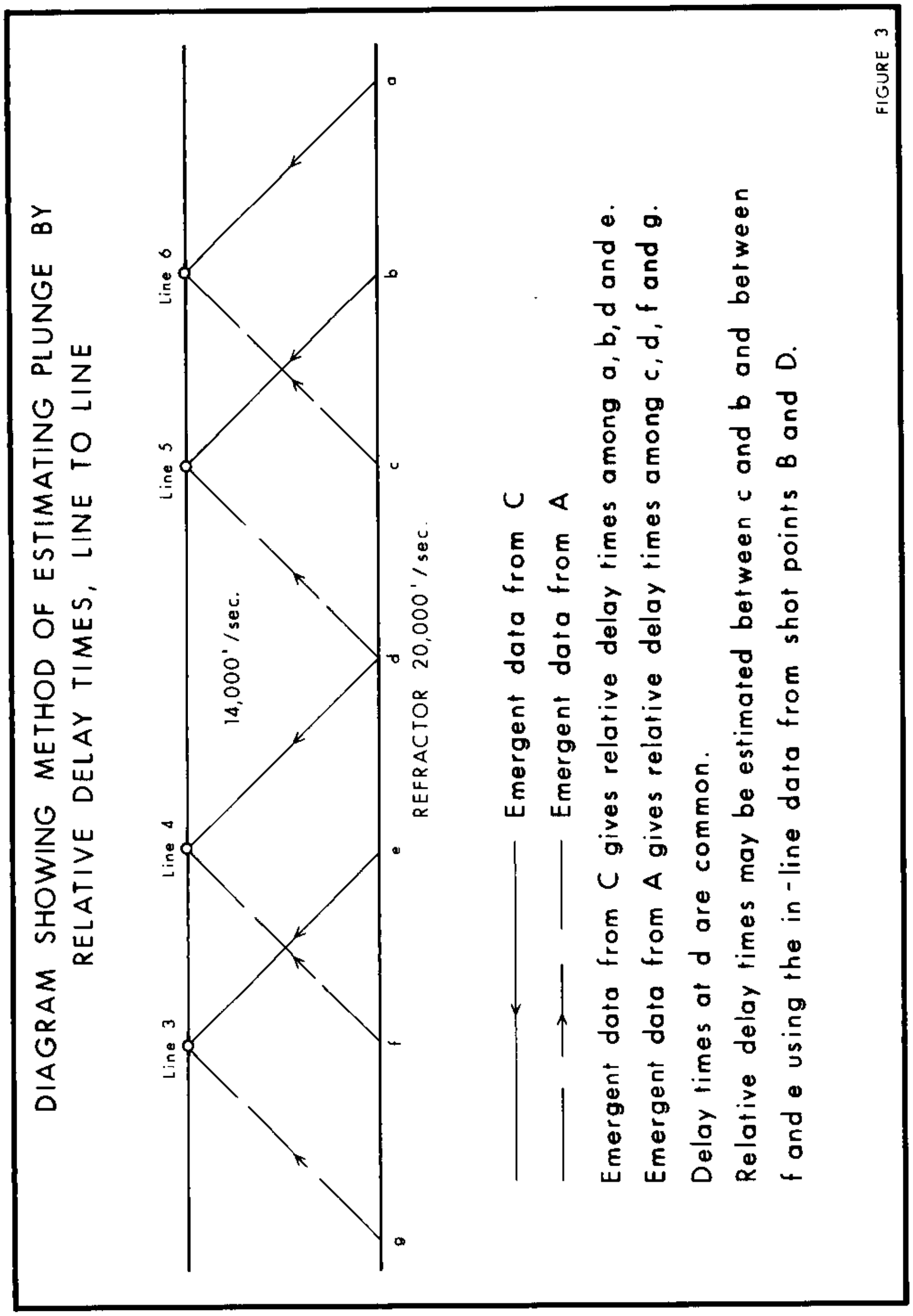
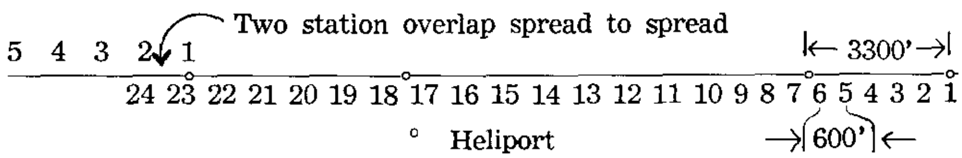


DIAGRAM SHOWING METHOD OF ESTIMATING PLUNGE BY RELATIVE DELAY TIMES, LINE TO LINE
Line 3
Line 4
Line 5
Line 6
14,000'/sec.
REFRACTOR 20,000'/sec.
g
f
e
d
c
b
a
Emergent data from C
Emergent data from A
Emergent data from C gives relative delay times among a, b, d and e.
Emergent data from A gives relative delay times among c, d, f and g.
Delay times at d are common.
Relative delay times may be estimated between c and b and between f and e using the in-line data from shot points B and D.

FIGURE 3



For each spread involving five heliports, two linemen were dropped into each of the three middle heliports, one into each of the two outside heliports. Each of the men layed out three stations and they met in pairs between the heliports. Communication was maintained with the recorder through a telephone line incorporated in the cable. The linemen carried hand phone units.

At night, the head lineman specified which men go to each heliport for a given spread and for the next spread. The operator kept track of line pick up through the telephone and informed the helicopter pilot by radio which linemen were ready for transfer to the next spread. In this way moves were coordinated from spread to spread. Moving the recorder and equipment generally required three trips. One to move the power supplies and amplifiers in a box on a sling, one to move the doghouse, and one to move the operator, assistant operator and aerials.

GEOPHONES, INSTRUMENT AND RECORDING

Geophones:

Four Minature A.S.J. 7 cycle lightweight refraction geophones per station were used placed in a 10 foot square configuration and connected in series. Because of the ruggedness of the topography, the size and number of geophones was limited such that a lineman could carry the cable and 12 geophones for 1,800 feet with reasonable dispatch.

Instrument and Recording:

A set of GS III amplifiers with an AM200 tape system was mounted in a heliportable wooden doghouse. In order to record long times on tape, a delay system was designed whereby the expected refraction energy could be recorded on the first, second or third pass of the tape. A variable delay was incorporated in order to take into account the 1.5 second gaps between rotations of the tape. In later processing of the data, the tape play outs, which contained no time break, had to be matched to the monitor in order to get total times. This was one of the weaknesses of this system. Also, it was found that this delay circuitry sometimes introduced spurious slashes across the tape recording. These slashes or cross talk sometimes occurred at crucial times, interfering with the refraction data itself. Fortunately in most instances this noise was highly attenuated in the monitor so we were able to transcord records, where necessary. Apparently the slash was caused by the radios. The tension on a relay in the delay circuitry seemed to be the problem. However, it kept recurring, so the basic design of the system was not satisfactory. It would be better to have a continuous tape recording of the data whereby the time break and refraction data may be recorded on the same pass of the tape. Digital recording would obviate this problem.

A more practical approach would be to avoid using tape at all and carry a portable instrument inside the helicopter rather than in a doghouse which requires slinging. This system would also have the advantage of allowing ease of transportation of instruments back to camp each night to keep the instruments warm.

ENERGY SOURCES

Initially the plan had been to record first arrival refraction energy from dynamite charges in drilled holes, such holes to be drilled in positions accessible to conventional rigs. This involved recording distances up to 40 miles. These locations were in positions near roads and consisted of 130 foot holes loaded with 200 pounds. The size of the charge was much too low for most of these positions.

Following initial experimentation and discovering no energy return from most of the drilled positions, powder was flown to a slough in the mountains, approximately 15 miles from a position broadside to our initial test line. A charge of 1000 pounds produced the required refraction energy.

At these sloughs the shooters rowed out with a load of charge and lowered it into the water. During the firing of the charge, the shooter would locate himself such that ground was between him and the charge, i.e. behind a gentle rise of ground and usually greater than 300 feet from the charge. The helicopter, if present, would lift off to a perch usually higher up on a mountain where he would be safe from the blast. Characteristically the charge would funnel upwards several hundred feet.

There were no fish in these sloughs. The Department of Fisheries had given permission to fire the first test shot on the understanding that a dead fish count would be reported. This figure was equal to zero, so we were allowed to proceed.

The advantages to shooting dynamite in these sloughs were as follows:

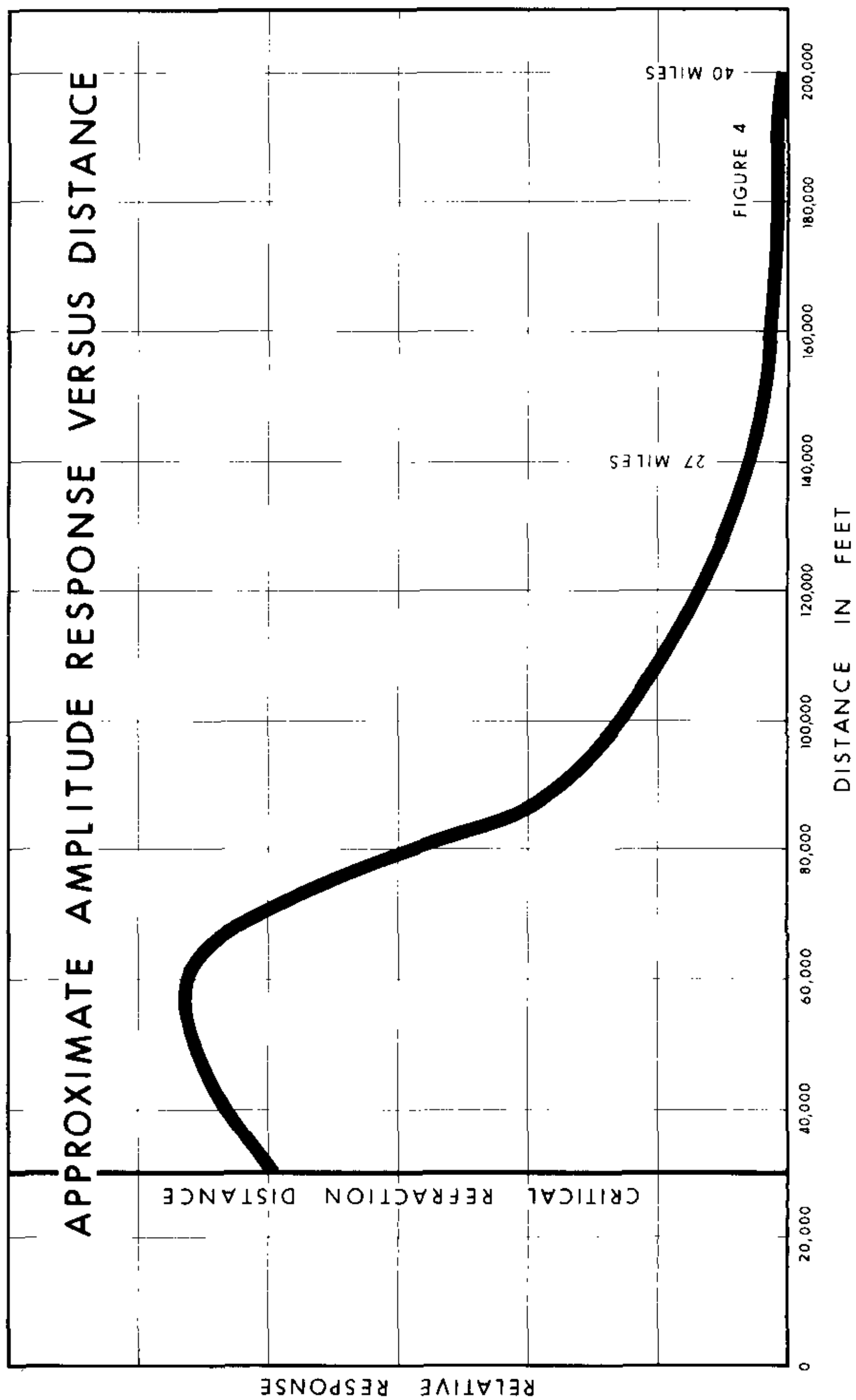
1. A tamp for the charge was provided.
2. The danger from fire caused by firing a charge was reduced.
3. Air blast was reduced.

The disadvantage was that the cost compared with nitro prills was much higher.

Had nitro prills been used in order to keep the cost minimized, the prills would have had to have been mixed with diesel fuel in essentially exact proportions and fired in dry circumstances. The volume and weights of the fertilizer as compared with dynamite were in the same order of magnitude.

However, considering the factors of tamp and danger from fire, and the experience of the shooters, the decision was to use dynamite.

In one portion of the area, energy sources were available sloughs from two quarters and holes from the other two quarters. In another portion


APPROXIMATE AMPLITUDE RESPONSE VERSUS DISTANCE
FIGURE 4
40 MILES
27 MILES
CRITICAL REFRACTION DISTANCE
RELATIVE RESPONSE
DISTANCE IN FEET
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000

only three quarters were used — two broadside and one updip in-line; one broadside and the in-line from lakes, and the other broadside from holes. Charges up to 2,000 pounds in the holes were used for distances in the order of 27 miles. From the sloughs, we found that charges of 1,000 pounds were satisfactory for distances 10 to 15 miles.

Although the initial intention was to record only first arrival data, because of the above mentioned problems in getting energy over such long distances, we settled for second arrivals in some instances and first arrivals in others.

The optimum distances for recording refraction data seems to be in the range of 10 to 20 miles. The data which was recorded from 27 miles was so weak and highly attenuated with respect to the higher frequencies that it was considered next to useless. (See Figure 4).

In general the best records came from the broadsides along strike with the structures and the in-lines from the southwest, or updip side. The in-lines from the northeast or downdip quarter were poor, probably because the energy was dissipated into a diverging geologic section. These last mentioned records from the northeast were very low frequency and showed only the very gross outline of the structure.

RADIO COMMUNICATION

This was found to be the most important factor relating to the efficiency of the operation. Several dry runs with caps were required to reach satisfactory communication conditions prior to firing the charge.

Satisfactory communications were obtained using the single side band CH25 radios. The 4300 KC frequency proved better than the 1652 KC frequency.

This arrangement proved the most satisfactory because of the large number of pairs of positions between which we required satisfactory communications.

A very high frequency configuration could have proved too impractical because of the topography. A suggested repeater station in a helicopter, although possible and practical, would apparently have required prolonged negotiations for licencing.

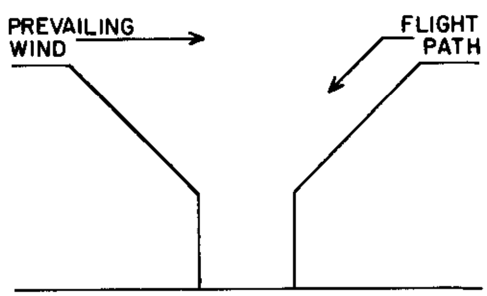
It was felt that, next to weather, radio communications affected the production rate by the largest amount.

The direction of aerial, breaks in the aerial from constant moves, and connections of the balun boxes proved to be the important facets of the radio set-ups.

SURVEYING AND LINE CUTTING

A point on each line was located using a topographic map. A helicopter with surveyor and a line cutter was dropped into an accessible clearing at or near a point on the proposed line. If the helicopter couldn't get down, the line cutter was lowered down with an axe in a very nearly clear area and cut out enough brush for a landing space. The surveyor used a theodolite to give an azimuth for the line, putting in three bearing pins spaced at about 50 yards along the azimuthal line so established. A six man line cutting crew was flown in in pairs and commenced cutting along the line, in line with the three stakes. Subsequently, a chaining crew followed and checked the straightness of the line using a theodolite and established another bearing pin along the newly cut line in line with the original three azimuthal stakes; and so on along the line. The hand cut line was cut about 5 feet wide so that cable laying linemen could easily walk without being encumbered by fallen timbers and underbrush, and such that all clean-up requirements of the B.C. forestry service were satisfied at the cutting stage. Heliports were cut every 3,300 feet along the line and were about 150 feet diameter. Underbrush was cleared right to the ground over a large portion of the centre of these heliports (100 feet diameter or so) in order to provide absolute clearance for the tail rotor of the helicopter. The remaining fringe area was cut low in the order of 2 feet or so. Away from the boundaries of the heliports, tall trees were removed in order to facilitate flight paths along the prevailing wind direction.

There were, of course, variations in these conditions from heliport to heliport, and also variations in the attitude of individual helicopter pilots towards the adequacy of each of the clearings. As an example, one pilot would have preferred much longer flight path clearings into the wind. There were also variations in the wind conditions which contributed to the ease of landing in these heliports. The heliports were cut approximately as shown in an attempt to avoid turbulence caused by the funnelling effect.



This design also gave a bit of a flight path, with the preferred direction along the line of the prevailing winds.

A chaining crew and a survey crew were employed in surveying the lines and keeping the line cutting straight during the line cutting phase of the operation. These men also surveyed in the original shot holes which had been located and drilled in the accessible locations. The lines were surveyed initially as an approximate position from a topographic map. At a later date, a tellurometer was used to give a fix on each of the lines, at the drilled shotpoints and at the sloughs. These shots were taken from Geodetic Bench Marks in the mountains.

LINE CUTTERS

A crew of 18 Indians from the Slave Lake area were employed for this work. Most of them had been trained for fire fighting duties in the forest as well as for cutting line. They worked in two line cutting crews of six each, and one heliport cutting crew of four men. The remaining two Indians were the cook and foreman. Eighteen men were required at all times to complete the line cutting.

The intention had originally been to have the line cutters camp along the line during the work and thus minimize air lift costs. However, in the early summer, there was dry weather and a high forest fire hazard. The Forestry ordered the line cutting crew camps out of the forest, but allowed them to continue working 1:00 PM to sundown. These conditions prevailed throughout one part of the project. It was felt that prior to the fire hazard period the use of the helicopter was justified because of the long travel times to and from work from the fly camps to the line. It would take the Indians about 4 out of 8 to 10 hours per day to where they were cutting and back again at night. For future work a coot (small wheeled vehicle) may work for transferring camp as line is being cut.

Following their expulsion from the cut lines, all workers camped near the highway.

HELICOPTERS

The single largest worry of the operation with respect to safety was the helicopter phase of the work. A Hiller 12E was used during the line cutting phase and an FH 1100 for the recording phase of the operation.

During the line cutting a 12E burned up. Apparently its motor stopped after take off from a heliport; it autorotated back into the heliport, turned over and burned. The pilot, surveyor, and linecutter escaped unhurt.

On another occasion during the line cutting phase, a linecutter walked into the tail rotor of the helicopter and badly mangled his hard hat.

During the recording phase an FH 1100 was written off. One of the skids slipped under a small rock ledge as the helicopter settled its full weight upon the spreading skids. Upon lifting off, with one skid caught under a ledge, the helicopter was turned over. The pilot was unhurt and the helicopter did not burn.

CONCLUSION

The greatest advantage to this layout of program was the ability to see gross features from four different directions. The updip in-line data gave a better idea of the shape of the back side of a structure than did the broadside information which is often distorted in shape because of geometry.

The anticipated advantages with respect to increasing the resolving power along the plunge of a structure were not quite so great as had been hoped for, because it was physically impossible to record all lines from one source from each direction.

ACKNOWLEDGMENT

The author wishes to thank Mr. H. L. Bowman who suggested the use of this program layout, and the Texas Gulf Sulphur Company and Sun Oil Company for permission to publish this paper.