ODA/BGS R & D Programme Project Completion Report: Thermal History of Petroliferous Basins of the CCOP Region (Project 91/23).

A report prepared for the Overseas Development Administration (ODA) and the Co-ordinating Committee for Offshore Prospecting (CCOP)

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ODA/BGS R & D Programme Project Completion Report: Thermal History of Petroliferous Basins of the CCOP Region (Project 91/23).

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Tectonics and Database Group

Cover illustration
HOTPOT pseudo-maturity plot

Subject index
Computer modelling, geothermics, hydrocarbon prospectivity

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SUMMARY

The ODA/BGS R & D project summarised in this report aimed to develop PC-based software capable of modelling the thermal history of offshore petroliferous Cenozoic sedimentary basins of eastern and southeastern Asia, in order to predict the timing and nature of oil and/or gas generation from appropriate hydrocarbon source rocks. The project was undertaken in collaboration with the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). Application of the software was demonstrated successfully by studies in China, Indonesia, Malaysia and Thailand. Technical reports generated by the project are listed in Appendix 1. Training was given to representatives from CCOP Member Countries in the use of the software and its applications, and the benefits to hydrocarbon resource development demonstrated. The software is widely applicable to energy resource investigations in both the public and private sectors worldwide.
1. Background and Introduction

This report summarises the principal results, applications and developmental benefits of work carried out under the Overseas Development Administration (ODA)/British Geological Survey (BGS) Programme of Research and Development in Developing Countries between 1989 and 1992 (Project 91/23). As such, it is intended as a reference and information source for scientists and technicians associated with the hydrocarbon industry in developing countries, for ODA Advisors, and for administrators and managers who seek to understand the value and applicability of a scientific technique without wishing to delve deeply into the underlying technology and scientific principles. This format is seen as part of the policy of wide dissemination of ODA-funded R & D work. The detailed technical reports produced by the project are listed in Appendix 1. A glossary of selected technical terms is included.

Temperature is one of the principal parameters which determines hydrocarbon generation and, particularly in geologically young (up to 65 million years old) Cenozoic sedimentary basins, is a more important factor than time. It has been suggested that most oil is formed between 100 and 150°C and most gas between 150 and 220°C. Thus, the study of the thermal history of sedimentary basins is one of the key elements in understanding the origin and location of economic hydrocarbon occurrences. From such studies it is possible to determine the subsurface location of the 100°, 150° and 220°C isotherms, both in the past and at the present day, and hence predict the timing and nature of oil and/or gas generation from any appropriate hydrocarbon source rocks (i.e. those containing relatively high amounts of organic carbon). Combining thermal history data with a knowledge of the structural history of the basin allows prediction of whether suitable trapping structures existed at the time of hydrocarbon generation or whether any oil or gas once present was allowed to escape.

The east Asia region (Fig. 1), covered by the intergovernmental Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP), of which the UK is a cooperating member, is already a major producer of oil and gas, but large areas within the region remain at best only sparsely explored. In 1989, at the request of the CCOP Technical Secretariat, located in Bangkok, BGS with ODA support began an investigation of the thermal history of petroliferous basins within the CCOP Region. The principal objective
of the work was to develop for use by Member Countries a system based on an IBM-
compatible personal computer (PC) for the prediction of subsurface present-day and
palaeotemperatures in sedimentary basins. To illustrate the feasibility and benefit of the
project to energy resource development, a pilot study of the Gulf of Thailand and Malay
basins (Fig. 1) was undertaken, using a preliminary version of the BGS software,
DECOMP3D, and data supplied by the Department of Mineral Resources (DMR), Thailand,
and by Petronas, Malaysia. Following the successful completion of this study, DECOMP3D
was distributed to all Member Countries.

In the light of these modelling studies, and in response to requests and suggestions from
CCOP Member Countries, development work on the software continued. It was agreed with
CCOP that the BGS sediment decompaction and geothermal modelling program, now renamed
HOTPOT, should be modified, and developed as a Microsoft Windows application. The first
results from the newly modified software were included in a study of the North Sumatra
Basin, and continued in an assessment of the Subei-South Yellow Sea Basin of China (Fig.
1). The HOTPOT software was demonstrated and distributed to Member Countries at an end
of project workshop.

2. Objectives

The project had the following main objectives.

1. To develop a user-friendly IBM-compatible PC-based software package for use
   by exploration geologists from CCOP Member Countries in thermal modelling,
   to aid hydrocarbon prospectivity analysis in the offshore Cenozoic basins of
   the region.

2. To establish the feasibility of the project, and evaluate early software
development, with a pilot study encompassing data from the northern part of
the Gulf of Thailand and the Malay Basin (Fig. 1)
3. To continue program development as a Windows application, further evaluating progress with data from other CCOP basins, in particular the North Sumatra and Subei-South Yellow Sea basins (Fig 1).

4. To prepare a guide to the software, and report on the basin modelling carried out (see Appendix 1).

5. To instruct geologists from Member Countries in the application and use of the software, in part by presentations and demonstrations at CCOP Meetings, and by visits to Cooperating Countries (Thailand, Malaysia, Indonesia), but more especially at the Project Workshop.

3. METHODS

HOTPOT is written in the computer programming language C and is designed to run on an IBM PC or PS/2 personal computer with the Microsoft Windows 3 graphical user interface. The program can also utilise more advanced hardware facilities where available (e.g. maths co-processor, greater memory capacity). The software comprises a self-contained sediment decompaction and thermal history program, whose operation is summarised in the flowchart (Fig. 2).

HOTPOT requires input data of two types, primary data and auxiliary data. Primary data include:

a) a set of isopach maps describing the required part of the basin’s depositional history.

b) average lithological composition of each isopached layer, expressed as the relative proportions of four standard lithologies - sandstone, limestone, silty mudstone and overpressured shale.
average water-depth during deposition of each layer.

d) chronological calibration of each time interval.

e) heatflow data expressed as either a single basin-wide value, or as a contour map, for the start and end of each time interval.

f) surface or seabed temperature expressed as a single basin-wide value for the start and end of each time interval.

g) thermal conductivities for each time interval (only if auxiliary datafile not available).

Auxiliary data include:

a) depth-density datafile containing digitised depth/density curves for four standard lithologies - sandstone, limestone, silty mudstone and overpressured shale.

b) depth-thermal conductivity datafile containing digitised depth/thermal conductivity data for the four standard lithologies.

These auxiliary data ideally should be derived from the basin under study, but in practice such information commonly is not available. In the present work these data were obtained from wells in the Malay Basin and the Gulf of Thailand, and applied in all basin studies.

The primary and auxiliary data are loaded into an internal program database. The calculation modules operate on the database. Firstly the digitised isopach maps are gridded using a distance-weighted moving-average algorithm. The resultant overlaying gridded layers define the 3-D stratigraphical architecture of the basin. This 3-D stratigraphical sequence is decompacted using an iterative backstripping method which adjusts layer thicknesses and densities according to the observed density-depth relationships. Chronological calibration of
the decompacted sequences generates the 3-D burial history of the basin. Merging the decompacted sequences with the thermal conductivity-depth data file enables a realistic thermal conductivity to be allocated to each decompacted layer.

The thermal calculation assumes simple vertical conductive heat transfer in a layered basin, with heat input from below. Heat production within the basin sediments is assumed to be negligible. Thus, the temperature (as a function of time and depth) at each grid-node can be described by the expression:

\[ T_N(t) = T_0(t) + Q(t) \sum_{n=1}^{N} \frac{\Delta z_n}{k_n} \]

where:
\[ T_N(t) \] = temperature at base of Nth layer at time \( t \)
\[ T_0(t) \] = surface/seabed temperature at time \( t \)
\[ Q(t) \] = heatflow at time \( t \)
\[ \Delta z_n \] = thickness of \( n^{th} \) layer
\[ k_n \] = thermal conductivity of \( n^{th} \) layer

Output from the program includes the following:

a) colour-shaded gridded maps depicting present-day and palaeo-sediment thicknesses, sediment densities, sediment thermal conductivities, subsurface temperatures and pseudo-maturity values (e.g. Figs 3-8).

b) 1-D grid node extractions depicting location burial and thermal histories (e.g. Figs 9-12).

Figs 3-8 provide examples of the colour output available from HOTPOT. They show a series of pseudo-maturity plots derived from the modelling of a three-layered sedimentary sequence, with the inferred hydrocarbon generating potential of each layer during basin evolution and at the present time. A is the youngest layer, deposited since 10 Ma. Layer B was deposited between 10 and 20 Ma, and Layer C was deposited prior to 20 Ma. Figs 9-12 provide examples of grey-scale plots and show 1-D extractions from the same modelling, each being
derived from the same grid-node.

4. RESULTS

All the main project objectives were met. The feasibility of the approach taken to thermal modelling, and the methods employed, were demonstrated by the successful outcome of the pilot study of the Gulf of Thailand and the Malay basins. The conversion to a Windows application proved to be justified, greatly increasing the speed, ease and versatility of operation and the range of user-options.

Three of the four areas studied are hydrocarbon producers, the Malay and North Sumatra basins being particularly prolific. These studies, therefore, enabled a comparison to be made between the distribution of oil and gas, and the likely trapping formations predicted by HOTPOT, with those that have been actually located in these basins. Even though the modelling was constrained by the limited and generalised nature of the geological and geothermal data provided, the predicted results in most cases closely matched those observed. Where there were significant differences in oil and gas distribution, these could be related to poorly defined parameters or to probable deficiencies in the basic assumptions made relating to basin evolution and the location of probable hydrocarbon source rocks.

The success of this modelling in such relatively well known areas suggests that HOTPOT can be applied to poorly explored and frontier areas with a considerable degree of confidence. Its ease of operation, and ability to model successfully with limited datasets, make it a valuable tool in prospectivity analysis of whole basins or of more restricted areas such as licence blocks.

Training of geologists from Member Countries to use HOTPOT during the course of its development proved more problematical. Brief visits to SE Asia and periodic demonstrations at CCOP Meetings were not an effective means of technology transfer, although at least two of the cooperating institutes were successfully able to complete some partial modelling from such contacts. Much more useful in this context was the Project Workshop held at the
Petronas Training Centre, Bangi, Malaysia, 25-28 February 1992. This was attended by 8 representatives from Malaysia, 2 each from China, Indonesia, Thailand and Vietnam, and 2 from the CCOP Technical Secretariat (Fig. 13; Appendix 2). An invitation to the Philippines to send representatives was not taken up. All aspects of the modelling procedures were illustrated and the interpretation and utilisation of the results in basin analysis and hydrocarbon exploration, most notably in acreage and licence block evaluation, were reviewed. A Manual and Userguide to HOTPOT was distributed to Member Countries at the Workshop.

By and large, all participants had developed sufficient skills to successfully use HOTPOT by the end of the Workshop, although with varying degrees of confidence and proficiency. Differences in level of attainment were in part due to differing degrees of prior familiarity with personal computers and with Microsoft Windows, as well as differing levels of technical background and proficiency in the English language.

The HOTPOT software was subjected to extensive and searching use and scrutiny during the Workshop. No significant deficiencies were encountered, although some minor points required remedial attention.

5. CONCLUSIONS AND RECOMMENDATIONS

The development of the HOTPOT software has provided CCOP Member Countries with a sedimentary basin thermal modelling program of considerable value in basin analysis, which is particularly useful in regional hydrocarbon prospectivity assessments and licence block evaluation.

Training has been provided to representatives from institutes of 5 CCOP Member Countries (listed in Appendix 2) in the workings of the program and in the interpretation and applications of its results. Use has already been made of HOTPOT by some Member Countries in basin studies.
The CCOP Technical Secretariat have indicated that they intend in future to include training in the use of HOTPOT in their petroleum and heatflow-related programmes. Together with in-house transfer within Member Country institutes, this should ensure a growing number of personnel within the CCOP Region becoming familiar with the software, with its application to thermal modelling in sedimentary basins, and with its benefits to hydrocarbon resource development.

Little or no provision has been made for further support to HOTPOT activities in CCOP and its Member Countries, and no specific proposals for regional assistance via CCOP have been received. There is considerable scope for additional cooperation in the field of thermal modelling within the CCOP Region. However, the future needs of each country are likely to differ considerably and a comprehensive regional programme may not be appropriate. In some countries, where the requisite hardware is readily available and use of HOTPOT is already well established, the need for additional backup is probably limited. In other countries, where the necessary computing facilities and the required technical experience not yet widely available, there is likely to be a need to ensure that the value of HOTPOT in hydrocarbon exploration is fully recognised, and that it is put to maximum use.

HOTPOT was developed for use on datasets provided by CCOP Member Countries, and some modification of the program is planned in 1992/3 to make the software more widely applicable. For example, whereas the CCOP datasets principally comprise isopach maps, structure contour maps are produced more commonly during hydrocarbon exploration and isopach maps are only prepared for key selected intervals, such as source or reservoir formations. In addition to such modifications, further extensive software usage and testing is planned using as wide a range of datasets as possible.

In addition to the benefits noted previously to the petroleum industries of CCOP members and other developing countries, the HOTPOT software is likely to be of interest to international and private exploration and development companies, and to geological consultants. Thus, the software may have significant commercial value, particularly when the modifications indicated above are completed.
Acknowledgements

It is a pleasure to record the cooperation and the support of past and present members of the CCOP Technical Secretariat, principally Dr G.R. Balce, Mr Sermsakadi Kulvanich, Mr B. Elishiwitz, Prof. He Qixiang, Prof. Weng Shijie, Mr I. Miljeteig and Mr S. Maehle. The constructive advice of Professor R. Sinding-Larsen, Special Advisor from Norway to CCOP, is also acknowledged. The project could not have proceeded without the generous support of Member Countries and their representatives at the CCOP Working Group on Resource Assessment. The Department of Mineral Resources (Thailand), through Mr Nares Sattayarak, and the Exploration Department of Petronas (Malaysia), through Mr Ho Wan Kin, provided data and valuable support to allow the pilot study to take place. Further data were supplied in support of later modelling by Lemigas (Indonesia), through Dr Ir Mujito, and the Institute of Marine Geology, Qingdao (China), through Mr Li Shaoquan. Special thanks go to Mr Ahmad Said and Petronas for their kind hospitality and logistical support of the Project Workshop. The project formed part of the BGS Overseas Research & Development Programme funded by the Overseas Development Administration (ODA).
APPENDIX 1: LIST OF TECHNICAL REPORTS


[These reports, with the exception of the HOTPOT Workshop Manual, contain confidential data supplied to BGS by the collaborating countries. Therefore, they are not yet available for general release.]

APPENDIX 2: ORGANISATIONS PARTICIPATING IN THE PROJECT WORKSHOP

China: Institute of Marine Geology, Qingdao.
Bureau of Marine Geological Survey, Shanghai.

Indonesia: Lemigas, Jakarta.

Malaysia: Exploration Department, Petronas, Kuala Lumpur.
Petroleum Research Institute, Petronas, Kuala Lumpur.
Petronas Carigali, Kuala Lumpur.

Thailand: Department of Mineral Resources, Bangkok.
CCOP Technical Secretariat, Bangkok.

Vietnam: Institute of Mining and Geology, Petrovietnam, Hanoi.
Vietnam Petroleum Institute, Petrovietnam, Hanoi.
### Glossary of Selected Terms

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<th>Term</th>
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<tr>
<td>Algorithm</td>
<td>A structured method of solving a problem, forming the basis of a computer program.</td>
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<tr>
<td>Backstripping</td>
<td>Reconstruction of the subsidence history of a point location by the sequential removal of successively older stratigraphical layers. As each layer is removed, the remaining layers are allowed to decompact according to some appropriate function.</td>
</tr>
<tr>
<td>CCOP</td>
<td>Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas; Technical Secretariat based in Bangkok, Thailand.</td>
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<tr>
<td>Cenozoic</td>
<td>The division of geological time extending from about 65 million years ago to the present day.</td>
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<tr>
<td>Decompaction</td>
<td>Calculating the original thickness of a layer prior to its burial and compaction by younger overlying layers. (See also Backstripping.)</td>
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<tr>
<td>Grid</td>
<td>System of regularly spaced observations (or calculations) over a mapped area.</td>
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<tr>
<td>Grid-node</td>
<td>A intersection between a N-S grid line and an E-W grid line of a map graticule, at which a parameter (e.g. thickness, temperature, etc.) is observed or calculated. (See also Grid.)</td>
</tr>
<tr>
<td>Hardware</td>
<td>The computer and its associated peripheral equipment (e.g. keyboard, screen, printer, etc.).</td>
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<tr>
<td>Heatflow</td>
<td>The rate at which heat is lost from the crust of the earth to the atmosphere.</td>
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<td>Isopach</td>
<td>A line joining points of equal layer thickness.</td>
</tr>
<tr>
<td>Isotherm</td>
<td>A line joining points of equal temperature.</td>
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<tr>
<td>Lithology</td>
<td>Rock type.</td>
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<tr>
<td>Ma</td>
<td>Millions of years before the present.</td>
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<td>Maturity</td>
<td>Measure of thermal alteration of organic matter in rocks indicative of their hydrocarbon generating potential; thus rocks can be classified as undermature, mature for oil, mature for gas, or overmature according to the degree of alteration of their organic matter.</td>
</tr>
<tr>
<td>Microsoft Windows</td>
<td>A Graphical User Interface for IBM-PC type computers in which data, programs etc. are represented by stylised images on the computer display screen and manipulated by a user-operated cursor. (Trade Mark of Microsoft Inc.)</td>
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<td>Overpressure</td>
<td>A situation commonly met in sedimentary basins where pressure of pore fluids in rocks is greater than would be normally expected.</td>
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<tr>
<td>Palaeo-</td>
<td>Ancient, of past times (Greek); e.g. palaeotemperatures, temperatures in the...</td>
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<td>Term</td>
<td>Definition</td>
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<tr>
<td>Pseudo-maturity</td>
<td>A HOTPOT display which presents present day temperature or palaeo-temperature maps as organic maturity estimates.</td>
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<tr>
<td>Sedimentary Basin</td>
<td>A depression in the earth’s surface resulting from crustal subsidence and infilled by rocks formed largely by sedimentary processes.</td>
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<tr>
<td>Software</td>
<td>A computer program or programs; c.f. Hardware.</td>
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<tr>
<td>Stratigraphy</td>
<td>The study of stratified rocks, especially their sequence, composition and correlation.</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Measure of ability of rocks to conduct heat.</td>
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Fig. 1  Map showing CCOP Member Countries (stippled) and the locations of sedimentary basins studied in this project.
Fig. 2 Flow-chart for thermal modelling program HOTPOT.
Layer Temperature: LAYER A at 0.00Ma

Fig. 3  Inferred organic maturity of Layer A at the present day.

Layer Temperature: LAYER B at 0.00Ma

Fig. 4  Inferred organic maturity of Layer B at the present day.
Layer Temperature: LAYER'C at 0.00Ma

Fig. 5
Inferred organic maturity of Layer C at the present day.

Layer Temperature: LAYER'B at 10.00Ma

Fig. 6
Inferred organic maturity of Layer B at 10 Ma.
Fig. 7  Inferred organic maturity of Layer C at 10 Ma.

Fig. 8  Inferred organic maturity of Layer C at 20 Ma.
Fig. 9  1-D Grid-node extraction of time vs depth for each layer.

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