positive indicator of the possible presence of economic deposits of detrital tin.

Elements of the generalised stratigraphic sequence mapped off Malaysia can also be identified in the unconsolidated sediment sequences revealed by seismic profiles from eastern Australia and from Korea. .

WHAT IS THE FUTURE FOR SEISMIC REFRACTION METHODS?

Derecke Palmer

Geological Survey of New South Wales (02-231 0922)

WHAT IS THE STATE OF THE ART?

Instrumentation is advanced

Historically, seismic refraction instrumentation has usually been equivalent to that which existed ten to twenty years previously in the seismic reflection industry. Accordingly, it is encouraging but not unexpected to see data acquisition units with stackers and digital recorders becoming more common. Twelve channel units have superseded single channel units as the most commonly purchased units.

Interpretation theory is stagnant

The most commonly used methods of

i) the intercept time method (Ewing, Woollard and Vine, 1939; Dooley, 1952; Adachi, 1954; Mota, 1954).
ii) the critical distance method (Heiland, 1940, p. 527)
iii) the reciprocal method (Hagiwara and Omote, 1939; Hawkins, 1961)
iv) the delay time method (Gardner, 1939, 1967; Barry, 1967)
v) the wavefront method (Thornburgh, 1930; Rockwell, 1967)

were all first published before the last war and have not changed significantly since then.

There have not been any significant advances on the problem of hidden layers (Maillet and Bazerque, 1931, p. 314; Hawkins and Maggs, 1961; Merrick, Odins and Greenhalgh, 1978), or the routine use of amplitudes and attenuation measurements.

Recently, the literature has been obsessed with a "comprehensive review" mentality, which is backward, rather than forward looking and which duplicates text books such as Dobrin (1976). Furthermore, in some cases, these catalogue type of papers have tended to confuse rather than clarify.

I believe there exists a forty year difference between refraction instrumentation and interpretation.

Management is poor

The present deplorable state of the seismic refraction method can be assigned to failure to employ basic management techniques.

Quality control is non-existent. Most geophysical techniques use the presentation of basic field data as a method of quality control. Although there has been an improvement in recent years, it is still the exception, rather than the rule to see the presentation to travel time curves for a seismic refraction profile. As a result, field and interpretation methods have drifted towards mediocrity.

It is commonly asserted that costs preclude the presentation of any thing except the final depth section. However, there has not been any serious attempt to separate the cost centres of data processing from interpretation. Data processing can be isolated and computerised, thereby resulting in lower costs and facilitating presentation of basic data.

Because it is rarely possible to follow an interpretation from the travel time curves to the final depth section, the dissemination of expertise has simply not occurred. At the present time, there exists a handful of experts, without the means and possibly the inclination to communicate their knowledge to the geophysical community at large. Unfortunately, debate and critical analysis, which are fundamental requirements for scientific advancement are not facilitated, and do not occur.

Is it any wonder that a method which has shown little real advancement in forty years, has no accepted methods of quality control, and no ways of disseminating expertise is slowly fading into the dreamtime?

WHAT CAN THE GRM OFFER?

Definition of irregular refractors at any depth

The generalised reciprocal method (GRM), (Palmer, 1974; Palmer, in prep.) is a method of processing and interpreting in-line seismic refraction data consisting of forward and reverse travel times. It combines the computational conveniences of the conventional reciprocal method with the migration properties of the delay time method.

The arrival times at two geophone positions, separated by a variable distance XY, are used in refractor velocity analysis and time-depth calculations. At the optimum XY separation, which is taken as occurring when the refractor velocity analysis and time-depths are the most detailed, the rays to each geophone emerge from near the same point on the refractor.

The GRM can define and accommodate irregular layers at any depth, multilayered overburdens and layers with velocity gradients.

Hidden layers can be detected and accommodated

The presence of undetected layers can be inferred when the observed optimum XY value differs from that derived from the computed depth section.

The optimum XY value can be used to form an average velocity which permits accurate depth calculations with commonly encountered velocity contrasts.

Data processing preceeds and is independent of interpretation

The GRM permits recognition and separation of the two cost centres of data processing and interpretation. Therefore processing can be carried out by non-specialised personnel, processing centres, or by computer, but the geophysicist maintains control of the interpretation. In fact, the geophysicist has more time for interpretation and so an increase in quality and productivity usually result.

Furthermore, the GRM permits processing to be carried out before interpretation. Therefore, one set of processing is usually sufficient for many attempts at interpretation and so the time and costs of reprocessing with each new interpretation are avoided.

SEISSF is the computer program based on the GRM

The GRM is not an iterative method, and hence does not need computers for accuracy. However, as there are large numbers of calculations involving a few simple arithmetic operations, computers and plotters can be invaluable in saving time in processing.

SEISSF (Hatherly, 1976) is the computer program based on the GRM. It permits quick and accurate calculation of processed data, and these, together with the original data, are accurately drafted with a flat bed plotted.

It does not make an interpretation. That is the geophysicists' job.

The plot is of sufficient quality to be used in final reports, and usually the interpretation is marked on the plots. This allows the client to conveniently assess the quality of the field work and interpretation; as well as facilitating re-evaluation in the light of additional information.

The computer plots are arranged so that interpretation flows from the top of the plot to the bottom. The supervisor can easily monitor progress of a project.

A major advantage of the presentation is that it helps rapid instruction of the beginner in the theory and practice of interpretation.

THE FUTURE IS AN EFFECTIVELY MANAGED HIGH QUALITY PRODUCT

IFP 48 trace equipment is desireable

The realisation of a superior product will involve the progression from simple first event studies to digital processing of the complete signal. Seismic refraction instruments need IFP recording, because signals can vary greatly from trace to trace, i.e. with distance, as well as with time.

Studies with the GRM have shown that close geophone spacings are desirable, and that existing 24 channel units do not provide enough coverage.

Concentration is the key to excellence

Many methods of seismic refraction interpretation, are either special cases, or very similar to the GRM. Under favourable circumstances, it can solve the hidden layer problem, whereas existing methods simply give maximum erros. Furthermore, it can conveniently define and accommodate very irregular layers, even with overburdens with velocity gradients. Accordingly the GRM is capable of becoming the most widely used refraction interpretation method, and provides a means of escaping the cataloguing and compreshensive review mentality.

Concentrating on the GRM also constitutes sound management practice. The words of Peter Drucker (1964), "Concentration if the key to economic results . . . . . . no other principal of effectiveness is violated as constantly as the basic principle of concentration . . . . . . Our motto seems to be: 'Let's do a little bit of everything' " apply to scientific achievement as well as economic performance.

Quality control and critical analysis are essential

Without quality control and critical analysis, the seismic refraction method will continue to stagnate in the hands of a few witch doctors.

With adequate quality control and avenues for critical analysis dissatisfied clients can become informed and more likely to give a second chance. Furthermore, conveniently presented data facilitate scientific debate, which is essential for the health of any method.

The use of SEISSF in routine processing can result in significant time and cost savings, as well as providing a means of quality control and a product capable of critical analysis.

References

ADACHI, R., 1954. On a proof of fundamental formula concerning refraction method of geophysical prospecting and some remarks. *Kumamoto Jour. Sci., Vol. 2, p. 18-23.*

BARRY, K. M., 1967. Delay time and its application to refraction profile interpretation. *Seismic Refraction Prospecting, (ed. A. W. Musgrave), Society of Exploration Geophysicists, Tulsa, P. 348-361.*

DOBRIN, M.B., 1976. Introduction to geophysical prospecting. *McGra McGraw-Hill Book Company, New York, 3rd edition.*

DOOLEY, J. C., 1952. Calculation of depth and dip of several layers by seismic refraction methods. *Australian Bureau of Mineral Resources, Geology and Geophysics, Bull. 19, Appendix, 9p.*

DRUCKER, P., 1964. Managing for results. *Harper and Row.*

EWING, M., WOOLLARD, G. P., and VINE, A. C., 1939. Geophysical investigations in the emerged and submerged Atlantic Coastal Plain, Part 3, Barnegat Bay, New Jersey section. *Geol. Soc. America Bull., Vol. 50, no. 2, p. 257-296.*

GARDNER, L. W., 1939. An areal plan of mapping subsurface structure by refraction shooting. *Geophysics, vol. 4, p. 247-259.*

1967. Refraction seismograph profile interpretation. *Seismic Refraction Prospecting, (ed. A.W. Musgrave), Society of Exploration Geophysicists, Tulsa, p. 338-347.*

HAGIWARA, T., and OMOTE, S., 1939. Land creep at Mt. Tuausu-Yama (Determination of slip plane by seismic prospecting). *Tokyo Univ. Earthquake Research Inst. Bull., vol. 17, no. 1, p. 118-137.*

HATHERLY, P. J., 1976. A Fortran IV program for the reduction and plotting of seismic refraction data using the generalised reciprocal method. *Rep. geol. Surv. of N.S.W., GS1976/236, (unpubl).*

HAWKINS, L. V., 1961. The reciprocal method of routine shallow seismic refraction investigations. *Geophysics, vol. 26, p. 806-819.*

, and MAGGS, D., 1961. Nomograms for determining maximum errors and limiting conditions in seismic refraction surveys with a blind-zone problem. *Geophysical Prospecting vol. 9, p. 526-532.*

HEILAND, C. A., 1940. Geophysical exploration. *Prentice-Hall Inc., New York.*

MAILLET, R., and BAZERQUE, J., 1931. La prospection seismique du sous-sol. *Annales des Mines, vol. 25, p. 1035-1053.*

MERRICK, N.P., ODINS, J.A., and GREENHALGH, S. A., 1978. A blind zone solution to the problem of hidden layers within a sequence of horizontal or dipping refractors. *Geophysical Prospecting, Vol. 26, p. 703-721.*

MOTA, L., 1954. Determination of dip and depths of geological layers by the seismic refraction method. *Geophysics, vol. 19, p. 242-254.*

PALMER, D. 1974. An application of the time section in shallow seismic refraction studies. *M. Sc. thesis, Univ. of Sydney, 157p., (unpubl.).*

, (in prep.). The generalised reciprocal method of seismic refraction interpretation. *Monograph, Society of Exploration Geophysicists, Tulsa, (in prep.).*

ROCKWELL, D. W., 1967. A general wavefront method. *Seismic Refraction Prospecting (ed. A. W. Musgrave) Society of Exploration Geophysicists p. 363-415.*

THORNBURGH, H. R., 1930. Wavefront diagrams in seismic interpretation. *Bull. AAPG, vol. 14, p. 185-200.*

COMPUTER PROCESSING OF SEISMIC REFRACTION DATA

P. J. Hatherly

Geological Survey of N.S.W. (02-231 0922)

In the generalised reciprocal method (GRM) of seismic refraction interpretation described by Palmer (1974, in prep.), the data processing and interpretation stages may be separated. The data processing stage is relatively simple but as it may involve handling considerable amounts of data, the use of a computer is desirable. In this paper some methods for the computer processing of seismic refraction data are discussed.

The data processing stage may be broken up into four main areas which involve:

1. Picking first arrival times
2. Making up hole and reciprocal time corrections
3. Calculation of time depth and velocity analysis terms
4. Calculation of a depth section from the interpreted time section.

A suite of Fortran programs have been developed to automatically process the seismic data in each of these stages. Field data is written onto magnetic tape using an S.I.E. RS49R seismic system and these tapes are then read, and the data processed and plotted using a PDP11/45 computer and Calcomp 563 and 745 plotters.

First Arrival Times

The first arrival time is usually defined by the first noticeable onset of seismic energy. Two complementary methods have been developed which pick this time very accurately. The methods are applied to individual traces and use the statistical properties of the noise prior to the shot instant to identify the noise after the shot. The seismic event is recognised as it has different statistical properties to the noise. Events may be picked even if their amplitudes are less than those of the noise. Such very early events can not be picked on a conventional seismogram and it has been found that the automatically picked arrival times are much more accurate than hand picked times.

Computer program SFA picks the seismic first arrivals which are plotted and stored in disc files. Up to 6% of the automatically picked times may be in error through crossfeed between the traces, geophones being disconnected, there being insufficient signal or through a failing in the automatic picking method. A program has been written for editing these bad picks.

Up Hole and Reciprocal Time Corrections

As in most interpretation methods, up hole corrections are made in the GRM. These can be simply made through using the time to an up hole geophone or by assigning a velocity to the surface layers.

The reciprocal time is the travel time between pairs of shots. In theory the two times between shot points should be equal but often this is not the case. The times may not be equal because of:

(1) The ground near the shot points being disturbed by previous shooting
(2) Delays in either the shooting system or in the detonator.
(3) Poorly picked arrival times
(4) Errors in the up hole corrections.

Ground factors such as anisotropy may also be a source of error.

Constant corrections are made to the times from each shot so that the reciprocal times agree in a least squares sense. The sum of the corrections is minimised and usually these corrections will be less than 2 milliseconds per shot. Both the up hole and reciprocal time corrections are made by program ADJUST.

The Velocity Analysis and Time Section

For nominated pairs of shots, computer program SEISSF (Hatherly, 1976) calculates velocity analysis terms and time depths using various XY spacings. Together with the travel time curves, these data represent all that is needed for the geophysicist to make an interpretation using the GRM. For convenience, these data are plotted at a useful scale beneath the travel time curves.

The Depth Section

For the conversion of time depths to depths an adaptation of the formula given by Dobrin (1976) is used. However, the depths calculated are not vertical depths but are instead the layer thickness measured perpendicular to the underlying refractor. For undulating or dipping refractors, the layer thickness is different from the vertical thickness and a migrated depth section should be constructed.

Computer program DSECTN (Hatherly, 1979) calculates and plots the depth section. It establishes arcs of radius equal to the layer thickness and the evelope of these arcs defines the refracting surface. The program uses the tangents between neighbouring arcs to give this envelope.

Often it is found that successive arcs do not intersect or give most unrealistic refractor surfaces. These unlikely arcs indicate the presence of errors in either the time depths or