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VAN DE REDAKTIE

Na een hectische jaarwisseling en tentamentijd kon de redactie begin Februari beginnen met het samenstellen van de voor hun eerste nieuwsbrief van de ingeokring en voor de vaste lezers de eerste editie van het jaar 1994. Wederom bevat deze editie enkele interessante excursie verslagen, boekverslagen, wetenschappelijke artikelen en berichten betreffende de stand van de ingenieursgeologie in Nederland.

In het kader van het vak 'special topics' deden TU studenten een literatuuronderzoek over verscheidene onderwerpen betreffende de ingenieursgeologie, waarvan twee verslagen in dit nummer zijn opgenomen. Maarten van Lange schrijft over de problemen die ondiepe gasvoorkomens kunnen veroorzaken tijdens geofysische onderzoek. Pieter Dijkshoorn bespreekt de verschillende geofysische methoden die gebruikt kunnen worden om ondergrondse holtes op te sporen en welke de beste resultaten opleveren in verscheidene (geologische) situaties.

De vaste kolom van Michiel Maurenbrecher brengt ons allemaal weer op de hoogte van wat er zich in Nederland zoal afspeelt op het gebied van de ingenieursgeologie. Ard den Outer bekeek en beschreef beknopt voor ons de proceedings van een recentelijk gehouden congres over grondmechanica en geotechnische 'earthquake engineering'. Verder maakten Robert Hack en Edmund Sides een samenvatting van de lezingen die onlangs gehouden werden op een symposium over GIS systemen en het gebruik van deze systemen in de toekomst.

Met enkele verslagen van excursies die het Dispuut Ingenieursgeologie onlangs organiseerde en met de agenda van in de toekomst te houden conferenties, symposia en seminars zit de Nieuwsbrief weer bordevol informatie.De redactie wenst U veel lees plezier en hoopt iedereen in Juni op het Jubilee symposium te zien.

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SEMINAR 3 DIMENSIONAL GIS - RECENT DEVELOPMENTS

14 December 1993

Seminar report

Robert Hack[1] & Edmund Sides[2]

The seminar '3 DIMENSIONAL GIS - RECENT DEVELOPMENTS' was organized by the Mineral Exploration and Engineering Geology sections (Earth Resources Department) of ITC in Delft on 14 December 1993. The seminar was organised as a platform to discuss the use of, and recent developments in, 3 dimensional geographical information systems (3D GIS). Seven presentations were given by invited speakers representing the main scientific fields where 3D GIS are actively applied (oil, gas & water exploration, mining, mineral exploration and engineering geology). The speakers outlined the main recent developments in their fields of specialisation. The individual presentations were followed by questions, and a general panel discussion took place at the end of the day. The meeting was chaired by Prof. Dr. Ir. Berkhout from the TU Delft, and was attended by approximately 50 participants which was the maximum possible. Extended abstracts and a summary of the presentations given, together with an account of the general discussions which took place during the meeting, are given below.

THREE DIMENSIONAL GIS FOR THE 1990s

Jonathan Raper

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3D GIS were simultaneously developed in the late 1980s in a number of different disciplines especially hydrocarbon exploration and mining engineering (Raper 1989, Turner 1993). Various commercial systems have developed to meet the specific needs of these fields (eg. EarthVision, gOcad, Stratamodel and Lynx) and are now widely used. Access by researchers to these systems has prompted the use of 3D GIS in other fields such as oceanography (Manley and Tallet 1990), sedimentology (Raper et al. 1993), geological surveying (McMahon and North 1993), and, methodological studies have been carried out to examine the sensitivity of the modelling tools (Eddy and Looney 1992).

However, the development of these 3D GIS systems has not satisfied all needs for new representations and analytical tools in 3D environments. Hence a variety of new systems have been developed in the research community, for example, to create tools for the superimposition of 3D objects on terrains (Kraak 1992); to integrate terrains into virtual reality systems (Raper, McCarthy and Livingstone 1993); to develop techniques of 3D octree representation (Prissang 1992); to develop systems to handle heterogeneous 4D datasets (O'Conaill, Bell and Mason 1992); and, to develop 4D process simulations as in the SEDSIM project (Harbaugh and Martinez 1993).

So far most 3D GIS have been developed in the raster domain due to the need to compress /index the data and given the readily available set of raster operators, Raster approaches are though inherently unsophisticated in database terms. Hence, the development of vector approaches to 3D GIS, based on adaptive tetrahedron building or edge geometry (Molenaar 1992), may lead to the creation of more mature database solutions to the complex definition and attribution of 3D spatial objects. This may require the use and extension of SQL3 query language standard to insert and retrieve 3D spatial objects from the

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database. The rapid development of virtual reality environments also offers the possibility of effective 3D vector modelling since some environments are controlled by object oriented programming.

Given the wide range of application domains where 3D GIS can be used, it is clear that much more research is required. Examples of work required includes the integration of new data types into 3D GIS models (such as geophysical data), the accumulation of knowledge into 3D GIS (for self-evolving process models) and better object manipulation in the 3D environment so that users can manipulate and extend models. Since the overheads for the development of a new 3D GIS are so large it is likely that such developments will be associated with one of the existing systems, or as standalone developments in research environments

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Presentation by Raper and Discussion

Raper highlighted the widespread development of commercial 3D GIS since the late 1980's, particularly in the hydrocarbon exploration and mining engineering fields. In overall terms he considered that we are now at an intermediate stage between the initiation of a new set of programs, and having fully functional systems. Some of the recent developments in 3D GIS research (as listed in the abstract) were also highlighted. The potential use of developments in other fields was also mentioned, and it was suggested that virtual reality would have a big impact in the future.

Raper also discussed the nature of 3D GIS data structures, pointing out that at present such systems are largely based around voxel-based volume representations with less emphasis on vector-based surface representations. He concluded that in future the emphasis would switch to a more vector based approach, and referred to recent work in the field of virtual reality which is based mainly on vector structures.

In a final summary he concluded that future developments would take place on three fronts;

- extensions to current 3D GIS
- development of new systems
- adoption of developments from virtual reality

In the subsequent discussion Raper's conclusion that voxel based 3D GIS systems would become less important in the future was disputed, and provoked a lively discussion on the relative merits of voxel-based and vector-based systems. There was also some discussion over the difference between a model representation system and one which allowed fully interactive modelling capabilities. For instance it was pointed out that Stratamodel had problems dealing with surface intersection or overturned surfaces; and that likewise whilst CPS can make 3D maps of stacked surfaces it cannot directly address points in between the surfaces.

WITH CHRONO-VOXELS YOU SEE THE (W)HOLE ALL THE TIME

Nanno J. Mulder

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Definitions :
Information is defined as a relation on the domains of a set of questions and a set of answers for an abstraction of part of the world. Geo Information is limited to question and answer domains about objects and processes referenced to the physical world. Some notations for the above definition of information: $X=\text{set\_of}\,x=\{x\}$. With information i, $I=\{i\}$; question q, $Q=\{q\}$; answer a, $A=\{a\}$; $I=QxA$, the relationship from questions to answers : qIa. The "quality" of information is defined by the probabilistic relation $P(i)=(q,a)$ from which conditional probabilities can be derived through the Bayes rewriting rule: $P(a|q)*P(q)=P(q|a)*P(a)$. For certain information $P(q,a)=\text{Kronicker}(qi,aj)$, [this is only 1 for one pair (qi,aj); for all other i,j the probability is 0]. Questions in the domain of Geo Informatics can be subdivided in questions about the value of nominal parameters and of ordinal parameters. The word parameter assumes a model of the world. Nominal parameters are often class labels or class names attributed (within a culture) to objects or processes. Ordinal parameters are of a physical nature and relate to measurable or derived properties.

Requirements for building and maintaining a world model:
As the world happens in space and time, it is necessary to build the model in terms of space and time intervals -> elementary volumes -> voxels and time intervals -> chrono-samples. We combine these requirements into a specification of chrono_ voxels(xi,yi,zi,ti) which are uniquely indexed by i and the corresponding tuple (xi,yi,zi,ti). It is a necessary condition for building a GIS, containing a model of the world, to be based on chrono_voxels. Chrono- voxels relate directly to the use of finite elements in the modelling of distributed dynamic systems. Each chrono_voxel has a state tuple, the definition of which is defined by the query domain of the application, state(cvi,s1..sn). The model must support the interaction of adjacent chrono_voxels. This requires a data structure representing adjacency in space and time: adjacent(cvk,cvl). If this relation is true then chrono_voxels k and l are adjacent. The geometry is supposed to be Euclidean, anisotropic effects are modelled through tensors in the state (property) vector of each chrono_voxel. The pun of the title of this presentation is that in a GIS with fewer than four dimensions you cannot see (query in virtual reality) the whole nor a hole e.g. a tunnel intersecting a mountain, nor follow a process developing in time.

Implementation issues :
- The state tuple or property tuple can, actually, be stored as a tuple per chrono _voxel, or as a column(cvi,statej), or per state variable a separate chrono_ voxel could be defined like in single value maps in 2 dimensional GIS's. As the definition of chrono_voxel boundaries is, usually, performed on the basis of gradients of property or state variable, there will be different time_space partitions for the single value approach as compared to the tuple approach.
- Space partitioning (for a time interval) is, usually, defined by derivatives (gradient, Hessian) of the state tuples and the complexity versus performance of the algorithmic implementation of the specifications given.
- For many problems the available finite elements software contains most elements needed for building world models. The adaptations needed will often only be of the nature of redefining the interaction between states of adjacent chrono_ voxels.

Working examples (ITC/UT).
- Parameter estimation of buildings visible in aerial photos. UT PhD project. A three dimensional model of a scene like the UT campus is instantiated and used by a ray tracer to predict remote sensing measurements or features such as image segments. The confusion matrix between predicted labelled area and evidenced labelled area is used to find the proper geometric parameters of the building blocks in combination with their shape name (block, prism, cone,..).
- Parameter estimation of an oilslick advection model. ITC MSc project. The model (public domain) is a four dimensional ocean model with finite elements in the horizontal plane and spectral modelling in the vertical dimension. State tuple components are temperature, density, position and speed. Initial and boundary

conditions are set, and forcing factors are tide (sun,moon) and wind-tension. With a given oilslick image we run the model to predict the state of the system at the next time of imaging, using an estimated forcing parameter(windspeed vector field). The error in misclassifying pixels -> confusion matrix, is multiplied with the local costs of errors of omission on commission and fed to the automatic parameter optimizer. This updates the estimated windspeed to the best fit on imagery of time+1.
- Lost voxel estimation, in the process of coastal zone erosion. ITC staff, R&D project. In order to apply the chrono_voxel approach we have to transform 2.5 dimension contour line and DEM to voxels at time ti. For practical reasons we have chosen to start with manual editing of surface triangles in a TIN (anaglyph shows areas instead of points !). The TIN of each date are transformed into TIN prisms by defining a fixed (under)ground plane. As the main query is to select all chrono_ voxels where [at t0, label=sand AND at t1, label=air] or select all chrono_voxels where [at t0, label=air AND at t1, label=sand] it is efficient to pre_calculate the intersect of voxel sets at t0 and t1, producing true chrono_voxels. The selected sets can be presented through available graphics routines or ray tracing and rendering packages. "Analysis" operations constitute of the application of arithmetic on the selected subsets of chrono_voxels.

Conclusions :
The major problem in promoting the concept of proper modelling in 4_dim appears to be of a psychological nature, which is more severe for the teaching staff than for many students. Students should have an intensive contact with the four dimensional modelling space while they are here! Once the concept is accepted, the struggle for elegant and efficient implementations is at least as challenging as trying to sell the concept over the last 8 years, and provides a stimulating research environment. This is in contrast with research directed at lifting 2.5 dimensional GIS's to a higher level. Folkloristic activities such as Kriging by mining geologists can now probably get their proper place in view of the available parameter estimators. These operate on a rationally defined cost function (merit function), based on the likelihood of volume misclassification during a time interval.

May our scope be less impaired most of the time.

Presentation by Mulder and Discussion

Mulder started his presentation with the question "Is 4D GIS new ?", and suggested that it had in fact been around since the 1960's when workers in the Technical University Delft had been working on 4D models of the human heart. He suggested that geographers were really only re-inventing work already done in finite element studies. Software for carrying out such work was available in the form of Fortran source code (since the 1970's), C-sources (much of it in the public domain) and as PC-software (3D CAD, ray tracing and rendering systems).

He stressed the need to model the physical environment correctly before trying to build 4D, or 3D, GIS models. The limitations of GIS systems based on replacing 2D drawing systems was pointed out, and that the fact that 2D drawings could not be extended to 3D models without the likelihood of impossible models being developed (eg Escher's drawings).

A suitable theoretical background for a 4D GIS was then presented, and followed up by examples of the application of this approach by ITC and the University of Twente, Netherlands.

A lively discussion followed with considerable disagreement from the floor on some of Mulder's conclusions. These objections were largely centred around the practicalities of sampling in real-world situations, and the lack of complete knowledge of how physical systems worked. Problems of changes in scale, and the recognition of overlap between objects, were also raised.

SPATIO-TEMPORAL (4D, DYNAMIC) SUBSURFACE MODELS

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The petroleum industry can be thought of as a chain of manufacturing processes. The activities involve the creation of an integrated earth model and production facilities. Decisions, based on financial risk analysis, are very dependent on this information. The required accuracy increases going from exploration, via appraisal to production activities.

Integration of applications, used in the earth model and facilities process chains, has never been achieved in the past, due to island automation and isolated user communities. Nowadays, business requires integrated multi-disciplinary approaches and therefore efficient information exchange, which is supported by computer and current information technology (IT) standards.

Major developments in IT standards are electronic data interchange standards such as the spatial model data exchange standards (POSC, addressing exploration and production earth models and STEP, addressing facilities). Computer tools in this area are based on translators (half links), which map the various types of data to be exchanged to a neutral datamodel.

So far only static spatial models (3D) have been standardized. This paper discusses the extension to dynamic (spatio-temporal) and versionable models, each having a different notion of time. Dynamic earth models are for example needed in simulation and inversion of sedimentation and tectonic processes, and in reservoir flow processes.

This paper reports on the three possible areas of extension of the GEOMOD datamodel to include time dependence,

- time dependent properties,
- time dependent geometry,
- time dependent topology.

Presentation by Ritsema and Discussion

The presentation was made by Ipo Ritsema from TNO, who referred the audience to a paper entitled "Inversion from Data to Models" (presented at the EAG conference in Stavanger during 1993) for further information.

He started by outlining three types of modelling used in the hydrocarbon industry, namely;

- spatial earth modelling
- spatio-temporal earth modelling
- integrated modelling

The application of different modelling approaches during the basin development cycle (exploration-appraisal-development-production-abandonment) was illustrated. The evolution of models from coarse "earth-models" (based mainly on physical measurements), to more detailed "earth-models" coupled to "facilities models" (based on studies of flow dynamics), was discussed.

Time was mentioned as a common element in both geological interpretation (eg strata deposition - thrusting - erosion) and also during production (eg hydrocarbon extraction rates).

A distinction was then made between the intrinsic dimensionality of models, and the dimensions of the model (sampling?) space. Model space was recognised as varying from 1D (eg drillhole) through to 3D (3D seismics). A 1D sample space could be used to define a model of a 0D object (eg the point at the crest of a dome), etc.

Scale was identified as a very important factor in the application of modelling in the hydrocarbon industry. Modelling often takes place at different scales at different stages in project evolution (eg basin analysis - local depositional environment - internal properties of reservoir beds).

Having discussed some of the key issues in 3D, and 4D, GIS applications Ritsema went on to outline the development of a data exchange format for use with information produced by such systems. Such data exchange is a critical aspect in such modelling systems with information coming from many different sources (eg drill logs, seismic studies, petro-physical analysis, etc.). The exchange format used was topology controlled (although this involves some redundant information for very regular data), and recursive (to allow scaling to be handled).

The data format thus involved a one-to-one correspondence between the following elements:

point	-	vertex
line	-	edge
surface	-	face

volume	-	cell
event	-	time

Model evolution (versioning) was discussed in terms of property updates, geometry updates and topology updates. The concept of scaling in 4D systems was also touched on with the examples of the change from geological - human - experimental time scales.

Ritsema ended with the following conclusions;

- the user environment requires the exchange of information between disciplines and different applications
- work is well advanced on the development of a neutral data exchange model
- the 3D world can be looked at in 1, 2 or 3 dimensions
- the real world is 4D
- data exchange is the first step in integrating multi-disciplinary simulation and inversion
- integrated simulation and inversion requires spatio-temporal earth modelling

The presentation was followed by a discussion which again highlighted differences between workers from theoretical and applications backgrounds. The validity of representing a 4D world by models with fewer than 4 dimensions was questioned. The relationship between scale and dimensionality was also mentioned (eg does a rectangular box reduce to a point as one moves further away from it ?)

3D GEOLOGICAL MODELLING IN MINING

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Three-dimensional geological modelling plays an important part in the generation of reserve models for use in planning the exploration, evaluation and exploitation of most mineral deposits. Computerised techniques are widely used for such work, as well as for 3-dimensional modelling in other fields.

The importance of using geological modelling to impose geological controls on computerised reserve/resource estimation has been widely recognised. In recent years this has led to the development of integrated interactive graphics, database, analysis and modelling software tailored specifically for reserve estimation and mine planning applications (eg Datamine, Lynx, Medsystem, PC-mine, Vulcan, Surpac, etc.) (Gibbs, 1990). A variety of different techniques are used for storing and manipulating 3-dimensional information in such systems (Henley & Stokes, 1984; Houlding, 1987; Howson, 1989).

Many of the techniques used for geological modelling in commercially available systems suffer from several limitations. To overcome some of these a system for modelling geological discontinuities was developed and implemented during research work carried out at the Neves-Corvo mine in southern Portugal (Richards & Sides, 1991; Sides, 1992a, 1992b). This geological discontinuity modelling system, with a model structure capable of storing points, lines and triangles, provides several advantages over other approaches. An important factor is the ability to - maintain close links with the different types of geological information which are used in the generation of 3-dimensional models of mineral deposits.

The system possesses several important features, including the following:

- links with drillhole and mapping databases
- graphical presentation
- interpretative hierarchies
- interactive editing
- 3-d visualisation
- conversion between 2-d and 3-d discontinuity models
- conversion to volumetric models

The work done during the development and implementation of this system, has high-lighted several general areas of 3-dimensional geological modelling which merit further research. Such work is necessary in order to improve the accuracy and precision of the geological models generated using such systems, as well as to improve the speed and performance of the systems used. Research topics which are currently being pursued, or under consideration for further study, include the following:

- quantification of errors associated with geometric models (eg Sides, in press);
- interfacing between different types of model structure, rather than dependence on a single type for a particular application;
- geological analysis of 3-d computer models (eg extraction of orientation data, spatial relation-

ships between different structural features, fold styles);
- improved 3-d displays, and interactive editing of 3-d models;
- development of new model structures and new approaches to modelling (eg interpretative hierarchies, boundary versus area concepts, knowledge aided systems);

In the mining context the end result of such work should lead to improved reserve models and more accurate planning of mine exploitation. Integrated packages developed in recent years offer significant advantages over the systems (both manual and computer based) used previously. In particular the ability to handle and display a large amount of data on section planes at any orientation or location in 3-d space allows much more rapid checking of information stored in the databases used (with a consequent reduction in the number of data errors). It also facilitates a much greater geological control on the generation of reserve models, and allows an increased amount of geological detail to be presented to planning engineers. Where properly applied such advantages should lead to improved accuracy and precision in the resultant reserve models, thus facilitating more effective deposit evaluation, mine design and production control.

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Presentation by Sides and Discussion

Sides gave a brief review of the development and application of 3D GIS to reserve estimation and mine planning in the mining industry. The development of a discontinuity modelling system, using a data structure based on a 3D triangulated irregular network, was described. Examples of the application of this system at the Neves-Corvo copper-tin mine in Portugal were given. It was pointed out that the selection of model structure in such systems often reflected the nature of the application. Whilst 'vector-based' structures (as used in the discontinuity modelling system described) were often favoured for geometrical modelling of geological features, these usually have to be converted to volume based models before being used for reserve modelling (in order to facilitate the calculation of tonnages and grades of materials present).

Several general aspects of 3D geological modelling were discussed, namely;

- Identity (when are two points regarded as the same one, when is a point taken as falling on a line or a line in a plane, etc.)
- Generalisation (meshing local and regional models, changes in scale, etc.)
- Quantification of differences (both overall differences and local mis-matches)
- Disjointness (whereby integral properties should be equal to the sum of individual model elements)
- Completeness (there should be no undefined gaps, or ambiguities, within the overall 3D volume being modelled)

Sides concluded with a list of topics requiring further research work (see abstract).

Subsequent discussion again touched on the relative merits of vector-based and volume-based approaches.

THREE-DIMENSIONAL MODELLING IN ENGINEERING GEOLOGY

Bogdan Orlic

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Engineering geology, as an applied geoscientific discipline, deals with the assessment of overall geological conditions with respect to engineering works. The range of problems that may be encountered, and consequently, are expected to be solved, by an engineering geologist are huge. This, however, depends both on the variability of local geological conditions and the type of engineering structure/work. The working scale can change dramatically: from 1:200 000 (in case of regional engineering geological mapping) to 1:10 (detailed core logging, mapping of adits etc.). The cost involved in obtaining data is high, especially for the most valuable large scale 'in situ' tests, but also for some sophisticated laboratory tests. The same applies for the case of core drilling which is almost inevitable at any construction site and therefore the most commonly used investigation technique. Under such circumstances it is essential to make the best use of the acquired information for interpretation of geological conditions.

Geological complexity and the increase in data quantity raises the issue of having a proper tool capable of effective handling of the acquired information. A three-dimensional Geo-Information System (3-D GIS), designed as an integrated tool to assist a geoscientist in all phases of geo-modelling process, should fulfil these expectations.

Four stages of the interpretation process using a 3D GIS can be distinguished:

- modelling of geometry,
- modelling of properties,
- visualization,
- export of data in a form suitable for numerical calculations.

Modelling of geometry is usually accomplished interactively. The reasons for this are in the need for detailed interpretation of site geology where a certain geo-detail can be of crucial importance.

The approach to modelling property distribution depends on the quantity and quality of available data. In general, three different situations can be distinguished;

(i) The data set is numerous and representative, therefore the use of existing (geo)statistical methods is possible and justified. The estimation of property distribution can still be improved by incorporating the local orientation of geological structure into the interpolation algorithms.

(ii) The quantity of data is less numerous and is insufficient, in a statistical sense, for (geo)statistical modelling. Algorithms for the assessment of property distribution should be flexible to honour the geological pattern when required.

(iii) The available amount of information is too small for (geo)statistical processing. Such data sets consist of a limited number of 'hard' (observed) data and 'soft' data. Interpretation is possible only by using the expert judgement of the interpreter.

Visualization tools provide a means for the verification of created models.

The final task to be accomplished by a 3D GIS in a site investigation project is to prepare defined models in the form of input data required for numerical calculations. The complexity of domain discretization depends on the calculation scheme adopted and the numerical technique utilized in computations.

The analysis of a typical site investigation project shows that a 3D GIS for engineering geology should integrate the following capabilities:

- full three-dimensional integration of all available types of data,
- interpolation routines with geo-structural control,
- tools for discontinuity modelling,
- interactive editing of modelling results,
- irregular volume discretization and component attributing for numerical calculations,
- visualization.

A few examples will be presented to illustrate the use of a 3D GIS in engineering geology.

Presentation by Orlic and Discussion

Orlic started by outlining the requirements for 3D geological models in the field of engineering geology. Two particular applications were mentioned, namely;

- assessment of overall geological conditions with respect to engineering works
- development of groundwater resources

The range of scales used, and the different stages involved in the interpretation process with a 3D GIS, were discussed. Three approaches to the preparation of engineering geology maps were identified;

- conventional map making techniques
- 2D digital maps (GIS + relational databases)
- 3D digital maps (GIS + object oriented database)

The possibility of incorporating knowledge based and expert system approaches into 3D GIS was discussed.

Examples of the use of the Lynx system for engineering geology applications were given. The problems caused by the general sparsity of data in site investigation studies were mentioned.

ESTIMATION AND EVALUATION OF PROPERTIES IN A LINEAR OCTREE BASED MODELLING SYSTEM

René Prissang

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This contribution focuses on the description of linear octree based modelling of continuous properties in geoscientific applications.

Computer-Aided Design in many geoscience-related areas relies on three dimensional information technology. Representation techniques for such information must be equally suitable for storage, retrieval, manipulation, and analysis of designed as well as revealed objects (Fried & Leonard, 1990). Designed objects (e.g. stopes, landfills) are the result of planning and decision making processes. Revealed objects (e.g. subsurface structures) generally cannot be observed in their full spatial extent. Therefore, models have to be established on the basis of a priori geological knowledge and abductive spatial reasoning (Köhnke, Prissang & Skala, 1993).

Linear Octrees, a special form of hierarchical data structure based on a recursive subdivision of objects into sub-cubes or octants (Atkinson, Gargantini & Ramanath, 1984), are suitable to represent all of the aforementioned classes of 3D objects. They are implemented as lists of unequivocal spatial indices associated with attribute information. In attribute octrees, the spatial indices are associated with continuous values, such as grades or concentrations. In geometry octrees the attributes are used to identify the membership of an octant to a region and an object as well as to store visibility information.

Modelling starts with the delineation of the shape of a geological object under consideration. To set up a model in boundary representation, wireframe modelling can be regarded as the most suitable user interface. The resulting model is subsequently transformed into a geometry octree. A detailed description of this procedure is given by Bak & Mill (1989).

The objective of property modelling is the generation of volume data sets from information at scattered data points. In general, the spatial distribution of a continuous property will be represented using homogeneous components. With the linear octree encoding technique this is achieved by hierarchically decomposing the 3D space guided by the local distribution of data points (Prissang & Skala, 1990, Prissang, 1992, Bak, Cram & Prissang, 1992). In voxel models, the subdivision of an entire model volume into uniform blocks would result in great storage requirements and long processing times for model manipulations.

Using linear octrees the process of property modelling can be subdivided into three distinct phases:

- discretization (hierarchical decomposition of the model volume guided by the local distribution of sample points)
- model refinement (subdivision of large blocks down to a given block size in conjunction with simultaneous removal of the blocks outside the geometric model of the geological body under consideration)
- grade estimation.

For the estimation of properties where their spatial distribution cannot be described by a deterministic process, a number of different techniques are available. These include the assignment of the value of the nearest neighbour, inverse power of distance weighting and geostatistical methods (e.g. ordinary, universal, disjunctive kriging).

A pragmatic approach referred to as "step wise interpolation" has been adopted to ensure that estimates for all blocks will be computed.

The 3D capabilities of the linear octree encoded property modelling system can be employed to analyze and visualise spatial distributions of properties. Classes may be defined and visualised as isovalue regions. Peeling off classes of material will reveal internal structures of the objects. Information in different property models may be combined to calculate derived variables. Connected component labelling determines the number and volumes of disjoint regions generated by means of classification techniques.

The application of linear octree encoded property modelling offers several advantages. The approach used for model setup results in an efficient discretization of the model volume. This significantly cuts down storage requirements and processing times for manipulations. Geometric and property models can be stored independently and easily combined without any transformations. Fast estimation and manipulation algorithms make use of the linear order of the 3D space inherent to the encoding scheme.

Attribute as well as geometry octrees can be exported to state-of-the-art visualisation packages (e.g. VoxelView^{TM}) to make use of such features as transparency or real-time model rotations.

Linear octree based property modelling combines modern estimation, evaluation and visualisation techniques. It may be applied whenever information on spatial distributions of properties is required, for example in mine planning or the evaluation of the spatial extent of contaminations in environmental engineering.

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Presentation by Prissang and Discussion

Prissang started his presentation by identifying two separate views of geological modelling in 3D GIS;

- producers viewpoint: modelling objects which elude observation based on abductive reasoning (ie using a priori knowledge and field observations)
- consumers viewpoint: pragmatic analysis of geological expertise (ie generation of definition limited objects)

Methods used for property modelling, whereby point observations are extended to 3D space, were then discussed.

The development of a linear octree based modelling system, in the context of two EEC funded projects for the use of CAD in underground metalliferous mining applications, was then outlined. The main objectives which led to the choice of this approach included;

- improved speed and accuracy
- adaptive data structures, to allow for greater detail in some parts of the overall volume being modelled

Examples of the application of this modelling system at the Cayeli mine in Turkey were then given. Property estimation in this deposit took about 5 minutes for 30 000 blocks using a linear octree model. This gave a 2m resolution in the centre of the deposit, with minimal extra data storage requirements (the same deposit would require 600 000 blocks in a regular voxel-type model, which would occupy about 160MB of disk storage).

Prissang concluded by identifying the following topics for future research;

- improved geometric accuracy using polytrees
- design of even faster routines to deal with larger data sets
- addition of other interpolation and simulation techniques to the system

Subsequent discussion pointed out that the talks of Sides and Prissang highlighted the need for different model structures for different purposes in the same application area (ie vector-based models for initial geological/geometric modelling, and volume-based models for subsequent modelling of spatial variations of internal properties).

In reply to a question Prissang stated that the geometry octree model currently used by the system has 2 attributes, defining the octree, and is stored as a 32 bit integer which allows for 10 subdivisions in the octree hierarchy. The block octree model permits a user specified number of attributes.

3D MODELLING OF OUTCROP AND SUBSURFACE DATA AT THE GEOLOGICAL RESERVOIR CHARACTERIZATION CENTRE

Hans Dronkert

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GeoRes

The Geological Reservoir Characterization Centre at the Faculty of Mining and Petroleum Engineering at Delft, University of Technology uses 3D modelling for the interactive visualization and interpretation of outcrop and subsurface data sets. For subsurface work, the volumetric and geometric distribution of properties of oil, gas and water reservoirs are considered. The data sets are usually too big to be interpreted and visualized in the old fashioned 2D manner with cross sections, panels and fence diagrams. Preparation of these 2D panels is very time consuming and often the chosen tracks prove to be in the wrong direction or just miss important features. Particularly extrapolation between existing panels is hardwork and often erroneous.

Data Sets

The construction of a subsurface data set has evolved to a certain standard (POSC) which, nevertheless, comprises an enormous amount of possible entries. Today several software programs are available to visualize most of the geometric and property data in 3D. Most of the more sophisticated 3D programs are company propriety and not available for public commercial use. Some of the commercial programs are very simple and very slow with bigger data sets, in particular when used on PC's (e.g. Surfer(Golden), and Rockware).

"Standard" reservoir

A "standard" reservoir measures 10km by 10km in the horizontal plane, and is 100 m thick. The corresponding 3D data set consists of at least 10 separate layer grids, each with 100 * 100 nodes, and about 100 wells penetrating the reservoir. Each of these wells contains at least 10 (often up to 50) series of data points for every 15 cm along the depth range. Geologically speaking, this data set gives only a very rough picture of the lateral extension of geobodies, because on average there is only one well per square kilometre.

3D geological modelling

3D modelling of geological features demands a different approach from that which geologists were used to with 2D modelling. Most outcrop studies are actually only thin 3D blankets that are easily projected onto 2D panels but are difficult to expand to real 3D data sets. Several projects have been carried out by GeoRes to compose outcrop data sets from turbidite environments (marine), deltaic environments (terrestrial to marine) and fluvial environments (terrestrial).

Digitizing Geology

The digitization of geological data forces the geologist to classify often seemingly incomparable features. It appears that an old fashioned geological data set contains much more information than can be drawn from tables in their texts. Nevertheless, when using old geological data sets, it is often necessary to go back to the field to collect new and additional information to complete the original data sets.

Extrapolation Techniques

The fact that geological outcrop data sets are only a thin 3D veneer immediately points to the necessity to use statistical methods to expand the nearly 2D set to 3D proportions. This can be done in various ways. Most modelling work starts off with a deterministic model. This model closely resembles the real data set because it is directly based on the data set and extrapolations, where necessary, can be done in a very simple and linear fashion. Only very dense data sets are capable of generating a realistic 3D deterministic model. When a dense dat set is not available extrapolation methods are used to fill in the missing parts. This can by done by simple geostatistical methods such as linear extrapolation, kriging or other algorithms. Only "layercake" reservoirs can be used for this approach. More difficult reservoir types such as "puzzle" and "labyrinth" types need additional information before prediction of their lateral extent becomes realistic. This can be done by incorporating certain geological rules, such as width/thickness ratios, inter-connectedness and porosity permeability - facies relationships. This data can be imported as tables, semi-variograms or other graphs that will be honoured by the modelling program. Research is proceeding at GeoRes but the step from 2D to 3D seems to be a very big one for the stochastic experts.

At GeoRes the program "Stratamodel" is used for 3D visualization. Depending on memory and computer speed some tens of grids can be loaded. Several hundred wells can be incorporated without difficulty. Each well can have up to 100 attributes (variables) that can themselves be formulas based on other attributes. In this way even simple rules can be built in. The program is based on a framework of sequence boundaries. The boundary layers have to be imported as a grid data set (ASCII, CPS3 or Zycor format). Using faults and other non bedding information for the frame work is cumbersome and cannot be interactively modelled or changed. Another option allows for the use of templates of typical geological models such as river channels or delta lobes. These can be given a certain weight for the prediction of the interwell area.

At GeoRes this program is mainly used for visualization of the geological data sets. In the case of reservoir analogues, or actual reservoirs, calculations of reserves of oil, water or gas are also performed.

Advantages of visualizing geological data sets with 3D tools include the possibility of panning horizontally and vertically through a data set and observing the data set from any angle. A very rapid impression of the data set is possible and most errors are easily identified and traced. Because of the endless viewing possibilities it is very difficult to transfer the results to paper prints with the same visual power as one was used to when watching the moving images on a computer monitor.

Presentation by Dronkert and Discussion

Dronkert opened his presentation by giving a general overview of the use of geological modelling in hydrocarbon exploration. He pointed out that such modelling is really always 4D, since the geologist takes into account the age relationships between different structures. The wide variety of data used for geological modelling, and the irregularity of sampling coverage, were also mentioned.

In answer to the rhetorical question "Why ?", Dronkert pointed out that volumetric models are required in order to predict production. The following phases, involved in reservoir analysis, were identified;

- outcrop analysis
- conversion of laboratory measurements of flow to in-situ permeabilities
- data processing preceded by statistical analysis
- modelling of the spatial distribution of permeability
- application of fluid flow models to derive improved predictions of fluid flow

Several general themes of 3D geological modelling were then touched on;

- deterministic models (these have the advantage of allowing accurate flow prediction and exact positioning of wells, however they require very accurate rules and fairly dense data; they are also static and difficult to use in "puzzle-type" reservoirs)
- stochastic models (these can allow for the exact determination of depositional environments but require a large knowledge base of geological rules to apply to the data; these can also be built on very scanty data)
- process based models (these include time as a model parameter)
- hardware
- software

The application of 3D and 4D modelling in the hydrocarbon industry were then illustrated by several case histories. This included a description of the facilities offered by the Stratamodel system, and examples of its use. Studies of turbidite fans in the abyssal plain close to the island of Madeira; sedimentary structures in the Carboniferous of Kentucky; and a Miocene point bar in Spain; were also described. Examples of the use of 3D modelling systems in the evaluation of a small offshore oilfield in Surinam were also given.

Dronkert ended his presentation by listing the following advantages and disadvantages of 3D GIS;

Advantages:
- interactive 3D is a big improvement
- the panning, all angle viewing, and volumetrics facilities offered by 3D systems allow the user a much wider range of evaluation tools

Disadvantages:
- the equipment used is still very expensive
- 3D models are very difficult to reproduce
- No program has it all

PANEL DISCUSSION AND SUMMARY OF INDIVIDUAL DISCUSSION SESSIONS

The seminar was originally envisaged as being restricted to 3D GIS, however, most speakers extended this to 4D GIS in order to include time as a parameter in their models. Visualization of the evolution through time of geological structures, and/or geologically related data, was considered to be one of the most significant areas of current research in the field. It was suggested that 4D modelling could provide extra information for refining the "static" 3D models.

In opening the panel discussion Prof. Berkhout gave three reasons why 3D GIS was necessary;

- the desire to represent the earth by realistic models (ie the need for a good toolbox)
- the need to build a model which is as close as possible to reality in a particular application
- given validated models, the wish to make predictions

Several speakers had pointed out that the application of 3D GIS had been led by developments in the hydrocarbon exploration and mining industries, where accurate 3D models of the earth had a direct impact on company cash-flows. It was also pointed out that sub-surface modelling is the common link in multi-disciplinary geoscience applications.

A recurring theme throughout the day was the controversy between those wishing to use GIS for representation of geology and those who wish to model geology in 4D GIS. The former group use GIS as a geological interpretation tool, whereas the latter (eg. Mulder) use GIS to model the physical and chemical processes, which have resulted in the present geological model, through geological time. Examples of the use of the SEDSIM program were cited in the context of the last approach. This method is potentially more interesting scientifically, however the equipment needed (fast computer) is still expensive. A more fundamental problem with modelling geological history is the lack of detailed and quantified knowledge of many of the physical and chemical processes which influence geological history. The need to obey sampling rules, and to take into account the cost of obtaining measurements was stressed.

The need to interface between programs and model structures was also highlighted in the days presentations, in particular with the work on data exchange standards described by Ritsema.

Several speakers predicted that the capabilities of, and options provided by, 3D visualization programs will improve rapidly. Developments in the movie and computer-game industries are expected to have a significant impact (Raper). Significant developments are happening in the field of virtual reality, and these are likely to provide additional tools which will be incorporated in GIS systems. Likewise, many CAD/CAM programs offer more realistic and/or better visualization options in real-time than present GIS systems, thus providing another source of new tools for use with 3D or 4D GIS.

Another topic of discussion was the question of whether 2D or 2.5D GIS systems are still able to fulfil a role in geological modelling. In general the audience was convinced that these are now outdated and that no serious further developments can be expected with such systems.

Discussion of the need to include measures of accuracy and precision with GIS models was also initiated (Sides). It was pointed out that gOcad offered some options in this regard. It was also noted that many users and program developers seem to assume that the quality of their programs and geological models are directly related to the accuracy of the calculation methods used. In reality input data often does not allow for very high accuracy and thus the resulting model inherits a high uncertainty regardless of the accuracy of the calculations, or the precision of the model. The need for further work on the quantification of the precision and accuracy of both input data and models was stressed. This would allow the relative merits of different modelling approaches to be considered on an objective basis.

Scaling was also identified as an important issue for future research in 3D and 4D GIS.

A general conclusion of the panel discussion was that proper modelling of geology is often hampered by lack of data. This is especially true in oil industry and engineering geology applications. In these fields data are often so limited in quantity and/or quality that the geological model is really more of an intuitive guess which fits the data rather than a model which is determined by the data. This problem is not solved by the use of a GIS system. Future incorporation of expert system approaches in 3D GIS may lead to improved modelling results in such circumstances.

ENGINEERING GEOLOGICAL HIGHLIGHTS

Changing of the guard

This section of the IngeoKring Nieuwsbrief is devoted to developments in the Netherlands that can have which have significance for engineering geologists. David Price after almost twenty years at Delft has retired with his wife to their cottage in Wyndmondham, (pronounced Windham) Norfolk England last September. Soon a new professor will take his place, Dieter Genske, who hails from Germany. Despite an absence of professors engineering geology at the TU Delft has had the largest intake of students yet, so that it is not inconceivable that the staff will have to increase to keep up with the engineering geology student population. Our honourary professor in Marine Engineering Geology, Adrian Richards will, too, be retiring soon, so that 1993/1994 has seen quite a number of changes.

David's farewell: orations, symposium and portraiture

David Prices's farewell address given in the Aula of TU Delft on 1st September, 1993 titled "Aardbeving met slagroom-(or shocking experiences)". The experiences have to do with the cultural and language changes that David experienced during his sojourn in the Netherlands. As for "*Aardbeving met slagroom- earthquake with whipped-cream*" readers will have to be kept in suspense, but if they would like to know more about this they are welcome to order, free of charge, a copy of the published transcript: stocks are limited so order now! They can be ordered through the editor of the IngeoKring Nieuwsbrief.

In honour of David's twenty years with TU Delft and the Netherlands engineering geology community (the latter which had grown from four engineering geology graduates when David took up his post at Delft and numbers in the region of 80 graduates) a symposium was organised by the DIG (Dispuut Ingenieurs Geologie- Students' Chapter Engineering Geology) titled, appropriately "An Overview of Engineering Geology in the Netherlands". All the presentations were by colleagues and old students of TU Delft. An excellent publication (front cover depicted next page) was compiled for the symposium proceedings. This can be obtained from the DIG at a give-away price of *f*20.

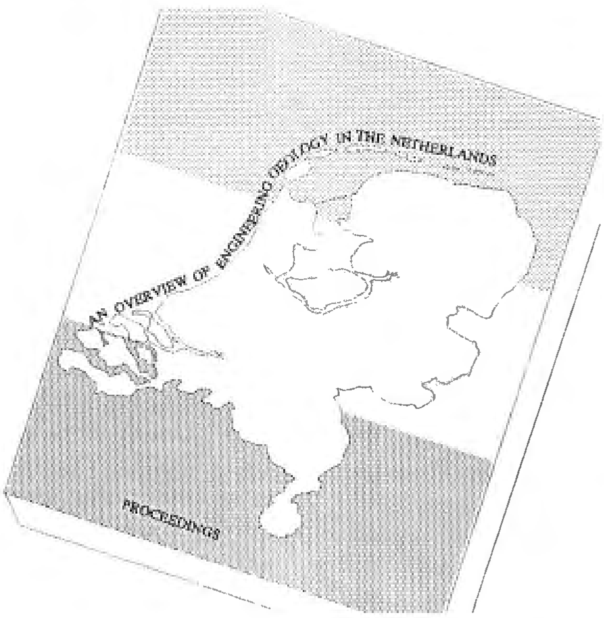
The President of DIG, Albert Bloem started the days proceedings with Niek Rengers in the chair wishing everyone a pleasant day amongst friends and old colleagues. Your columnist then made a controversial Opening Statement stating that environmental soft ground engineering geology has a better market in the Netherlands and that engineering geology hard ground has limited commercial possibilities judging by the themes of the contributions presented at the symposium. This is expanded upon later in this column. Ard Nooy van der Kolff presented the first paper on "engineering geology in (hyper)arid regions"- or where the Dutch engineering geologist scores: his knowledge of the more exotic soils. Roland van Steveninck presented Sven Plasman's paper on off-shore site investigation- or should one say a unique world-wide Dutch export industry. Imke Deibel presented a paper which subject matter dominated the symposium subsequently: environmental engineering geology, in this instance a paper on Maintenance dredging in the Rotterdam. Freek van Eijk continued on the environmental theme with his paper titled "The design of a regional landfill in Landgraaf". Titus de Ruijter, in his talk showed that Dutch environmental engineeering geology is also an export product as he presented a case hisory of work carried out in Hungary on "Determinative soil investigation at Metallochia and its surroundings. Budapest, Hungary".

In the afternoon the symposium was chaired by a familiar personality from Engineering Geology community Erno Oele (for years Mr. IngeoKring and secretary of the KNGMG). Joost van der Schrier started the afternoon off with his talk on "Soft soil shield tunnelling close to foundations piles simulated in a geotechnical centrifuge"- Joost heads the centrifuge at Delft Geotechnics and is putting it to good use; tunnels are believed to be the largest civil engineering growth industry in the coming two decades in the Netherlands and hopefully from literally a non existent industry the Netherlands will be world experts in (very) soft ground shield tunnelling and its engineering influences on existing structures.

Rock mechanics engineering geology: heading for the rocks?

Little has been mentioned on rock mechanics, and one of the questions posed in the opening statement was the commercial relevance of rock mechanics in the Netherlands. Both Jan Reinout Deketh, Peter Verhoef and Robert Hack should be given full credit for trying. Jan Reinout (with Peter as co-author) presented a paper on " Abrasive wear of rock cutting tools by rock". Now actively engaged in this research for over a decade, the engineering geology section can be justifiably be renamed the "Rock cutting tools abrasive wear centre". The dredging industry was the principal interested party in the research, however, more recently, land-based rock cutting tool manufacturers have also asked the "centre" to carry out research for them. Though the few slopes we have in rock in the Netherlands are generally stable Robert Hack presented a paper on "Slopes in rock" using his experience gained earlier as a final year student at TU Delft and subsequently in the mines in Zambia on rock classification for underground works design he then came back to Delft with ITC to develop in collaboration with David Price a similar classification system for rock slopes.

It is surprising how many Dutch workers are involved with slopes in rock: Jan Nieuwenhuis, Theo van Asch, Jan Rupke and Kees van Westen. Now my controversial question: which Dutch workers in rock slope stability have been paid commercially to carry out such studies? I have done projects Hong Kong and in Oman, when working for Fugro and similarly Ben Degen has worked in Hong Kong with Fugro and subsequently as GeoCom carried out a project in Bolivia. All the non-paid or grant-based work is usually done in association with students field work; at some stage one of the Dutch earth-science disciplines have to be confronted with rock outcrops and hence, to make field work worthwhile research projects are started. Jan Nieuwenhuis studied, during fieldwork in France the indeterminate problem confronting most stability problems: at what the rate failures take place? for which he earned a doctors degree. Robert Hack with David Price has devised a field mapping classification system for discontinuous rock masses and Jan Rupke/ Theo van Asch have been devising geomorphlogical maps of unstable slopes. Kees van Westen carried out mapping of unstable slopes from airphoto interpretation in the Andes at Manizales, Colombia and also earning his doctors degree on this work.



Peter Verhoef summed up the day with a slides showing David Price in his true light (thus that of an engineering geologist) in the field during fieldwork with students in Limburg, Spain and Scotland. We have a duty as a legacy of having been colleagues of David to ensure that the tradition of fieldwork is maintained as at sometime, somewhere and somehow data has to be obtained of the subsurface and this is increasingly becoming the (sole?) role of the engineering geologist. A portrait painted in a the Hague studio by Marieke Bok of David was made for the occassion: it now dominates the engineering geology section to remind us daily of that legacy.

For in-depth appreciation of the symposium please request a copy through the editor of the newsletter or through the DIG (same address). Your contribution of *f*20 will be for a worthwhile cause: the DIG. It is they who organised an excellent and well attended symposium. Delegates came from far afield, not only from all parts of the Netherlands and Belgium but also from Canada; Chris Dijkstra. He is the first TU Delft graduate in Engineering Geology.

Rumblings from the south-east

Tremors from the Roermond Earthquake of 13th April 1992 are still having its effects in the Netherlands. The initial interest seems to have died down but new hazards and disasters have visited the south eastern Netherlands in the form of floods. This prompted the local television to look back on recent misfortunes and we were asked at the Engineering Geology Section to be interviewed on the local television covering what is now the municipal region of Roerdalen consisting of the towns of Herkenbosch, Meelick and Vlodrop. Ard den Outer just joined the staff at the section to work as a doctorate researcher on the earthquake project. So a week after taking up his post he was in a local studio with me being asked questions on results of the questionnaire survey carried out by the section. It is surprising, though, the diminished interest in the earthquake, despite the numerous puzzles and questions that have arisen from the earthquake: why, for example are houses of identical design are some damaged whilst others are not, or what designs are more susceptible to damage then others? There is a huge archive from the Disaster Fund begging for a building structural engineer to study this aspect. Eric Mwingira from ITC is looking at the liquefaction phenomena of the Brunssummerheide slide; only to discover major slides occurred in the past in that location without the aid of earthquakes! The area is the spring line of the Roode Beek a small tributary of the Mass and instances of horses sinking into quicksand have been reported.

For those interested in the Roermond Earthquake can obtain later this year a special volume on the Roermond Earthquake is due to be published by Kluwers in *Geologie en Mijnbouw of the KNGMG* at the end of 1994.

P.M. Maurenbrecher

Shallow-reflection seismic over-water surveys of gas-charged sediments.

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The Netherlands. (December 1993)

ABSTRACT

Gases in marine, estuary and lakefloor sediments are found all over the world. The gases in these sediments can be of different origin. A great variety of features on acoustical profiles obtained by high resolution seismic profiling are indicative for the presence of gas-charged sediments.

There is a two way effect of gases in sediments on acoustical signals: the sound speed is influenced and the signal strength is attenuated. Both depend on the properties of the sediment, the gas and the bubble size. The frequency of the signal plays an important part.

The detection of gas-charged sediments hinders the interpretation of the sub-bottom, but certainly has engineering significance.

INTRODUCTION

The basis of this paper is a literature study performed as a part of the subject 'special topics' of the fourth year curriculum in engineering geology at the faculty of Mining and Petroleum Engineering of the Delft University of Technology in the Netherlands.

With the aid of the AUBID on line literature search system of the Technical Library of the university and its CD ROM facilities papers and literature found of relevance by the author were selected. All information obtained is compiled in this article. The total duration of this project is one week.

Since the 1946 technical report 'Physics of Sound in the Sea' of Division 6 of the U.S. Navy reseach department very much has been published about subjects related with the acoustics of gas-charged sediments.

From all seas in the world the prsence of gas-charged sediments is reported, such as South Chinese Sea, offshore Louisiana, Gulf of Mexico, North Sea, Adriatic Sea and so on. Also gas-charged sediments are observed in estuaries, bays and lakes, as Chesapeake Bay, Delaware Estuary and Bay mouth, Patuxent Estuary, Say Gon Rivers, Lake Florida and Lake Rotorua (New Zealand).

Articles can roughly be divided in dealing the more applied seismic surveys, describing the appearance and locations of gas-charged sediments and in the fundamental branch, dealing with the theory and mechanisms leading to the acoustical effects of gases in sediments.

Although the geotechnical properties of gas bearing sediments are of great significance, little is published about it.

ORIGIN OF GASES IN SEDIMENTS

The gases observed in sediments vary in source and composition. Kaplan (1974) distinguishes four sources:

-atmospheric, those are the gases that were dissolved in the water at the time of deposition. The main gas is CO_2, the dissolved O_2 has reacted with carbonate ions to form CO_2.

-biogenic degradation of organic matter. Hydrogen is used by bacteria to reduce carbon dioxide to methane. Dominant gases are N_2 (small amounts of nitrate are reduced to leave N_2 gas) and

methane.
-thermocatalytic cracking of complex organic compounds has taken place in deep sedimentary rocks after which migration takes place to shallow sediments. The gas consists of methane and a fraction of ethane.
-submarine volcanic or geothermal processes. The major gas is CO_2. Depending on the depth of the igneous source and its relation to the continental margin other gases may occur, as CH_4, H_2, N_2, H_2S and halogens.

Various gas sample techniques have been used through time, but a fully successful one is not yet develloped. Moreover quantative data are hard to obtain as the permeability of the gas-charged sediments is very low by its nature. Generally from source point of view the major resulting gases are stated to be methane, carbon dioxide and nitrogen.

ACOUSTIC EFFECTS OF GAS BUBBLES IN SEDIMENTS

Often the prove of the presence of gas was given by the ebullience of gas from the sea bottom. Reliable sediment samples indicating gas were taken by Schubel (1974), who immediatelly frooze the samples after recovery to deck. This was done by immersing the sample, still in the tube, in liquid nitrogen. Then X-ray photographs were made of the froozen samples. Samples from areas where good seismic records were obtained did not show any voids, whereas samples from locations were the sub-bottom did not show any reflectors showed many spherical cavities and voids. See figure 1. The fissures which are predominantly in the length direction of the core are due to expansion of the gas during recovery of the core. Laterally the sample is confined by the corer, the upper and lower sediment surfaces are not confined.
According to the appearance of gas in bubbles Anderson and Hampton (1980) develloped models of this three phase sediment-water-gas system, to predict the acoustical properties of gassy sediments.

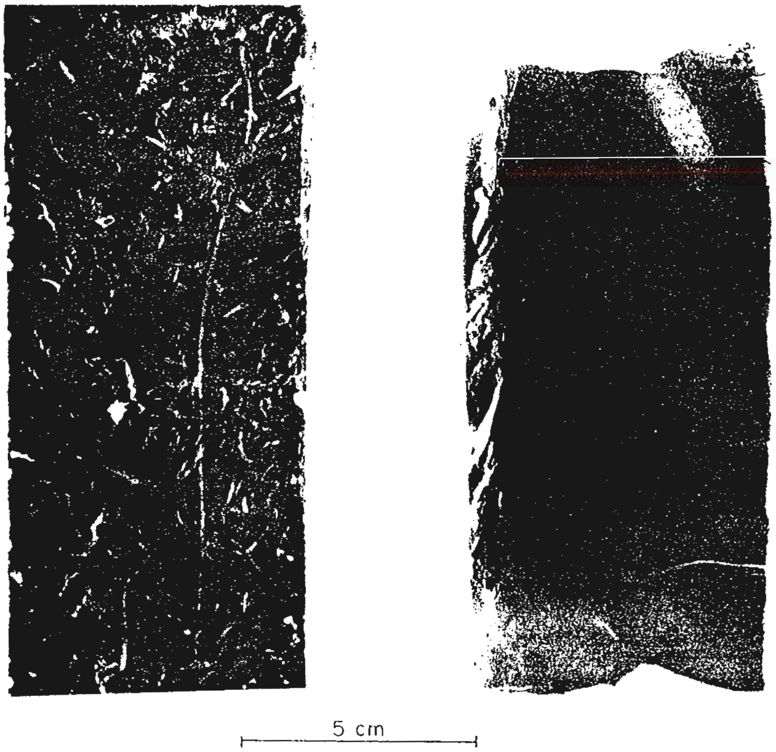

Figure 1. X-ray photographs of two cores taken not far apart of similar composition, besides the gas. Left from an acoustically turbid zone, right from a zone where good records were obtained.

The most observed bubble sizes range from 0.5 to 5 mm diameter. The resonance frequency f_0 of gas bubbles in sediments is determined by both the properties of the gas and the sediment. The important parameters are the ratio of specific heats of the gas, the density and the dynamic shear modulus of the sediment, the ambient pressure and the bubble size. The damping of bubble motion consists of radiation, thermal and friction terms, of which the last is by far the biggest. It is shown that the resonance frequency increases with the ambient pressure. This implies that the effects of bubble resonance is less in ocean bottoms than in shallow water sediments. These are exactly the sediments where gas bubble ocurence is more probable.
Now a prediction of the acoustic behaviour of gas-charged sediments can be made.

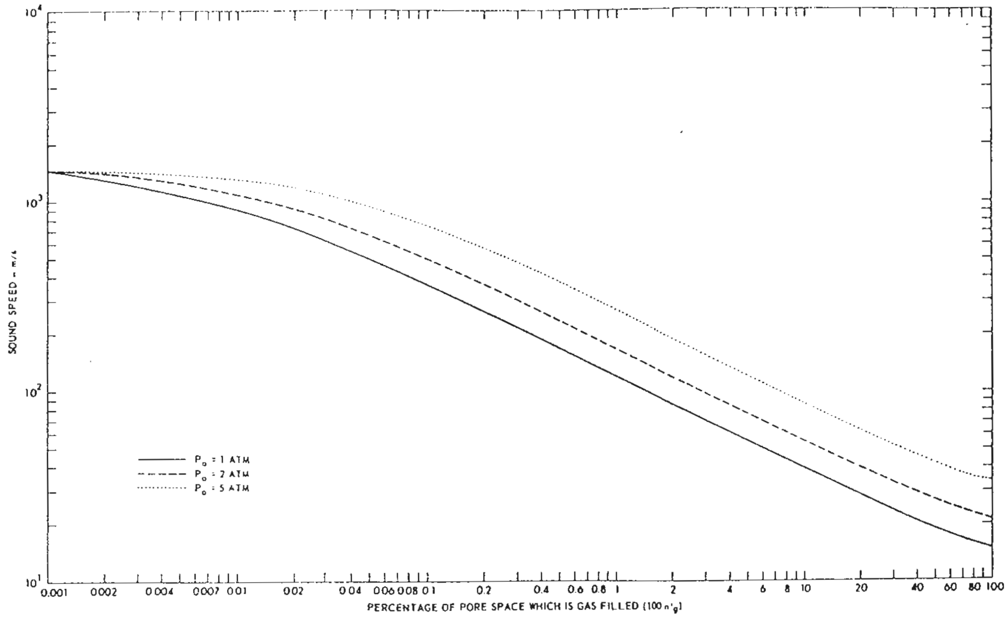

Figure 2. Sound speed vs. gas content silt sediment. Model-based, 60% porosity (Andersen, 1980).

SOUND SPEED
From the models it appears that with increasing gas content the total sediment bulk modulus decreases with grain size. Also the sediment (shear) ridgidity decreases with grain size. In all sediment types the sound speed decreases with increasing gas content. This is until the gas content exceeds 1% of the pore space, from where the decrease in density causes a small increase in sound speed with gas content. This holds for frequencies lower than the resonance frequency of the bubbles (figure 2). Overall sound speed increases with frequency near resonance. Above resonance frequency the sound speed first exceeds and later approximately equals sound speed in gas free (water saturated) sediments. The figure also shows that the bubble resonance effects are much less in ocean bottom sediments, as the bubble vibration is damped by the much higher internal friction (figure 3). Thus a strong negative bottom reflection obtained with a signal of frequency lower than resonance (e.g. 3500Hz, water depth 10 m) is due to low sound speed in the probably gas bearing sediment.

ATTENUATION
Attenuation in gas-charged sediments is caused by frame friction absorption, absorption due to loss mechanisms associated with bubble motion and scattering by the bubbles. Figure 4 gives the attenuation as function of the frequency ratio. It appears that attenuation is maximum near bubble resonance frequency, but is even high at frequencies off resonance. Thus small quantaties of gas, decreasing sound speed only slightly can significantly increase the attenuation.

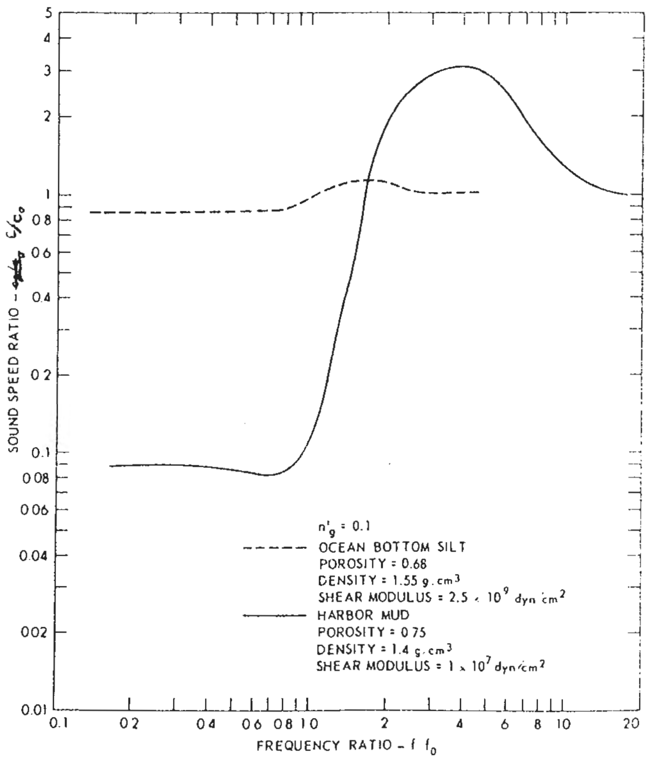

Figure 3. Gassy sediment sound speed vs. frequency ratio (Andersen 1980).

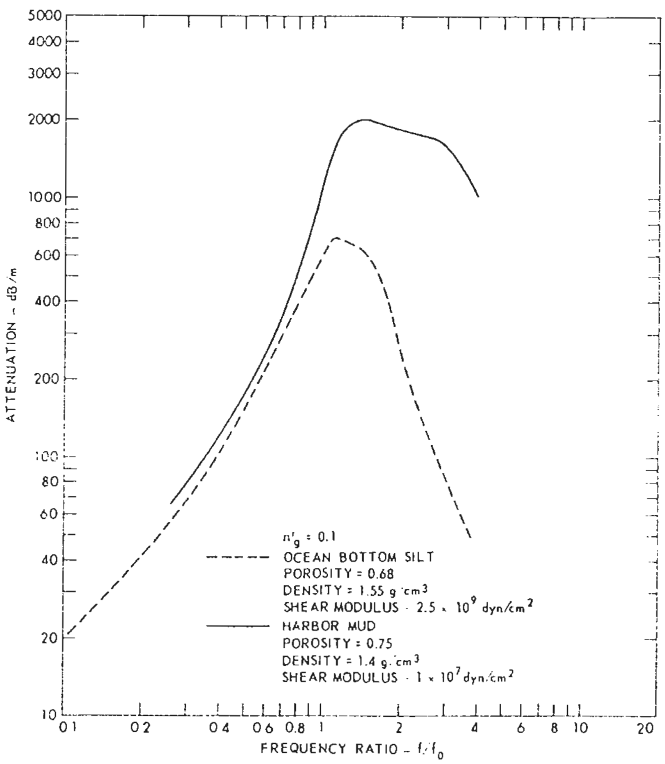

Figure 4. Gassy sediment attenuation vs. frequency ratio. (Andersen 1980).

TYPICAL APPEARANCES OF GAS-CHARGED SEDIMENTS ON ACOUSTIC PROFILES

In practice many shallow water fine grained sediments appear to be almost acoustically impenetrable to the energy from high resolution continuous seismic profilers, with peak outputs of up to 2-3 kJ at frequencies of 0.2-10 kHz. The strong reflections, due to the low impedance of the gas-charged sediments, cause the masking of the underlying strata, which are called to be acoustically 'turbid' sediments. The vertical dimensions mostly do not exceed 2 m, the horzontal dimensions can be considerable (Schubel, 1974). Offshore West India Karisiddaiah (1993) reports on vast acoustically masked areas, extending more than 1 km in horizontal dimensions. In places narrow seeps can be detected below the so called acoustically transparant clays. Those are clays in which no separate reflectors can be distinguished (figure 5).

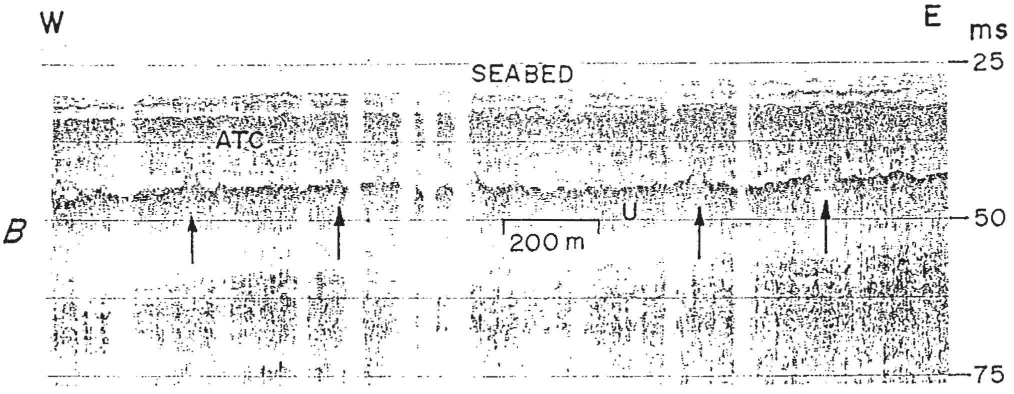

Figure 5. Acoustically transparant clays (ATC) over extensive gas bearing strata with some seeps.

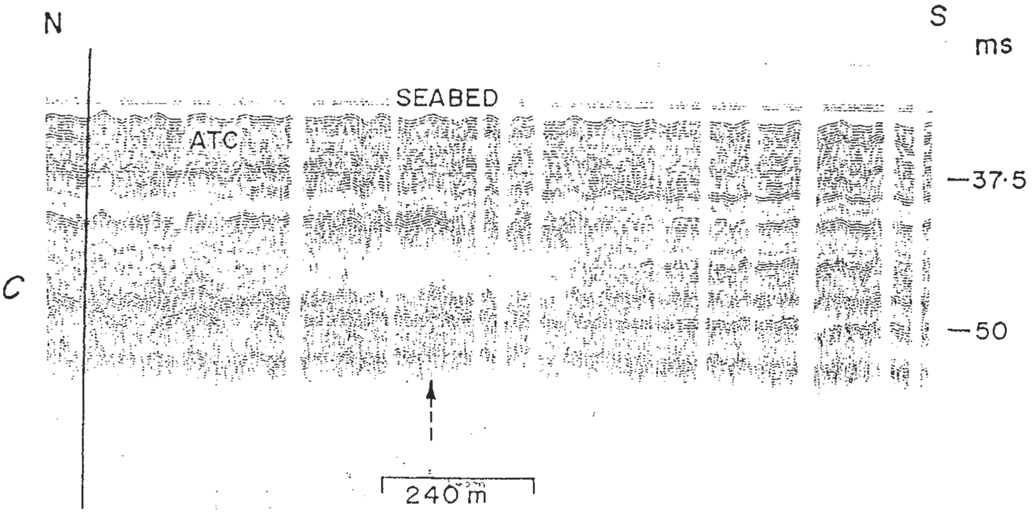

Figure 6. Acoustic whipe out zone over a possible seep.

In figure 6 an acoustic wipe out zone is seen, below which a discontinuity in the seismic reflections is present, probably being a gas seep.

In the Northern Adriatic Sea a lot of classic features in seismic profiles due to gases in sediments are found and described by Stefanon (1980). The basin effect is defined as the ultimate one among these, where all sub-bottom structures are masked by the high reflectivity of the whole mass of gassy sediments. In figure 7 a concentration of gas can be seen below a certain horizon, from which it locally escapes to form cloud-like features. There are no acoustic windows and phase reversal seems to take place at some of the boundaries, which have strong first multiples. Typical migrated gas from deeper sediments can be seen in figure 8, where accumulation is evident below the almost unstratified top strata. The ringing at the arrow confirms the presence of gas. The gas pocket in figure 9 is a representation of in situ generated gas. Below the pocket the velocity pull-down effect causes the apparent slight sag in the continuous strata.

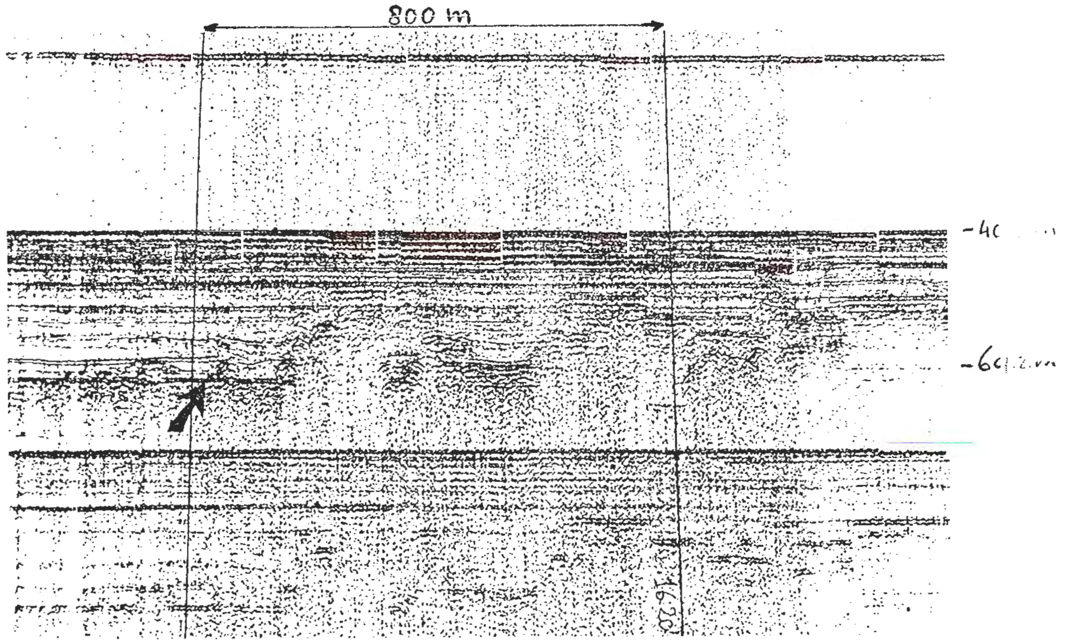

Figure 7. Gas accumulation under very well stratified sediments. The cloud-like structures are caused by a sequence of bright spots, due to single small reflectors.

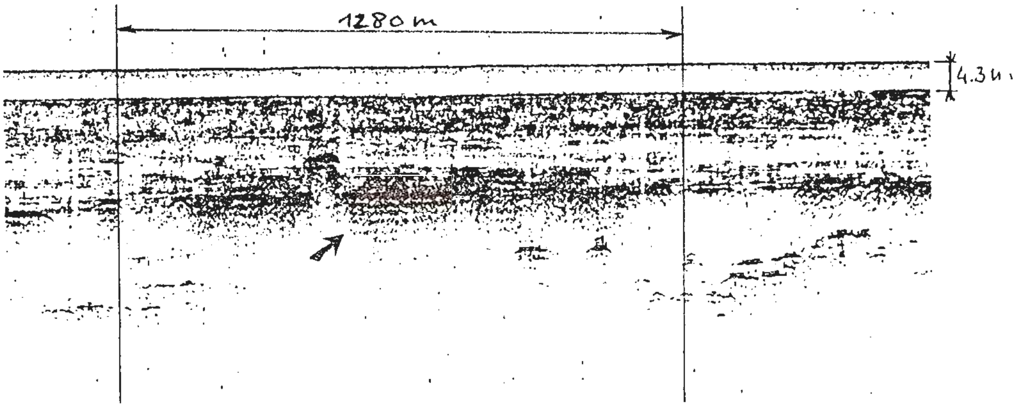

Figure 8. Migrated gas in less stratified sediments of the river Po over an erosional surface.

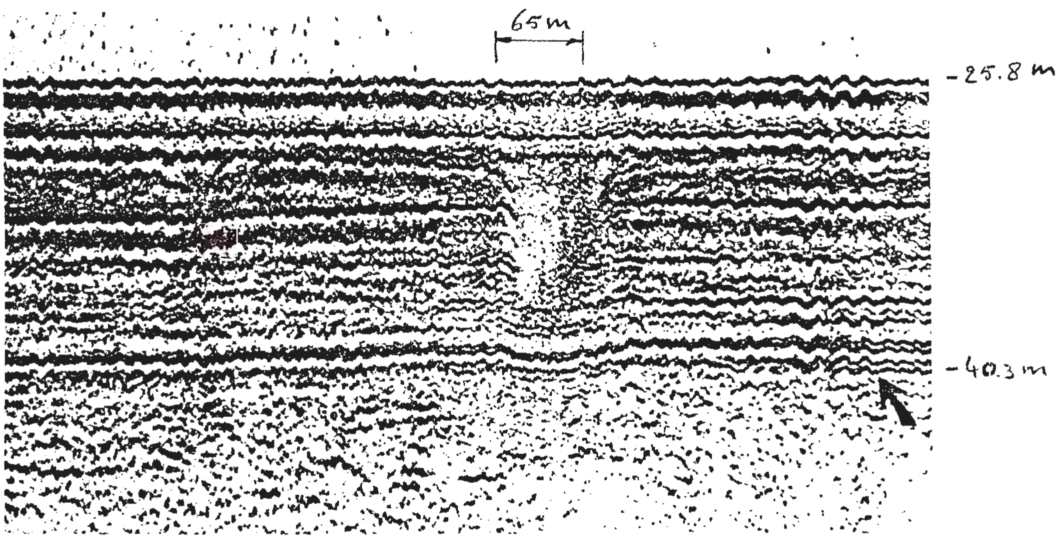

Figure 9. Gas pocket with in situ generated gas. Within and below the pocket the velocity pull-down effect is very clear.

Figure 10 shows so called gas-charged sediment cones, which often vent if they reach the surface and can measure hundreds of meters in diameter. Clay layers intebedded by thin peat deposits, as proved by borings, are shown in figure 11. The hypothesis of Stefanon is that the peat layers, although very thin produce some gas, that remains confined between the clay layers. The double phase reversal, due to the low impedance of the signal passing through enhances the thin stratum that normally may be beyond the resolution limit of the profiling system. Here the abrupt disappearance of some strata not necessarily is due to an acoustic void, but may instead point to the absence of gas locally and thus the absence of the enhancing effect.

In Lake Rotorua (New Zealand) reflection seismic was part of the investigation to map faults, associated with the circulation of geothermal hot water (Davy, 1992). The low frequency signal of an airgun (dominant frequency band 15-100 Hz) could not be used because of the high propeller noise of the vessel, so a high frequency electrostatic plate boomer was used. After deconvolution of the data to minimise lakefloor multiples in places strong lakefloor multiples remained. Indicative for lakefloor gas is first the negative polarity of the initial pulse reflected.

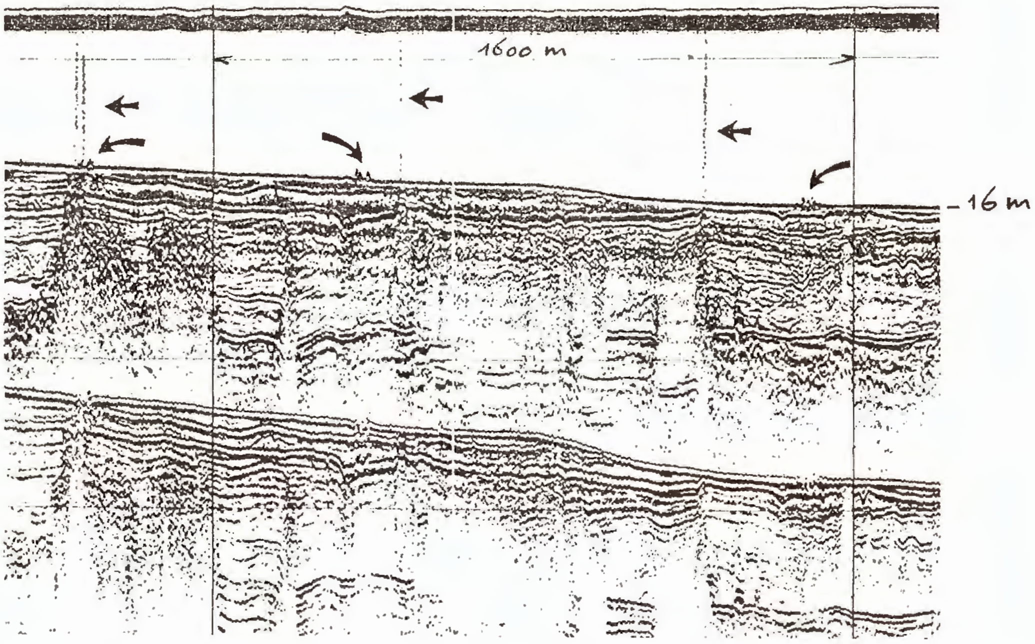

Figure 10. Venting gas-charged sediment cones. Bent arrows mark mounds of dredged material that is dumped offshore.

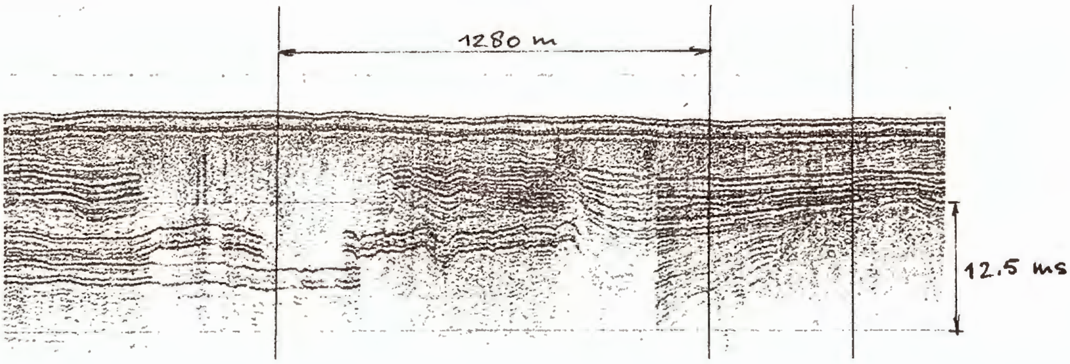

Figure 11. A sequence of very well stratified sediments, showing abrupt interruptions possibly caused by the absence of gas.

This 180°phase shift is produced by the pressure release surface (reflection from a boundary involving a strong decrease in sound speed), formed by gas bubbles in the sediments (figure 12). Secondly the constant phase of the lakefloor multiples indicates gassy sediments. A water saturated sedimentary lakefloor will give a positive primary reflector, but a 180° shifted first multiple, due to the 180° phase shift at the water/air interface. These multiples can be treated by ordinairy deconvolution. A gas-charged sediment however will give a negative primary lakefloor reflection and succesive negative multiples because of both a 180° phase shift at the lakefloor as a 180° shift in phase at the water/air interface. See figure 13. An exemple of such strong lakefloor multiples is given in figure 14. The pockmark, a typical sink in gas bearing sediments where pressure releases, is studied in detail in figure 15. It clearly indicates the presence of gas in the center of the pockmark.

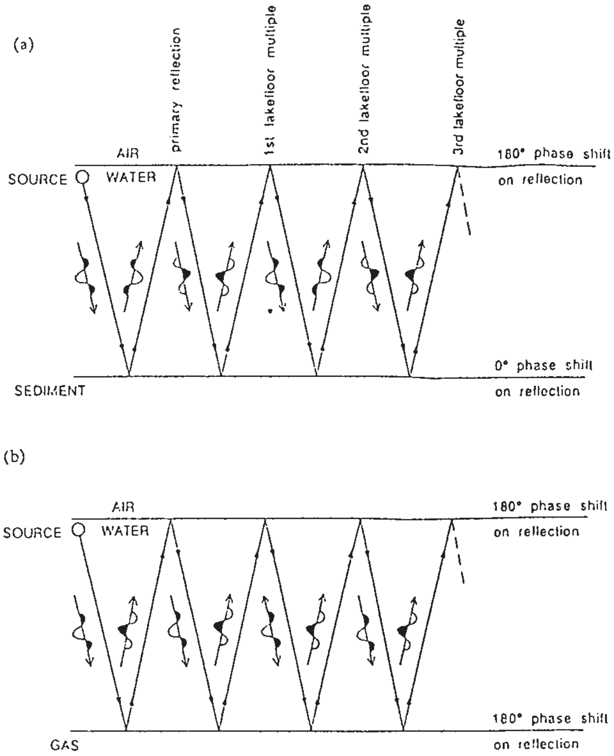

Figure 12. A water saturated sediment gives a reflection without phase shift (a). A gassy sediment gives a 180° phase shift on reflection (b). Phase shift occurs at the water/air interface.

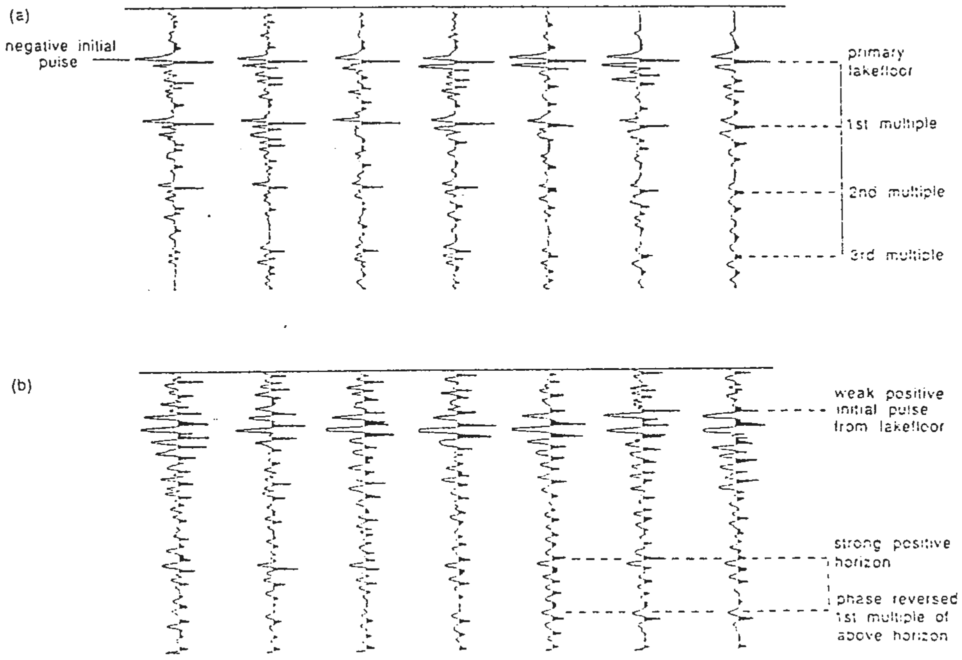

Figure 13. Constant phase multiples of a gas bearing lakefloor (a). A 180° phase shift of the first multiple of a saturated sedimentary lakefloor.

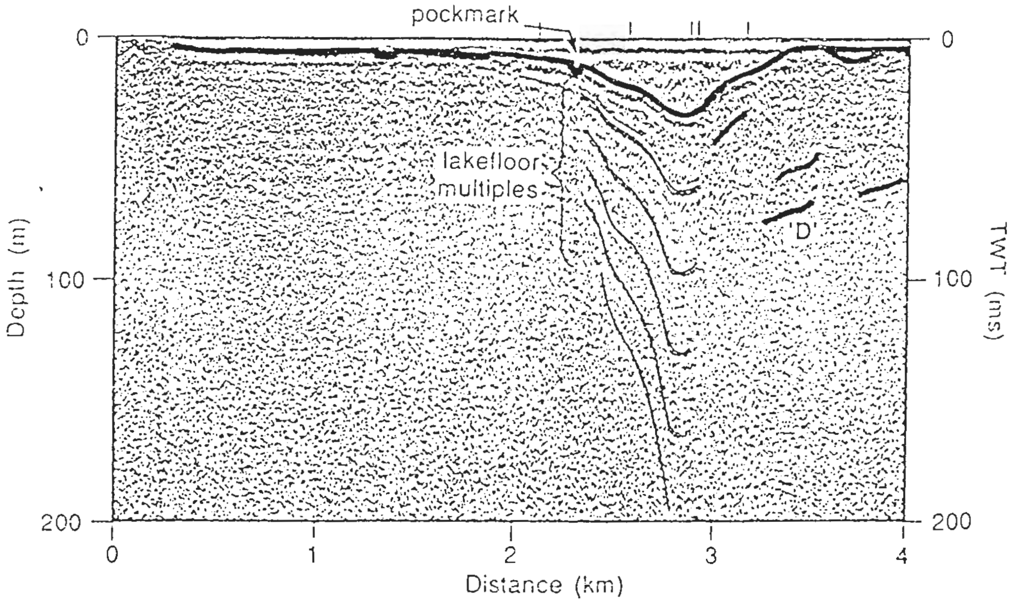

Figure 14. Lakefloor pockmark and strong, gas associated, multiples.

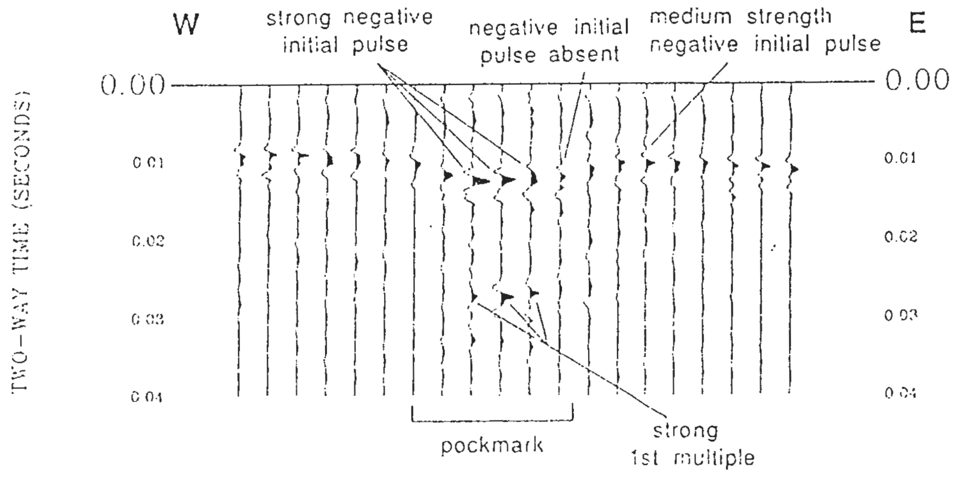

Figure 15. Expanded section of the pockmark above, showing the presence of gas in the center.

Sieck (1973) shows a sea-bottom mound or mud lump from which apparently gas at a higher pressure has escaped. The sedimentary strata facing the central channel have been pulled up (figure 16).

Deeper horizons below gas-charged sediments normally can be observed at frequencies below 100 Hz and will show velocity pull-down due to the low sound speed in these sediments. However resolution decreases with frequency. Because of the phase shift and 20-90% reduction of the velocity distinct gas bearing horizons appear as 'bright spots' in the records. Gas distributed throughout a sedimentary section scatters the energy and shows a seismic 'whiteout'.

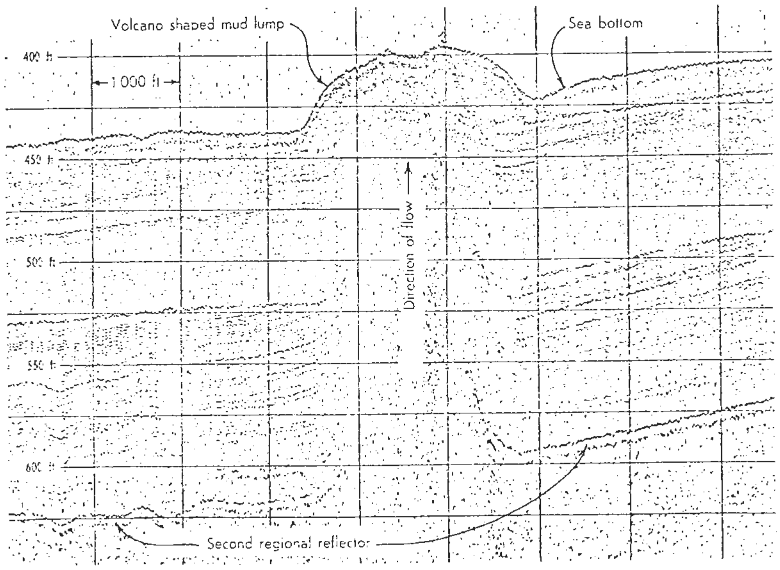

Figure 16. A mud lump offshore Louisiana.

Schubel (1974) warns for the interpretation of acoustically turbid zones, as they also can appear by burried shell beds. These should be distinguished by their morphology, that is characterised by limited lateral dimensions and a more irregular upper surface.

ENGINEERING SIGNIFICANCE

Shallow acoustic voids and other features pointing towards the presence of gas-charged sediments could pose hazards to offshore drilling and foundations for offshore structures (Sieck, 1973; Stefanon, 1980). Low densities, low bulk moduli and decreasing shear strengths under increasing loads in these sediments of low permeability mean instable zones. Sudden gas eruptions may occur. Especially the gas-charged sediment cones, often venting, should be taken care of. Because of their large dimensions danger will not be less by staying away some distance from observed bubble clusters.

CONCLUSIONS

Gas-charged sediments are found all over the world, at the bottom of seas, lakes, bays and estuaries. They may be of atmospheric, biogenic, thermo-catalytic or volcanic origin. The probably most occuring gases are methane, carbon dioxide and nitrogen.

Only small amounts of gas, e.g. less than 1% of pore space, may make the gas-charged sediment acoustically impenetrable and masks the sub-bottom structure. Even smaller amounts of gas that cause small decreases in sound speed can produce considerable attenuations. Attenuation is maximum near the resonance frequency of the bubbles, this frequency is depending on both the properties of the gas and the properties of the sediment. Below resonance frequency the sound speed in a gassy sediment is less than that one in a water saturated sediment. Above resonance sound speed first is higher than and later equals the sound speed of the water saturated sediment.

The higher the ambient pressure and the higher the bulk modulus and dynamic shear modulus, the less the bubble resonance acoustic effects are. This often means that coarser gas bearing sediments in deeper waters are less acoustically turbid.

As bubbles form an effective pressure release surface, these are strong acoustical reflectors. A 180° phase shift of the sound wave occurs at this reflection.

A lot of features are indicative for the presence of gas in a sediment on the shallow reflection profile: phase reversal of the initial pulse reflected from the sea/lake floor, abrupt ending of continuous strata, acoustically turbid zones, gas-charged sediment cones, gas vents, mud lumps, pockmarks, wipe-outs, velocity pull-down effects and strong constant phase multiples.

Care should be taken in the interpretation of acoustically turbid zones: they might be caused by burried shell beds.

High energy, low frequency acoustical sources can penetrate gas bearing sediments, but the records obtained cannot result in high resolution shallow seismic profiles.

Although gas-charged sediments mask or hinder the interpretation of the sub-bottom in high resolution seismic profiling, they always are a warning for possible hazards in offshore drilling and foundation engineering activities.

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EXCURSIEVERSLAG McDERMOTT-ETPM

E.J.B. van der Holst

Op woensdag 2 maart 1994 heeft het DIG een excursie georganiseerd naar Mcdermott-ETPM, een offshore bedrijf dat zich o.a. bezig houdt met het leggen van pijpleidingen, over bijna de hele wereld.

Om half drie vertrokken wij dan ook naar de rotterdamse haven, waar de basis van het Noordzeegebied zich bevond. Hier lagen twee enorme "pipeline laybarges" aangemeerd, die binnenkort weer vertrekken om ergens op het continentale plat een pijpleiding te leggen.

Nadat wij kennis hadden gemaakt met onze excursieleider dhr. Peterman, en een helm hadden ontvangen gingen we op weg naar het schip, dat we dit keer konden bezoeken, de DLB 1601.

Het eerste wat onze aandacht greep was een enorme ploeg, die op de werf stond. Deze ploeg word gebruikt om een sleuf in de zeebodem te trekken, zodat de pijpleiding netjes bedekt ligt.
De DLB 1601 is in staat om 20 km. per dag over de zeebodem te ploegen.

Nu konden we de loopplank op om het schip van binnen te bekijken. Het hele schip werd van top tot teen bekeken. Zo zagen we de brug, het helidek, en de verschillende lasstations waar de pijpsegmenten aan elkaar worden gelast.
Vervolgens liepen we naar het eindpunt, waar we bijna met onze schoenen in het koude zeewater stonden.
We waren beland bij de plek waar de pijpleiding via de stinger, langzaam naar de zeebodem werd afgezonken.
De andere werkzaamheden die bij het leggen van een pijpleiding moeten gebeuren, laat Mcdermott-ETPM door subcontracters verrichten.
Je moet hierbij denken aan het onderzoeken en in kaart brengen van de zeebodem, rockdumping, baggerwerkzaamheden e.d..
Het schip is in staat om 6 km. pijpleiding per dag te leggen.
Hierna volgde een fantastisch diner, naar frans model in de eetzaal van het schip.

Ik wil de heer Peterman hartelijk bedanken voor deze leuke en leerzame excursie, en wens het schip een behouden vaart toe naar het volgende project in Noorwegen.

VOID DETECTION
BY USING
GEOPHYSICAL METHODS

By P.H. Dijkshoorn
211476

ABSTRACT

In this paper, geophysical methods to detect subsurface voids are discussed. Their succes is limited by the resolution and penetration, obtained by the particular method applied in a given situation. No single geophysical method will provide the answer to all problems associated with cavity location but improvement can be achieved by the application of several methods to a given problem. Before a certain method is chosen, a desk study should be done to study all available information.

With most geophysical methods it is possible to detect cavities whose depths of burial are less than twice their effective diameter. The concept of effective diameter is rather important as the presence of voids does also affect the physical properties of the surrounding rock mass. This gives rise to a much larger anomalous zone than produced by the cavity on its own.

During the latest decades, not only existing methods have been improved, but also new techniques, such as Ground Penetrating Radar, cross-hole methods and tomography, have been developed which show very promising results.

1. INTRODUCTION

The presence of solution features or abandoned mine tunnels beneath a highway, dam, or buiding can pose a serious threat to the stability of the structure. Investigators have experimented with all manner of geophysical techniques in the search for an inexpensive, reliable means of locating cavities before construction begins, thus permitting the builder to avoid those problems associated with the subsidence or collapse of a structural foundation.

This paper discusses geophysical methods that are useful for detecting voids or caverns. These methods are all based on measurements related to differences in physical properties between the cavities and the bedrock. The general depth towards the detection of anomalous zones is down to about 50 m, which is the main area of interest in a site investigation.

The presence of an anomaly in the survey area is controlled by the physical dimensions, shape and depth of burial of the cavity, and the properties of the material that it contains in relation to those of the surrounding rock mass. All of these parameters influence the performance of the geophysical technique used in relation to four fundamental controlling factors (McCann, 1987), namely:

(1) Penetration;
(2) Resolution;
(3) Signal-to-noise ratio;
(4) Contrast in physical properties.

Before the geophysical survey starts, it should be known whether the proposed method is capable to resolve and locate cavities with minimum specifications at a given depth.

It must be stressed beforehand that to maximize the success of locating a cavity, not only choosing the correct geophysical method but also studying all available information is essential. A desk study can save a lot of money and avert taking wrong decisions. Below, the various geophysical methods, used to detect voids, will be discussed.

2. GEOPHYSICAL METHODS

2.1 SEISMIC METHODS

2.1.1 Reflection Seismics

Although this method (figure 1) has been successful in several cases (e.g. Cook, 1965; Lepper and Ruskey, 1977), in general it can be said that its utility for karst localization is not very great. There are several reasons for this: first of all, its lack of resolution for shallow depth when used with a low-frequency seismic source. This is because when the wavelength of the incident seismic energy is greater than the cavity diameter, very little energy will be reflected back to the surface. Moreover, in a shallow survey, reflections from near-surface interfaces are often completely obscured by the large- amplitude surface wave arrivals, and consequently difficult to identify. Secondly, this method is relatively expensive to run and to process data (Greenfield, 1979).

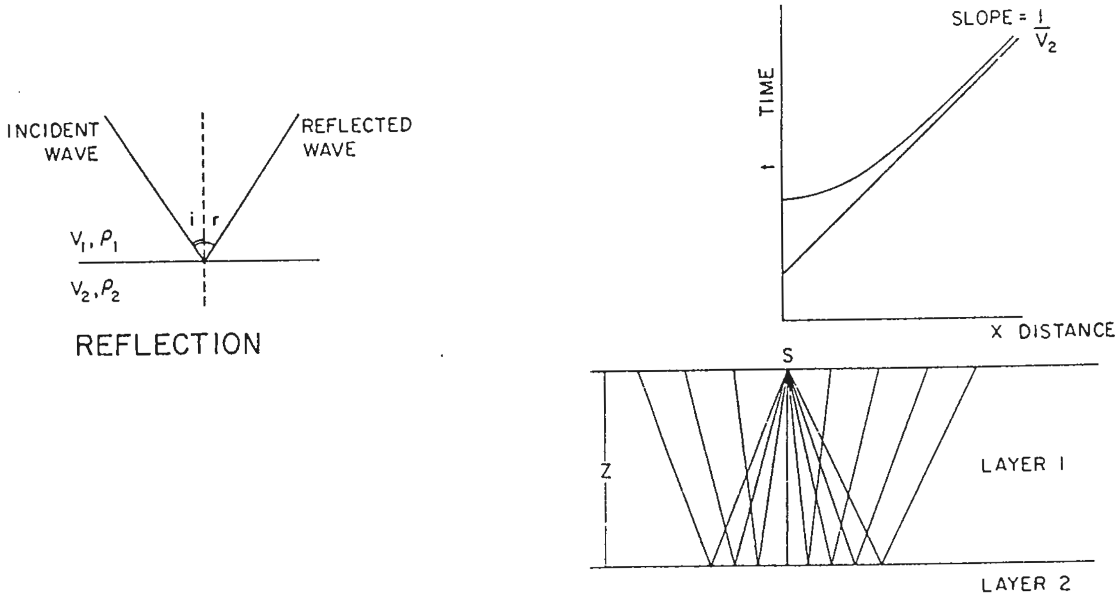

Figure 1: Schematic representation of reflection seismics.

2.1.2 High-Resolution Seismics

The disadvantages of the normal reflection method might be avoided by using the so-called high-resolution seismic method. This relatively new method uses a high-frequency source which improves the resolution considerably, especially when used in combination with modern data processing techniques and an understanding of the basic wave-cavity interaction mechanism. The high-frequency energy will be attenuated so that under normal circumstances the reflected energy would be small and probably lost in environmental and source-generated noise. The use of multiple-geophone or accelerometer arrays combined with digital averaging should reduce this problem. It may well be that the seismic reflection method will be more widely used in the future as improved systems become available for shallow engineering surveys. It is concluded that a high-frequency seismic source (700-1500 Hz band-width) used in conjunction with common depth point, reflection processing does have considerable potential for cavity location, but a practical system for shallow depths down to 30 m has yet to be developed.

2.1.3 Refraction Seismics

This method (figure 2) is also used to detect sub-surface cavities but, like the reflection method, few writers report successes with it, except where the cavities are close to the surface. When a cavity is at a depth that is greater than its diameter, the resolution of the cavity from a seismic refraction survey becomes increasingly difficult. It is, however, observed that while the cavity may not in itself be a significant seismic anomaly, the rock mass surrounding the cavity may be disturbed by stress relief and weathering effects related to the presence of the cavity. The detection of an open cavity is a function of its dimension and the characteristics of the seismic line, i.e. its overall length and the geophone spacing. Most seismic sources radiate energy at too low a frequency to resolve the small, localized targets represented by a cavity system. Not only cavities produce anomalous perturbations but also variations in the surface topography of the refracting horizon, or changes in the thickness of the overburden or weathered layer can give rise to similar results. Therefore, care should be taken when identifying a cavity in the results of a refraction survey.

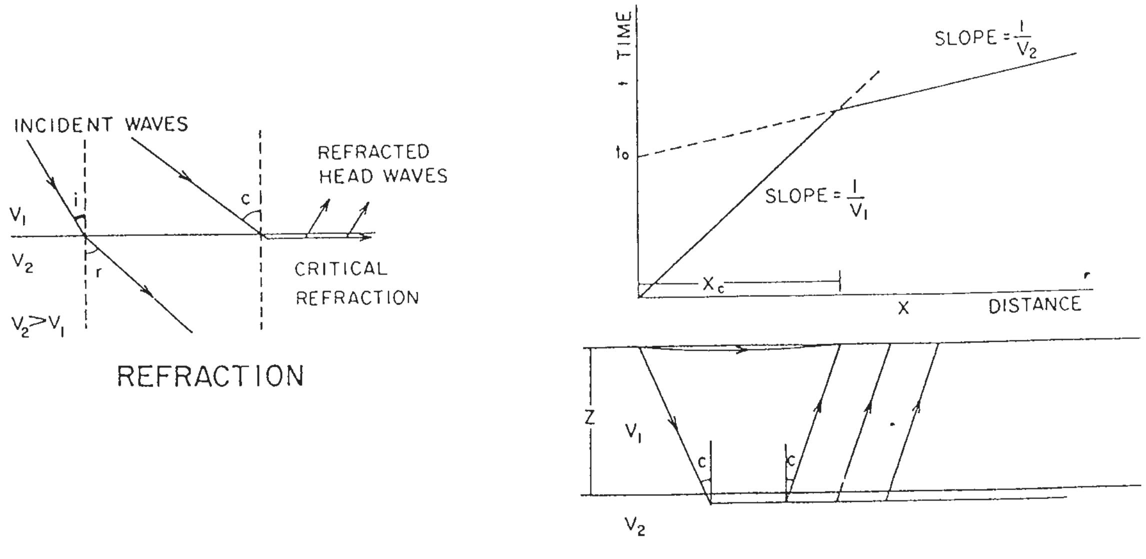

Figure 2: Schematic representation of refraction seismics.

2.1.4 Vertical Seismic Profiling

The method, which is also used in oil-industry (Kenett et al., 1980), works by moving a seismic source around the top of a borehole at several distances and so to investigate a cone-shaped volume of the rock mass. Again, the relationship between the wavelength of the seismic energy and the cavity is critical, because a small cavity would probably have very little effect on the travel time and amplitude unless the presence of the cavity also affected the properties of the surrounding rock mass.

The method is relatively easy and not expensive.

2.2 ELECTRICAL RESISTIVITY METHOD

This method has found favour in the detection of cavities and old mine workings. In the resistivity method, artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface (figure 3). This can be done be using different electrode arrays such as the Schlumberger, Wenner or dipole arrays (figure 4a). For detection of underground voids even special arrays have been developed (figure 4b) of which the Bristow method seems most favourable (Lowry et al., 1990). Deviations from the pattern of potential differences expected from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities (Kearey et al., 1989).

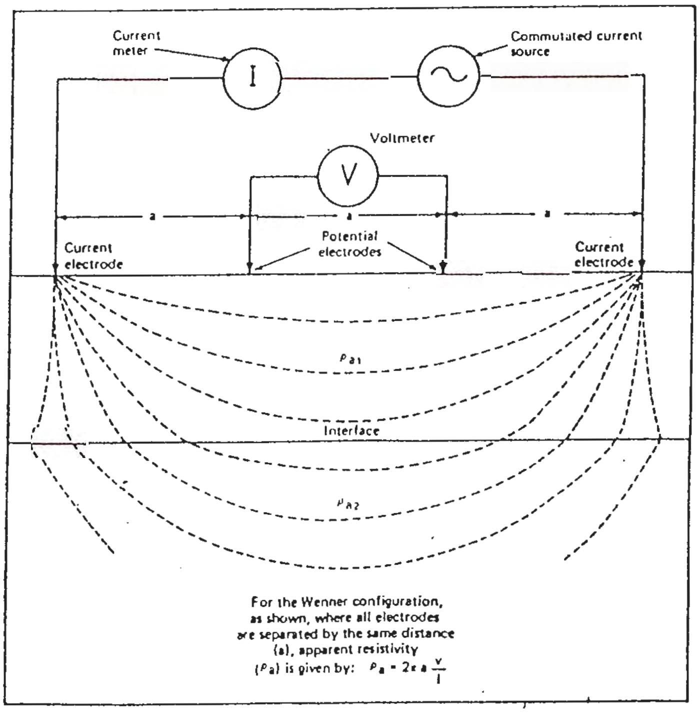

Figure 3: Principle of electrical resistivity technique.

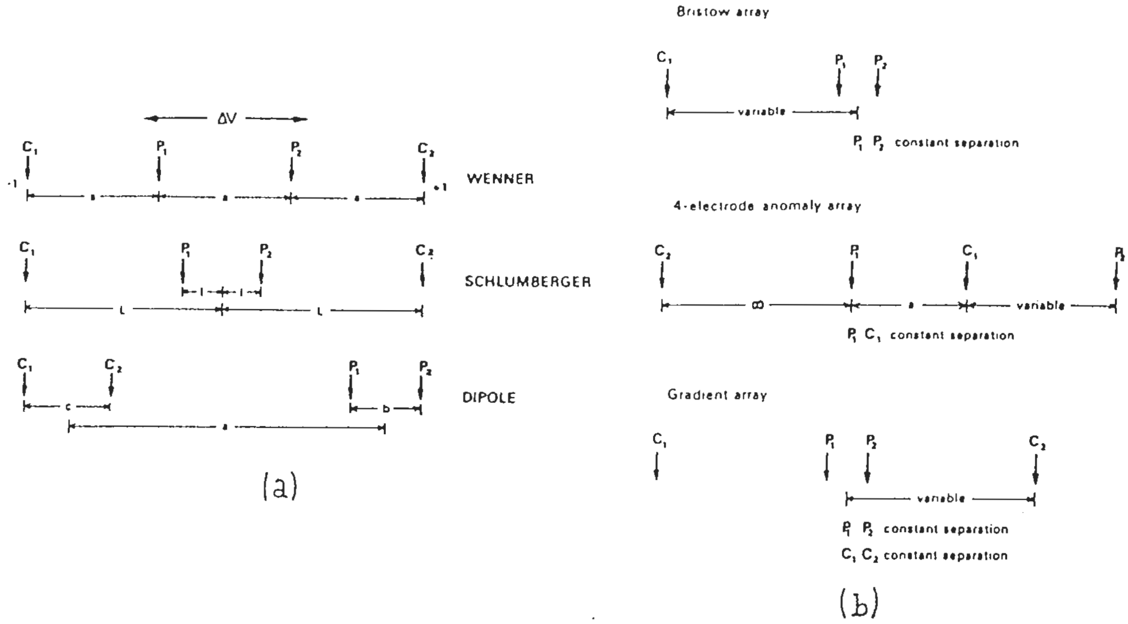

Figure 4: Composition of electrode arrays (a) Normal arrays; (b) Arrays specially developed for the detection of cavities.

According to McCann et al. (1987), there are two electrical surveying techniques that are suitable for cavity detection:
(1) Mapping and traverse surveys, which have a limited depth of investigation, can be used to delineate near-surface lateral variations and surface expressions of cavity.
(2) Specialized electrode arrays having sufficient depth of investigation and resolution have been developed to detect perturbations due to the cavity itself.

The first technique has proved to be very useful because although they cannot locate voids directly, their presence often changes the condition of the overburden. Caves in karst areas are most often part of underground drainage systems and often have cracked rock above the actual void. This cracked rock will allow the soil above the cave to be rapidly drained and thus will have higher than normal electrical resistivity (Greenfield, 1979). In the case of infilled voids, the reverse will happen because of the poor drainage (McDowell, 1975).

For the second technique, a high resolution and a deep penetration is required because solution caverns are usually buried at depths equal or greater than their diameter. An unfilled cave or void will of course be a zone of near infinite resistivity. When a cave, however, is filled with water or mud, it may be a better conductor than the surrounding rock. For these reasons caves can be expected to have anomalous electrical conductivity.

In order to decide whether the resistivity method is suitable at a particular site, it is necessary to compare the interaction of the background noise produced by inhomogenities in the host rock with the anomaly caused by the expected cavities.

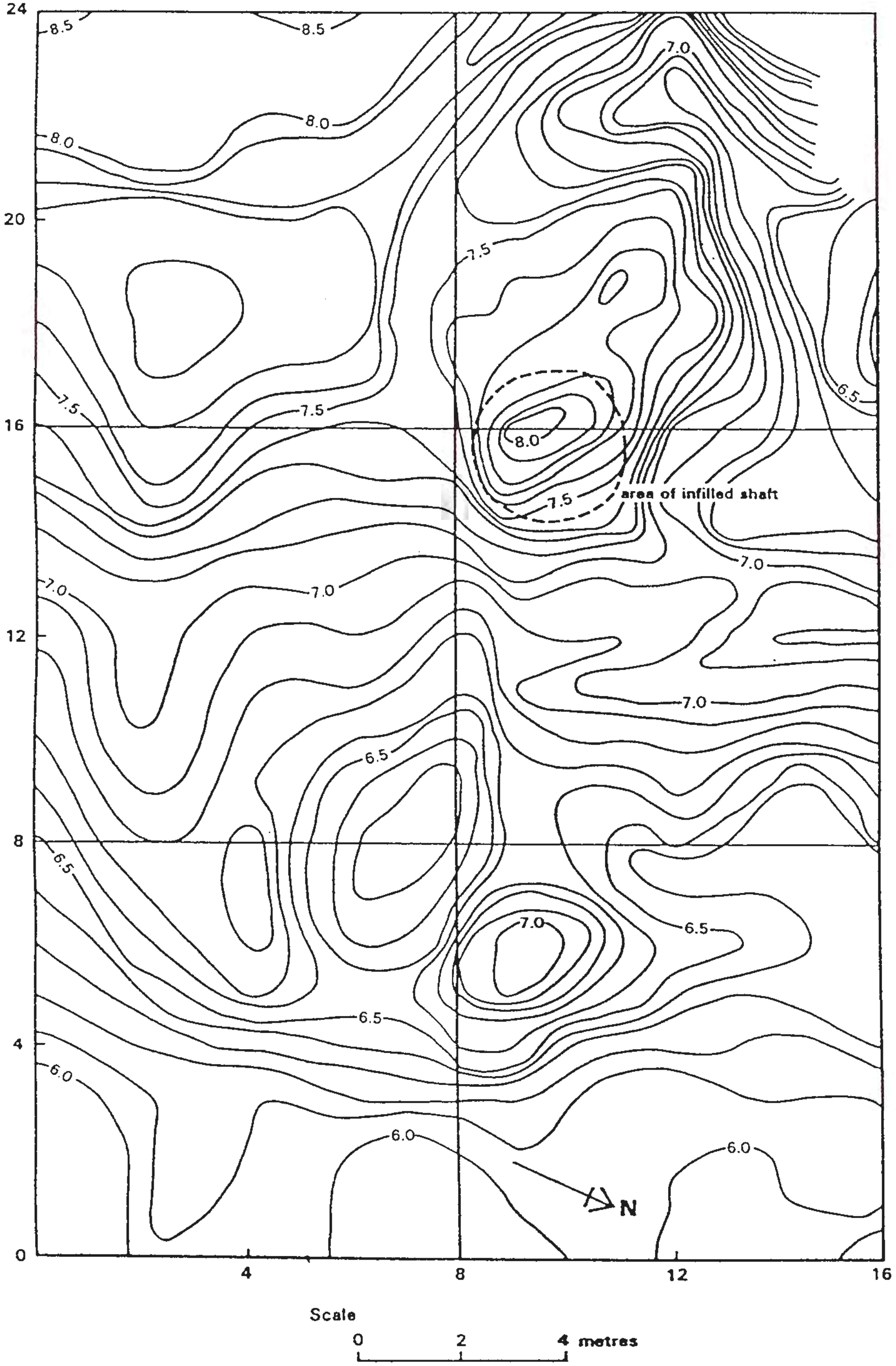

FIG. 5. A magnetometer survey over an area containing a brick-lined shaft which is thought to be inclined. Values in gammas plotted relative to 48600 with base station at 0,0 of 48650 gammas.

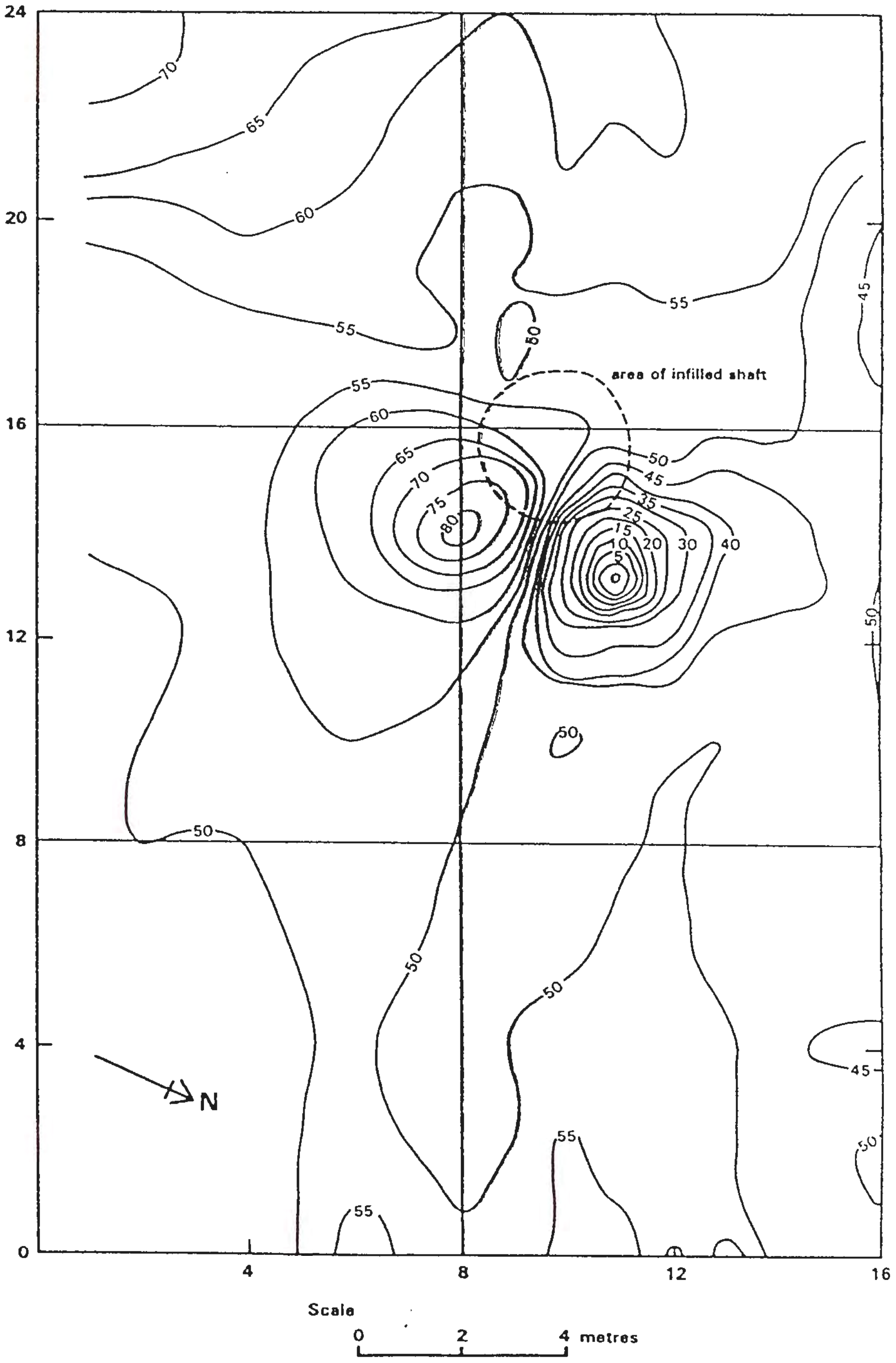

FIG. 6. An EM31 electromagnetic survey over the shaft in Fig. 5. Values are millimhos m^{-1} uncorrected.

2.3 GRAVITY METHOD

Gravity measurements have been used extensively to survey karst areas and a number of authors (e.g. Neumann, 1967; Thiaudiere et al., 1989) refer to the use of the micro-gravity meter for this kind of investigations. From the micro-gravity survey a map is obtained (figure 5) which shows the variations of density of near-surface geological materials. It should be noted however, that the anomalies are not necessarily cavities but only represent a density variation. Greenfield (1979) states that the most important use of the gravity is as a means of screening large areas to locate areas of potential problems. A restriction to the method is that it should best be used in relatively flat areas.

Also here it is possible that the cavity itself lies outside the resolution of the method but because a cavity affects the properties of the surrounding rock mass -one could think of fracturing or the intersection of solution channels- it is still possible to detect the present voids.

2.4 MAGNETIC METHOD

This method shows similarities with the gravity method as it is hoped that the void will appear on the map as an anomaly (figure 6), showing the variation of the earth's magnetic field. For a successful result it is required that the cavity is filled in with a material that has a different magnetic susceptibility to that of the surrounding rock mass.

In general, it is tought that the method is more appropriate for locating old mine shafts as they are often filled in with magnetic material or bricklined. Successes have been reported for instance by Raybould and Price (1966) and by Dearman et al. (1977). It is clear that when the infill material is the same as the surrounding rock mass, no anomaly will occur.

2.5 GROUNDRADAR METHOD

Ground Penetrating Radar (GPR) is a relatively new technique which offers a way of viewing shallow soil and rock conditions. In general, it can be said that GPR is a technique similar to reflection seismic and sonar techniques. The radar produces a short pulse of high frequency (10-1000 MHz) electromagnetic energy which is transmitted into the ground (figure 7 and 8). The propagation of the radar signal depends on the high frequency electrical properties of the ground.

Several authors (Darracott and Lake, 1981; Leggo and Leech, 1983) have reported successes with the GPR to detect cavities. The penetration of the electromagnetic energy is difficult to predict in any geological situation, but a high moisture content in the deposits and the presence of clay near the surface reduces it considerably. However, when the penetration of the electromagnetic energy is adequate, the resolution of even small features can be high.

Although the GPR is still a relatively new technique, it has already shown good results. When data processing will improve, this method will see expanded use in the future, especially because the data can be obtained rapidly and economically.

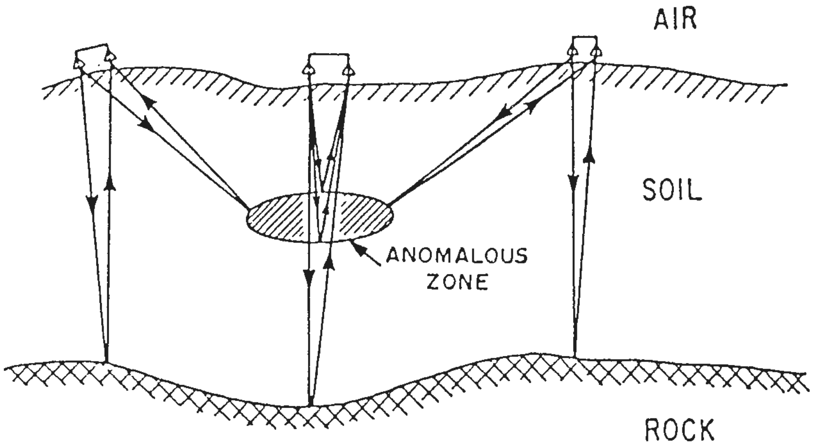

FIG. 7. Conceptual illustration of the radar being used in the reflection profiling mode on soil over bedrock.

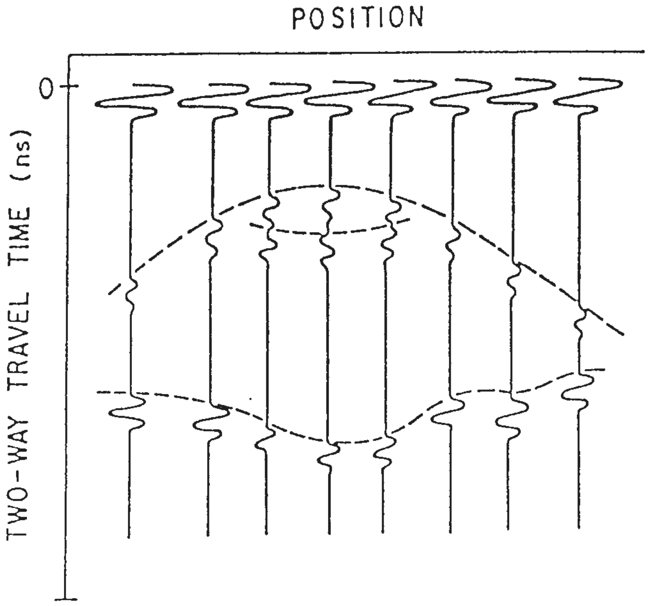

FIG. 8. Resulting radar record obtained over the idealized situation in Fig. 7.

2.6 CROSS-HOLE MEASUREMENTS

In this method, the rock mass between a grid of boreholes can be assessed for the presence of cavities by making careful seismic or groundradar measurements down the length of the borehole (figure 9). The great advantage of this method is that anomalous zones are quickly and easily identified and positioned. The best results are obtained with a high-frequency source, combined with modern signal-averaging techniques applied to the received signal (McCann et al., 1975). With a high-freqency source the optimum borehole separation is about 25 m for a cavity with dimensions of approximately 3-4 m, provided that there is adequate seismic contrast between the discontinuity and the surrounding rock mass (McCann et al., 1986). Assessment of the rock mass condition between the boreholes can be extended by the use of computerized tomographical modelling techniques. With this method the rock mass between the boreholes is scanned by a series of multiple seismic or electromagnetic measurements. The plane between the boreholes is devided into a grid and the spatial distribution of the seismic properties is calculated from line integrals along rays in the plane and displayed as a digital picture (Dines and Lytle, 1979). This is illustrated by figure 10.

A disadvantage of the cross-hole seismic method is that fairly sophisticated instrumentation is required and that this makes the method rather expensive. The cross-hole radar method is also relatively expensive but has even a higher resolution.

2.7 TEMPERATURE MEASUREMENTS

This method is for instance described by Moscicki (1987) and works by measuring shallow temperatures. It is proved that temperature anomalies up to 1 degree C exists over underground cavities. Temperatures are measured at depths of tens of centimeters and in general, temperatures in winter are lower over the cave that those away from the cave.

The advantage is that the method is simple and the equipment inexpensive, but the disadvantage is the considerable influence of weather conditions, the need to make probe holes and interfering factors such as inhomogeneities, humidity changes and ground cover. As it requires a period of measurement of up to 6 months, it is not an attractive method in a site development study. The same results might be obtained in less time by electrical resistivity.

Cross-hole measurements

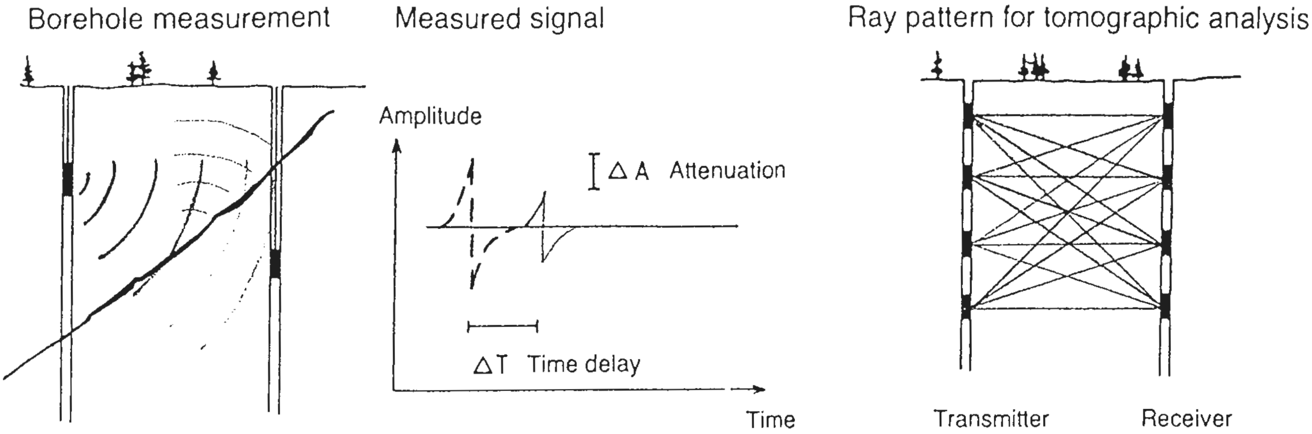

Figure 9: Principles from the cross-hole method. Cross-hole measurements provide information on the rock mass between the boreholes. Low quality rock, such as fractured zones and solution features, will cause delay in arrival time and an increase in attenuation which can be dectected and analyzed by tomography.

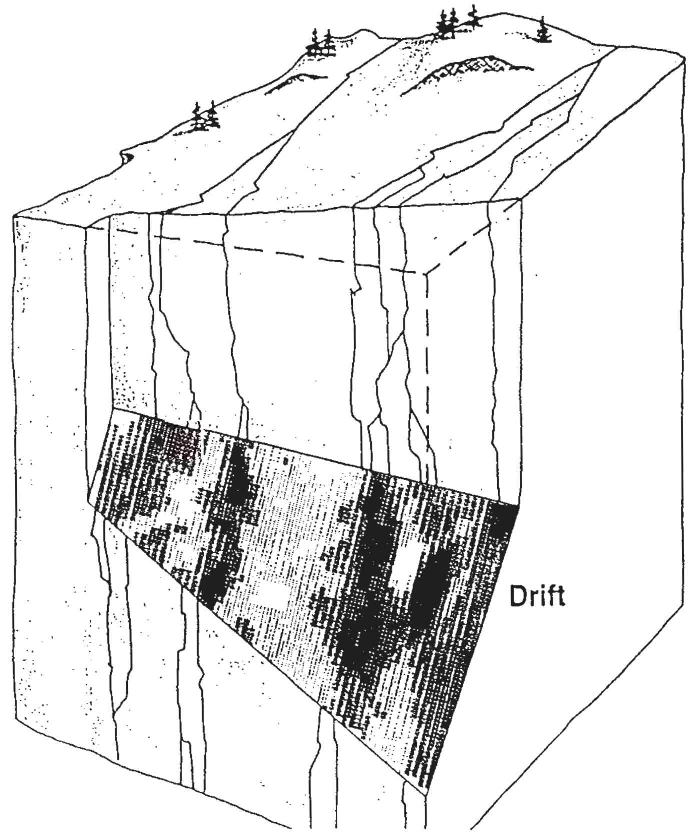

Figure 10: This is the result from a cross-hole survey. A number of fracture zones have been identified in two of the holes. A cross-hole radar survey, followed by tomographic analysis of the data uniquely reveals the extension of the fracture zones between the boreholes. Dark areas indicate poor quality rock (fracture zones). An air-filled drift passing between the boreholes is also clearly seen by the radar (from information brochure Swedish Geological Co.).

3. SELECTION OF GEOPHYSICAL METHOD

McCann et al. (1987) stated some general principles in order to establish whether a particular geophysical method would give rise to a detectable anomaly from a likely cavity:

(1) The physical properties of the cavity and the host rock should be known to within an order of magnitude to assess the contrast in physical properties. This can be done at a literature stage, but usually the required data are obtained from the initial site investigation boreholes.

(2) Other effects due to the presence of likely cavities, such as changes in the drainage patterns, should be considered. In these circumstances it is the altered properties of the rock mass above the cavity which can be detected.

(3) When the depth of burial is more than two to three times the diameter of the cavity then cross-hole techniques provide the best approach for direct detection.

The table below (table 1) gives an overview of the geophysical methods to detect cavities and makes a comparison between them.

	Penetration	Resolution	Cost
Reflection Seismics	(++)	--	--
High Resolution Seismics	+	+	--
Refraction Seismics	-	-	-
Vertical Seismic Profiling	+	+	+
Resistivity method	+	+	+
Gravity method	+	--	-
Magnetometry	(+)I	-	--
Groundradar method	-	++	++
Cross-hole measurements	(+)H	(+)H	-
Temperature measurements	-	-	+

Table 1: Comparison between geophysical methods to detect cavities.
+ =good; ++ = better; - =bad; -- =worser; H =horizontal; I =depending on infill volume.

4. CONCLUSIONS

In the latest decades, geophysical methods to detect cavities in engineering site investigations, have been improved considerably. The detection of these cavities is limited by the penetration and resolution of the particular geophysical method and the environmental noise at the site. The geophysical survey, in itself, only provides physical data which can be used to construct a model of the underground, but the cavity can only be confirmed by an subsequent borehole programme.

In favourable circumstances it is possible to detect a cavity whose depth of burial is less than twice its effective diameter. It has, however, been pointed out that the cavity also affects the properties of the surrounding rock mass, and so, the geophysical parameters will be influenced by both the cavity and the different physical properties of the surrounding rock mass. It should be clear that no geophysical method can provide all answers during the investigation. The best solution is provided by combining all available data and selecting the most appropriate method(s).

It is encouraging that geophysical methods not only have been improved, but that also new techniques have been developed. In that repect the Ground Penetrating Radar seems to be very promising in the future. Also the cross-hole and surface to borehole, seismic and electromagnetic methods might be applied more frequent, as the geophysical and borehole programme than could be combined. Finally, integration of computerized tomographical modelling is a welcome new evolution in cavity detection.

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Seco e Pinto (ed.): **Soil Dynamics and Geotechnical Earthquake Engineering**, Proceedings of the seminar on soil dynamics and geotechnical earthquake engineering, Lisboa, Portugal, 26-29 Juli 1993, Balkema, Rotterdam, The Netherlands. 499 pp. Price Fl.134,=

General

The proceedings of this seminar are easy to read and understand. The articles give a reasonable introduction to the problem. This results into papers useful to any geotechnical engineer, with or without knowledge on soil dynamics.
The layout of the book is good, especially the quality of the photographs, although the differences in fonts used for the text is somewhat disturbing.

Contents

The topics discussed by the articles have a large variety. From more numerical studies (for example [**Prevost**] and others), via a wide description of laboratory tests [**Ishihara**], to well described case studies [**Ansal**].
Being busy myself with making an overview of all kinds of seismic hazards that can occur during an earthquake, the article by Ansal is specially interesting because the amount and variety of hazards is well documented. On the other hand the article by Ishihara is a great help during a case study of a landslide that occurred in Brunssum, The Netherlands, during the Roermond earthquake with a magnitude of approximately 6 at april 13 1992.

Specific comments

The article by Ishihara is discussing some formula's for the initial shear modulus of different soil types (cohesive,sand,gravel). Also the similarities and differences between testing disturbed and undisturbed samples is being investigated. It is made clear that the influence of disturbance on the shear modulus (ratio) is not constant but depending on the amount of strain and stress. This research is interesting while retrieving undisturbed soil samples from saturated layers might become very costly. A formula to correct for the disturbance of the sample could reduce the costs for retrieval of samples.

One other article, **'Centrifuge tests - A dynamic approach'** by Minh Phong Luong is also very interesting. It gives a clear introduction of the type of equations used for the dynamical behaviour of soils. Furthermore a nice development of dynamical tests is given. This article is specially interesting while it considers the scale effects that are induced by applying high g-forces to the soil-model under investigation. Also the limitations, partly related to the scale effects, of the centrifuge tests are mentioned. In the end several types of foundation are loaded dynamically using an earthquake simulation.
This article is even more interesting with respect to another book by Balkema, **'Verification of Numerical Procedures for the Analysis of Soil Liquefaction Problems: Volume 1'** of which a review will appear in a following 'Newsletter.'

Finally

This book is an example for other proceedings, giving an overview of the contents of the seminar in such a way that people who have not been there still understand what has been going on.

ir. A. den Outer,
Engineering Geology Section TU Delft.

Bericht van de Secretaris

The International Associationof Engineering Geology heeft een ledenlijst 1993 gepubliceerd. Indien U belangstelling heeft voor deze ledenlijst dan kunt U deze opvragen bij de secretaris van de Ingeokring,

S.J. Plasman
Fugro Engineers B.V.
Postbus 250 2260 AG
Leidschendam
Tel: 070-3111281

Announcement.

EUROCK '94
ROCK MECHANICS IN PETROLEUM ENGINEERING
A joint SPE/ISRM MEETING
29 August-31 August 1994
Delft University of Technology
The Netherlands

Themes:

I. Rock Characterisation & Behaviour
II. Stability of Wellbores & Excavations
III. Fracture Mechanics
IV. Rockmass Response to Hydrocarbon Production & Mining
V. Storage, Waste Disposal and Enviromental Applications
VI. Chalk (Response of chalk reservoirs)
VII. In-Situ Stress Downhole Probes, and Acoustic Emission

Further Information:

Society of Petroleum Engineers
4 Mandeville Place, LONDON W1M 5 LA, U.K.
Tel: (44) 71 487 4250 Fax: (44) 71 487 4229

or:

Faculty of Mining & Petroleumengineering
Laboratorium voor Gesteentemechanica
t.a.v. J.P.A. Roest / H.C. Heilbron
Mijnbouwstraat 120
2628 RX Delft
tel: 015 786024 / 785109 Fax: 015-7894891

Announcement:

Engineering Geology of Unconsolidated Sediments
June 3, 1994
Delft, the Netherlands

The Jubilee Symposium Day of the Netherlands Engineering Geology Group will highlight the engineering geology of deltaic environments by eight keynote lectures. The themes are:
Development in Engineering Geology in the Netherlands
Field Data Collection Techniques
Classification and Dharacterisation of Soft Soils
Subsurface Mapping and Moddeling Techniques
Engineering Geology and the Environment
The Use of Underground Space in Deltaic Areas

Info:
Ir. Sven Plasman, Fugro McClelland Engineers BV, P.O.Box 250, 2260 AG Leidschendam, the Netherlands, tel. (31) 70 311 1281, fax (31) 70 320 3640.

International Symposium on Geological Engineering and Geoenvironment Protection
May 23-28 1994
Constantza, Romania

The main topics are:
Agressive processe, and geoenvironment vulnerability (landslides, deep erosion, coastal processes, land subsidence, sinkholes, flood protection, man-made earthquakes, natural earthquake risk)
Impact of the industrial, mining, quarring and land using design on geoenvironment; protection and rehabilitation policy.
Forecasting models for geoenvironment evolution and conservation.
New approaches for waste management using local geologic features.
Geochemical environment and public health.
Tourism promotion and geoenvironment protection.
Promoting conservative and environment ethic for geologists and engineers
Geologic habitat protection in administrative and local regulations

Info:
Prof. Petre Bomboe, Faculty of Geology and Geophysics
Str. Traian Vuia 6, 70139 Bucharest, Romania.

Third Symposium on Strait Crossings
June 12-15 1994
Ålesund, Norway

The main themes of the Symposium are: bridges, tunnels and ferries. During the first plenum session invited speakers will present large and complex strait crossing projects. In parallel sessions

/ work shops more specific aspects concerning strait crossings, such as technical solutions and environmental effects are open for discussions and presentations. The official language will be English.

Info:
Strait Crossings Secretariat, Norwegian Road Research Laboratory,
P.O. Box 6390 Etterstad, N-0604 Oslo, Norway.
Tel. +47-2-63 99 00, Fax. +47-2-46 74 21.

EUROCK symposium
August 29 - September 1, 1994
Delft, The Netherlands.

The main objective of this symposium is to bring together rock mechanics researchers and engineers from the petroleum industry with those from the fields of mining and engineering geology. The main themes are:
Rock Mass Characterisation
Excavation and Production
Fracture Mechanics
Rock Mass Response to Hydrocarbon Production
Storage, Waste Disposal and Environmental Applications

Info:
J.P.A. Roest, TU Delft, Fac. M&P, P.O.Box 5028, 2600 GA Delft
tel. 015-781326, fax. 015-784951

Modern Geophysics in Engineering Geology
September 12-15, 1994
Liège, Belgium.

The conference will review current methods and their application to solving a wide range of engineering and geological problems. The following key applications of geophysics will be included:
Determination of the depth of bedrock
Cavity location
Environmental issues
Rock mass condition assessment
Investigation for major civil engineering works
Borehole geophysics

Info:
Mr. S. Baker, Conference Secretary c/o Ready Mix Concrete (UK) Ltd.
RMC House, High Street, Feltham, Middlesex, TWI3 4HA, Great Britain

Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics.
April 2-7, 1995
St. Louis, Missouri, USA.

Themes: Static and dynamic engineering soil parameters
Liquefaction and ground failure
Stability of slopes and earth dams
Geotechnical analysis of recent earthquakes

Info:
Shamser Prakash, University of Missouri-Rolla, Rolla MO 65401 USA

Dr. VASCO FASSINA
Congress Secretariat
Laboratorio Scientifico della Misericordia
Cannaregio 3553
30131 VENEZIA - ITALY

SCHEDULE OF PROCEDURES

30 May 1993:
preliminary inscription and title of paper

15 September 1993:
deadline for receipt of abstracts

30 December 1993:
deadline for receipt of manuscripts by Scientific Committee

30 December 1993 to 30 January 1994:
the Scientific Committee review, edit, and rank papers, returning them to the authors where necessary for recommended changes.

28 February 1994:
The Scientific Committee return those papers requiring changes to authors for final revisions.

15 March 1994:
authors make any necessary changes and submit the resulting hard copy together with a new computer diskette to:

EXHIBITION

Exhibits of products and demonstrations of processes can be arranged in the framework of the Congress.
Persons or Institutions who wish to exhibit are invited to present a request to the Organizing Committee to define conditions.
The exhibition will be organized if there are sufficient requests.

CORRESPONDENCE

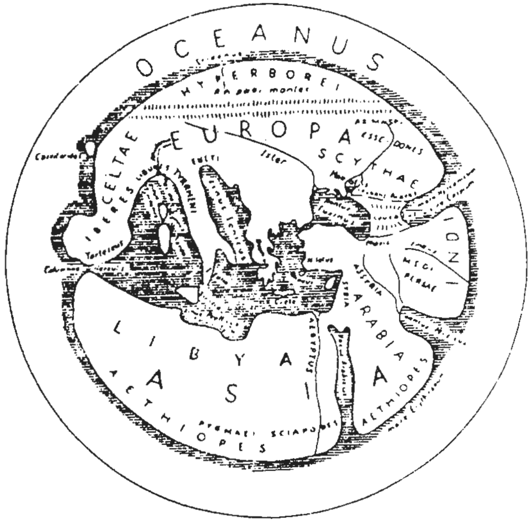
All correspondence must be sent to:

Dr. VASCO FASSINA
Congress Secretariat
Laboratorio Scientifico della Misericordia
Cannaregio 3553,
30131 - VENEZIA - ITALY
Phone number 041/718284, 041/720661
Fax number 041/720661, 041/5210547

IIIrd INTERNATIONAL SYMPOSIUM ON THE CONSERVATION OF MONUMENTS IN THE MEDITERRANEAN BASIN

Stone and monuments: methodologies for the analyses of weathering and conservation.

First Circular (February 1993)



Organized by I.G.C.M.M.
(International Group on the Conservation
of Monuments in the Mediterranean Basin)

SOPRINTENDENZA PER I BENI ARTISTI E STORICI
DI VENEZIA

VENICE 22-25 JUNE 1994

An important part of our culture is chiseled in stone, and we are in danger of losing it.

This heritage we have of the past and present glories of human creativity is slipping away, slowly, silently, but inexorably and at an increasing rate. The voices of many artistic and historic stone works have already fallen silent, and many more are in imminent danger.

Although interest in the conservation of stone has a venerable history, its emergence as a specialized craft began slowly and tentatively in the nineteenth century.

However, the problems of the deterioration of exposed stone proved to be intractable to the science and technology of the nineteenth century. Only in recent decades has there developed an extensive scientific literature dealing with the conservation of stone. A significant degree of understanding of the nature and mechanism of action of the vari decay processes has been developed, and detailed understanding can be expected to be followed by successful techniques of intervention.

The present is therefore, a propitious time to survey the state of our knowledge, to inventory the treatment methods that have been proposed and tried out, and to consider what needs to be further explored and what experience teaches us to repeat.

WHO IS CONCERNED?

- Restorers of works of art who want to improve their knowledge in conservation problems
- Architects who seek full information on restoration problems
- Art historians dealing with conservation problems
- Conservators who want to exchange their knowledge and experience
- Scientific people (geologists, chemists, physicists, biologists, mineralogists, etc.) involved in the conservation field who can contribute to a radical innovation of analytical techniques of investigation to gain a better knowledge of the decay processes and of new treatment products especially experimented for conservation problems.
- Building contractors who specialize in rehabilitation and restorat
- Producers of building materials
- Public authorities and governmental institutions with responsability for conservation of the Cultural Heritage.

PROGRAMME

The aim of the symposium is to analyze and develop the most recent studies in the field of conservation and restoration of stone in buildings and monuments of historical, archaeological and artistic value located in areas of significant cultural interest and in particular in the Mediterranean Basin.

The main purpose of this Conference is to point out the most appropriate methodology for the assessment of the degree of weathering of stone.

It is the time to introduce new methodologies of study for a better comprehension of stone decay processes.

Development of new methods and instruments for the diagnosis of the state of conservation, for the study of alteration mechanisms and for conservation treatments.

Definition of Technical European Standard Methods for the conservation treatments of artistic and historic stone objects and monuments.

The following topics will be studied:

- Properties and durability of natural and artificial stones
- Historical and architectonic aspects of stone in monuments
- Structural and technological aspects of monuments
- Forms and mechanisms of weathering: physical, chemical and biological aspects
- Environmental studies and climatology: typical problems of indoor and outdoor microclimate
  Analytical methods for investigation of damage in monuments
  In field assessment of damage to monuments
- Cleaning and biocide treatments
- Consolidation and preservative treatments
- The conservation of the Mediterranean Cultural Heritage: case studies

CALL FOR PAPERS

This is a call for papers to be presented orally or by poster display during the IIIrd International Symposium on the Conservation of Monuments in the Mediterranean Basin.

All the papers accepted for orally or poster presentation will be published in the Congress Proceedings.

In order to make a primary selection an extended abstract (about 400 words) containing the purpose of the work, the principal findings and the most outstanding facts obtained, must be submitted.

Abstracts submitted must reach the Congress Secretariat before 15 September, 1993.

Authors of accepted abstracts will be invited to present the typewritten manuscript with illustrations plus two photocopies and a computer diskette to the Congress Secretariat before 30 December 1993.

The manuscripts will be selected by the Scientific Committee and referees who will review, edit, and rank papers, returning them to the authors where necessary for recommended changes.

The Scientific Committee will decide which papers will be accepted for publication between 30 December and 30 January, 1994.

All corrected papers must be received by the Preprints Editor in their final form no later than March 15, 1994.

In order to allow for adequate review of the manuscripts by the Preprints Committee, papers that are not received within the specified timeframe cannot be considered for publication. A delay at any stage may make it impossible to meet the final delivery date. There is no grace period.

Instructions for presentation of the typescript of the paper will be included in the 2nd circular.

We expect the fee to be in the order of $ 200. The amount and conditions of payment will be specified in the 2nd circular.

Congress languages: English, French and Italian for written presentations.

III INTERNATIONAL SYMPOSIUM ON THE CONSERVATION OF MONUMENTS IN THE MEDITERRANEAN BASIN

22-25 JUNE 1994
VENICE - ITALY

PRELIMINARY INSCRIPTION

It is my intention to attend the Sympsium

I intend to submit a paper on the following subject

Title of the paper (provisional) to be submitted

I wish to rent an exhibition place

Name and Surname

Organization

Mailing address

Telephone and fax number

Signature

To be returned as soon as possible (before 30 May 1993) to:
Phone number 041/720661 - 041/718284
Fax number 041/720661-5210547

Only those who have sent this form can be sure of receiving the forthcoming bulletins.


KONINKLIJKE SHELL