Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

THE MICROSEISMIC MONITORING SYSTEM AT THE CAMBORNE SCHOOL OF MINES, GEOTHERMAL ENERGY PROJECT, ROSEMANOWES QUARRY, CORNWALL, U.K.

John E. Udd

Mining Research Laboratories

February 1987

MINING RESEARCH LABORATORIES
DIVISION REPORT MRL 87-24 (TR) c.2

THE MICROSEISMIC MONITORING SYSTEM
AT THE CAMBORNE SCHOOL OF MINES, GEOTHERMAL ENERGY PROJECT,
ROSEMANOWES QUARRY, CORNWALL, U.K.

by

John E. Udd*

ABSTRACT

One of the most sophisticated microseismic monitoring systems in the world is installed at the Camborne School of Mines Geothermal Energy Project site at Rosemanowes Quarry, near Camborne, Cornwall, U.K. The system was installed to permit accurate mapping of the propagation of fractures induced around energy recovery wells drilled into a naturally-heated rock mass. The fractures were induced in order to create an underground reservoir of fractured rock which would serve as a heat exchanger. The efficiency of the system is very much dependent upon the accuracy with which the reservoir is created.

This report presents an overview of the project and the details of the microseismic monitoring system. These were obtained during a visit to the site on September 4, 1986.

---

*Director, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Keywords

Microseismic, Monitoring, Geothermal, Hydrofracturing, Cornwall, United Kingdom

LE RESEAU DE SURVEILLANCE MICROSISMIQUE DE LA CAMBORNE SCHOOL OF MINES, PROJET SUR L'ENERGIE GEOTHERMIQUE CARRIERE ROSEMANOWES, CORNOUAILLES, R.-U.

par

John E. Udd*

RESUME

L'un des réseaux de surveillance microsismique les plus évolués au monde est installé dans la carrière Rosemanowes près de Camborne (Cornouailles) R.-U., à l'emplacement du projet sur l'énergie géothermique de la Camborne School of Mines. Le réseau a été installé afin de permettre une cartographie précise de la propagation des fractures autour des puits de récupération d'énergie forés dans une masse rocheuse naturellement chauffée. Les fractures ont été produites pour créer un réservoir souterrain de roche fracturée qui servirait d'échangeur de chaleur. L'efficacité du système dépend dans une large mesure de la précision avec laquelle le réservoir est créé.

Ce rapport présente une vue d'ensemble du projet et les particularités du réseau de surveillance microsismique, telles qu'obtenues lors d'une visite à l'emplacement le 4 septembre 1986.

---

*Directeur, Laboratoires de recherche minière, Le Centre canadien de la technologie des minéraux et de l'énergie (CANMET), Energie, Mines et Ressources Canada, Ottawa (Ontario).

Keywords

Microsismique, surveillance, géothermique, fracturation hydraulique, Cornouailles, Royaume-Uni.

TABLE OF CONTENTS

APPENDIX

FIGURES

BACKGROUND

The energy crisis of the past few years, caused by rapid rises in the price of oil and subsequent market instabilities, have caused many nations to explore the possibilities of finding alternative sources of supply. The efforts have been particularly serious in countries which are lacking or limited in sources of fossil fuels, or which would be confronted by serious balance of payments problems as the result of purchases of imported energy.

Where geological conditions are favourable, principally in volcanic regions, consideration is being given to the recovery of heat stored in the earth's crust. Very large quantities of heat may be potentially recoverable in the regions of the boundaries between the earth's crustal plates. In these regions, heated rock masses are more easily accessible. Drilling of heat recovery wells to greater depths, however, would result in much more heat energy becoming available.

A pilot project, to determine the feasibility of creating an underground heat exchanger in a heated crystalline rock mass at a depth of almost 2000 m was initiated in the U.K. in 1973. The site selected was the abandoned Rosemanowes granite quarry, near Camborne, in Cornwall. At this location, near the centre of the Carnmenellis granite mass, the heat flow (120 m W/m^2) is about twice the national average. At a depth of 2000 m, the ambient temperature of the crystalline rock mass is 80°C.

The concept, then, was that two wells would be drilled fairly close together to a depth of about 2000 m. After inducing a fractured reservoir at a depth between the two wells, heat would be recovered from water pumped through the system. The flow of water would be such that the source of heat at depth would be more-or-less self regenerating.

The objective of the project was to develop the technology which could be used subsequently to develop a full-scale production system. In such a system, it was visualized that wells would be drilled to depths as great as 6000 m, at which depth the heat of the rock mass is said to be 230°C. It was estimated that the temperature of water recovered would be about 180°C.

The ultimate success or failure of the project would depend on the accuracies with which the wells could be drilled, and the successful creation of an underground reservoir of fractured rock. Both pose tremendous technical challenges.

EVOLUTION OF THE PROJECT TO DATE

During the period 1976 - 1980 an experimental system, consisting of four wells drilled to depths of 300 m, was developed. In 1980 the second phase of the project, invloving the drilling of injection and recovery wells, to depths of 2000 m, was begun. With a separation of 350 m between the wells in the underground reservoir region, the wells were completed near the end of 1981. The drilling operations were much more successful that originally visualized and were considered to have been very successful.

After the casing of the holes to the top of the planned reservoir, there then followed a period during which the rock mass at depth was fractured. This was achieved by detonating explosives to stimulate fracturing, followed by the injection of water under high pressure to cause hydrofracturing. Pumping commenced during the summer of 1982 and was continued until about mid 1983. A major problem which occured, however, was that most of the water which was injected (about two-thirds) was never recovered. It was thought that this very large quantity lost had been consumed by filling the cracks which were created.

In the latter half of 1984 a new well was drilled to cut the fractured area which had been located through microseismic monitoring. The idea was to determine the extent to which permeability had been increased due to hydrofracturing. While the results indicated that the previous injections had indeed, created a large reservoir of fractured rock, the permeability of the rock was still not adequate for a long term production test.

Consequently, in July 1985, the largest hydraulic fracturing operation ever attempted in Europe took place. During an 8 hour period, on July 4, water was injected at the rate of 200 ℓ/s (or 75 bbl/min). In August, 1985, the system was put into production. The production trials are continuing.

An isometric view of the concept and a photograph of the surface installations are shown in Fig. 1 and 2, respectively.

THE MICROSEISMIC MONITORING SYSTEM

Throughout the peroid of injection, it was essential to know if hydrofracturing would be successful in creating the reservoir of fractured rock mass which would be vital to the success of the concept. Even though the orientations of the jointing at depth were known, and the directions in which fracturing would proceed could be predicted with reasonable certainty, it was necessary to have some means of monitoring the rate and the extent to which the rock mass was being fractured. A very sophisticated system, perhaps the most sophisticated in the world, in fact, was installed for this purpose. The cost has been estimated in the millions of dollars (perhaps of the order of $1 million to $2 million Canadian).

The system design follows a local area monitoring approach. In Canadian mining monitoring terminology, it would be described as an "out-of-mine local area" seismic monitoring system.

The sensors of the monitoring grid consist of accelerometers mounted near the surface in short boreholes and hydrophones installed in the wells. The former, cemented into boreholes 200 m deep, are located from 2 km to 3 km from the centre of the grid, and about 3 km from the underground reservoir of fractured rock. The latter are required to constrain solutions for locations of seismic sources. It was mentioned that reliance upon a system composed entirely of sensors mounted near the surface would result in problems of locating the depths of sources of seismic emissions.

The accelerometers used in the Camborne system are high-gain single vertical sensors with a sensitivity of 1000 v/g. The technical specifications given were: frequency range of 0-1 khz; $\pm$ 0.5 db band width; gain of 5; resolution of 2 μg noise.

There are, at present, six such sensors being used at the quarry. The locations are as shown in Fig. 1.

The hydrophones are mounted in a string; 2 km long, in one of the boreholes. Regular core-logging cable is used to lower and raise the string. It was also mentioned that the hydrophones have a dynamic range of 55db and may be left in place for up to 4 to 5 months at a time under ambient temperatures of from 80°C to 90°C. The locations are also shown in Fig. 1.

On the surface, a UHFM telemetry system, which matches the sensors, is used to transmit the data to the location of the computer. The band width of the transmitting system was given as being up to 4KHz.

A DEC VAX 11/780, located on the site is dedicated to real-time analysis of seismic data and other scientific and engineering functions. The computing system includes an array processor and a Datalab digitizer, It was said that the latter normally samples 8,000 samples but can handle up to 16,000. Vertical resolution was given as 10 bits. A view of the seismic monitoring station is shown in Fig. 3.

Data display facilities at the site represented state-of-the-art technology and are very impressive. These include: a Ramtek 4115 unit, with local memory for frame displays; a number of small computers; and several display screens. The system is designed so that all of the data analysis may be done from any terminal located in the building. Two views of some of the equipment are given in Figs. 4 and 5. An example of how results may be displayed on-screen is shown in Fig. 6. All of the results may also be produced, equally impressively, in hard-copy form.

METHODS OF DATA ANALYSIS

The system has been designed so that data can be acquired and analyzed on a real-time basis. All of the data which meets criteria for acceptance is stored by the VAX onto disks. It was mentioned that the only time that the system is really "down" is when their data storage operation is in progress.

When data is received from the various transmitters, the pre-set threshold value determines whether it is accepted or not. After this criterion has been met, the primary tasks become those of digitizing and storing the data. Calculations follow once this has been done. The preservation of complete data is assigned a very high priority in the logic which underlies the system.

Between acquisitions of data, the system is programmed to examine the events not yet analyzed, or the most recent if there is no backlog. In any event, analysis is almost on a "real-time" basis.

At Camborne, as elsewhere, the calculation algorithm is based on an adequate number of first arrivals at the sensors within a certain time. At Camborne, the time "window" is set at 90 ms. This was established, in the conventional way, after considering the sonic velocities in the local rocks and the distance involved.

During the calculation phase, an examination is made of the data from the event. If an acceptable number of onsets have been recorded the data is analyzed and displayed. The analyses are very sophisticated in comparison with Canadian mine monitoring practices. In addition to the "normal" calculations of determine the location of a source and the energy invloved, the procedures at Camborne also involve determinations of the corner frequency, geophysical moment, and slope.

TECHNICAL ASSESSMENT AND FUTURE DIRECTIONS

The staff at the Camborne site were very pleased with, and justifiably proud of, the performance of their system. Nonetheless, it was mentioned that continuing efforts are being made to both improve it and upgrade it. Most of these efforts seem to be directed towards the equipment used for analyses rather than towards the sensors and data transmission system. In comparison with mine monitoring systems, however, the surface-installed small grid is much less complicated and involves fewer constraints and limitations.

In the context of the development of an "out-of-mine local area" macroseismic monitoring system, which is presently taking place in Canada (by Noranda Research Centre under contract to CANMET), the experience at Camborne is very reassuring. The accuracy of the system in locating the sources of events was said to be very good, There is no question that the overall patterm has defined the underground reservoir of fractured rock. Without a visual means of inspection, however, it is not possible to verify the accuracy in locating any single event. While that is of great importance in mining, it is of secondary interest in the Camborne application.

With reference to the computing facilities, mention was made that the next advance would be in the incorporation of optical disks. Costing approximately $600 Canadian per disk, each permits the storage of 1 gigabyte of data.

Work is also in progress on the development of improved algorithms and in making all of the software used fully compatible with the VAX system.

ACKNOWLEDGEMENTS

The writer is grateful to the following, who gave freely of their time and experience during the visit:

Andy Green - Geophysicist

Mike Manning - Instrumentation Manager

Hayden Scholes - Computing Manager

Tony Bennett - Reservoir Engineer

NOTE:

A list of papers and articles on the microseismic monitoring aspect of the project was provided by the Camborne Staff. This is given as an Appendix to this report.

APPENDIX

A LIST OF PAPERS ON MICROSEISMIC MONITORING AT THE CAMBORNE SITE
(Provided by the Staff)

BATCHELOR A.S., BARIA R., HEARN K. Monitoring the effects of hydraulic stimulation by microseismic event location: a case of study. In IMM conference on Rockbursts: prediction and control, London, Oct. 1983.

BATCHELOR A.S., BARIA R., HEARN K. Monitoring the effects of hydraulic stimulation by microseismic event location: a case study. In the SPE-AIME 58th annual technical conference, San Francisco, California, Oct. 1983. (SPE 12020)

BARIA R., HEARN K., BATCHELOR A.S. The monitoring of induced seismicity during hydraulic stimulation of the potential hot dry rock geothermal reservoir. In 4th conference on acoustic emission/microseismic activity in geologic structures and materials, Pennsylvania State University, University Park, Pennsylvania, Oct. 1985.

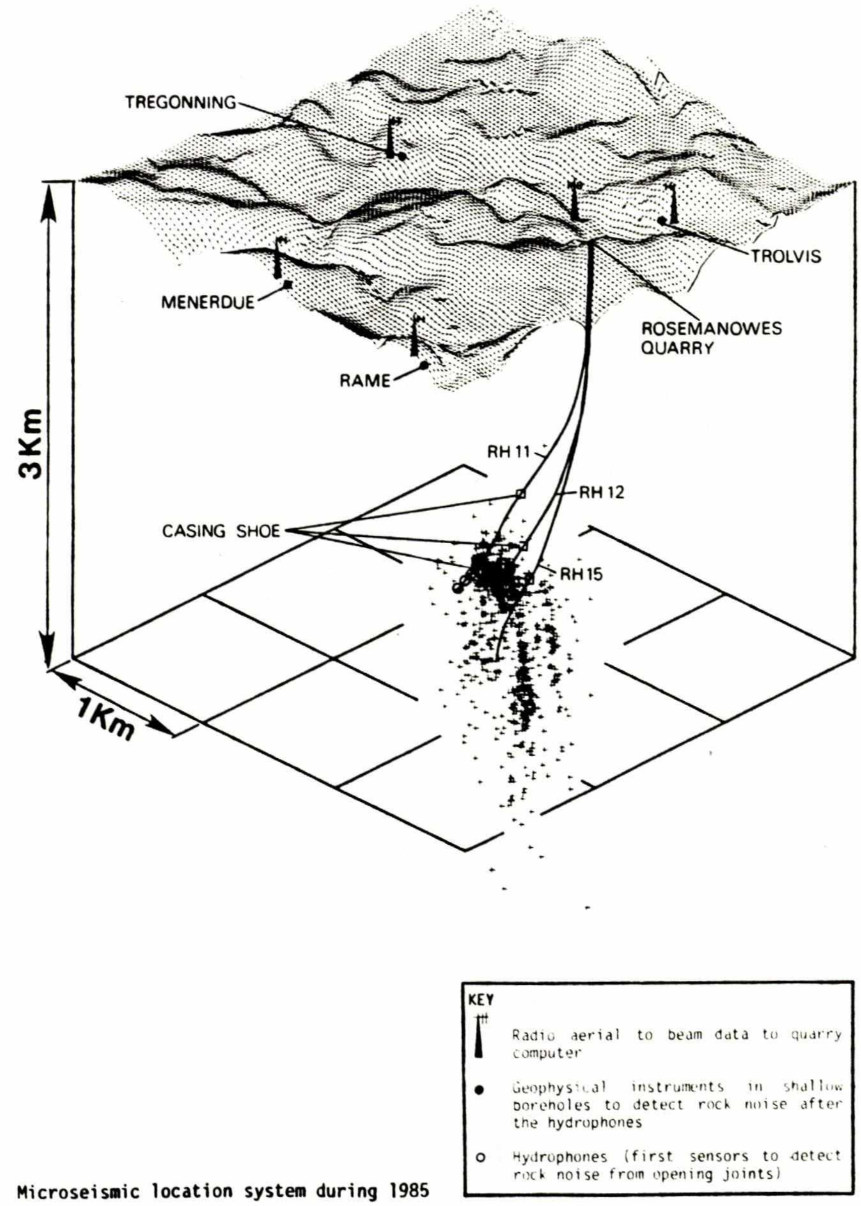
HEARN K. Application of surface to borehole seismic surveys to delineate a hot dry rock geothermal reservoir. In Society of Professional Well Log Analysts 10th European formation evaluation symposium, Aberdeen, Apr. 1986.

BARIA R., GREEN A.S.P., HEARN K. Seismicity induced during a viscous stimulation at Camborne School of Mines hot dry rock geothermal energy project. In 10th UK geophysical assembly, University of Glasgow, Apr. 1986.

GREEN A.S.P., BARIA R., HEARN K. Cross-hole seismic surveys at the Camborne School of Mines hot dry rock geothermal energy project. In 10th UK geophysical assembly, University of Glasgow, Apr. 1986.

HEARN K., BARIA R., GREEN A.S.P. Surface to borehole seismic surveys at the Camborne School of Mines hot dry rock geothermal energy project. In 10th UK geophysical assembly, University of Glasgow, Apr. 1986.

BARIA R., GREEN A.S.P., HEARN K. Seismicity induced during a viscous stimulation at the Camborne School of Mines hot dry rock geothermal energy project. In 8th international acoustic emission symposium, Tokyo, Japan, Oct. 1986.



Microseismic location system during 1985

FIGURE 1

Reproduced from Information Series, Camborne School of Mines, Geothermal Energy Project, November, 1985, No. 3

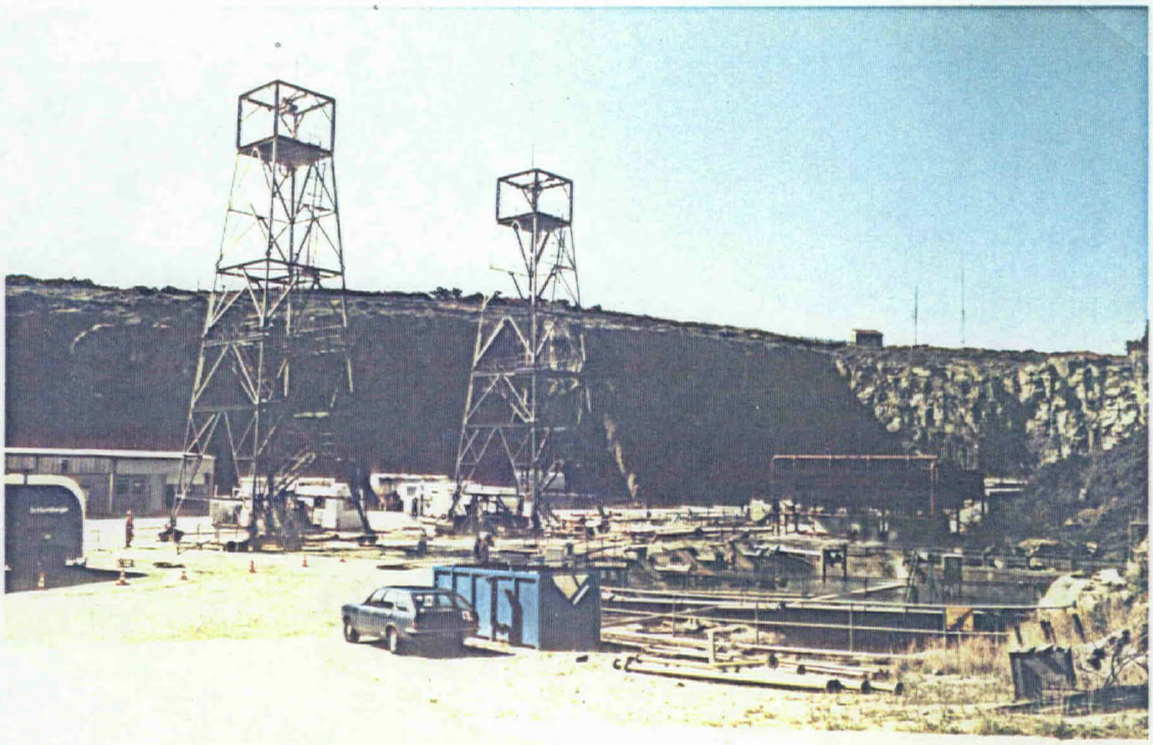


FIGURE 2

A general view of the site, showing the injection and recovery wells. Cooling ponds, for the recovered heated water, are shown in the right foreground.

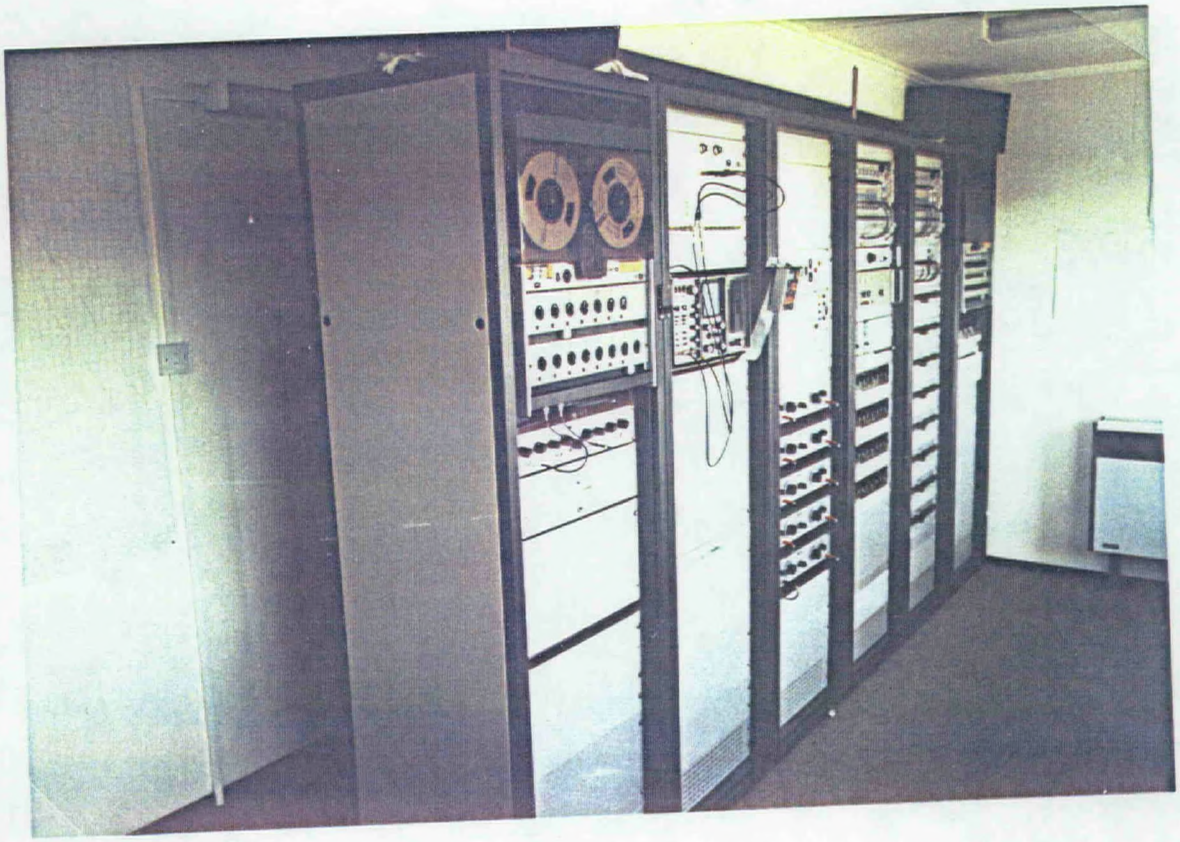


FIGURE 3

A view of the microseismic monitoring system

FIGURE 4

Display Facilities

FIGURE 5

A terminal and display screen. Note the wave-form of the event which is shown.

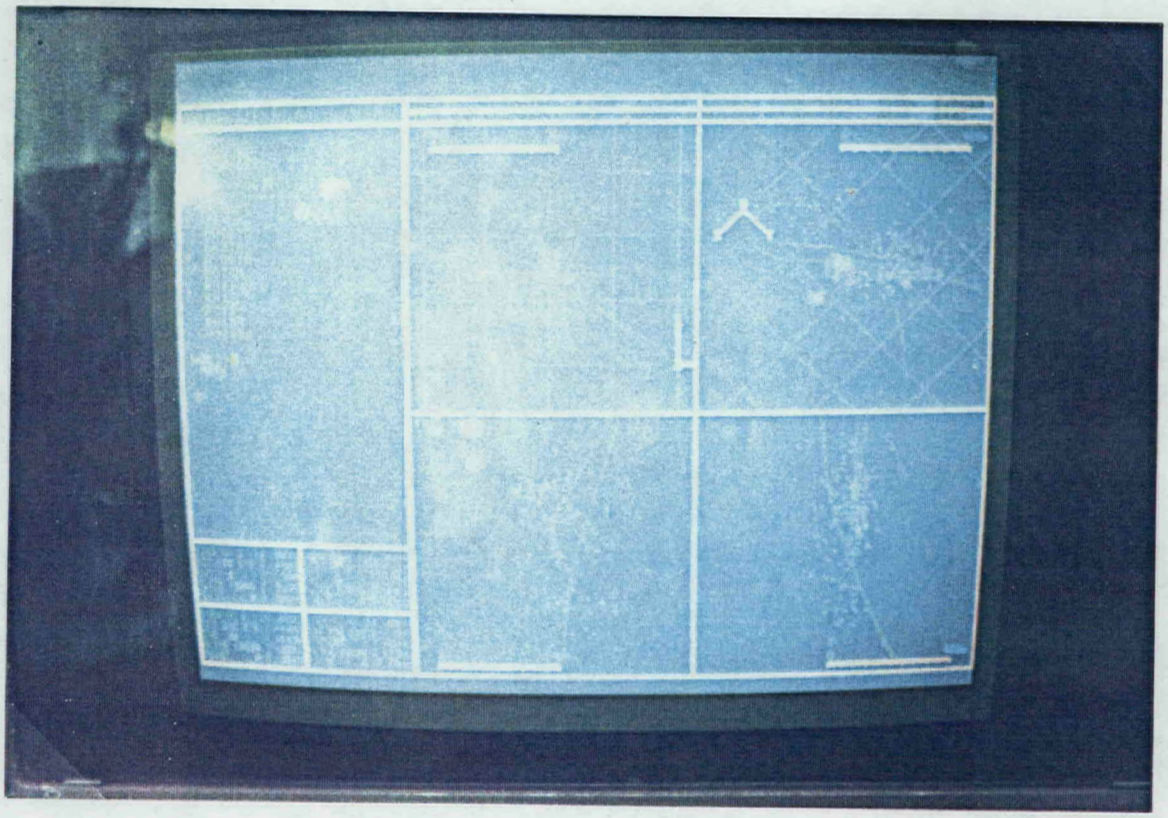


FIGURE 6

Multiple image displays of source locations.