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FOCUS ON

JORDAN

A GEOTHERMAL INTERNATIONAL SERIES

SPONSORED BY:

U.S. DEPARTMENT OF ENERGY
GEOTHERMAL TECHNOLOGY DIVISION (GTD)

PREPARED FOR:

LOS ALAMOS NATIONAL LABORATORY
UNDER CONTRACT NO. 9-X36-3652C

PREPARED BY:

MERIDIAN CORPORATION
4300 KING STREET, SUITE 400
ALEXANDRIA, VIRGINIA 22302-1508
(703) 998-3600

PREFACE

The *Focus on* Series is prepared to give the U.S. Geothermal Industry a quick profile of several foreign countries. The countries depicted were chosen for both their promising geothermal resources and for their various stages of geothermal development, which can translate into opportunities for the U.S. geothermal industry. The series presents condensed statistics and information regarding each country's population, economic growth and energy balance with special emphasis on the country's geothermal resources, stage of geothermal development and most recent activities or key players in geothermal development. The series also offers an extensive list of references and key contacts, both in the U.S. and in the target country, which can be used to obtain detailed information.

The series is available for the following countries:
Argentina, Azores (Portugal), China, Costa Rica, Ecuador, El Salvador, Ethiopia, Guatemala, Honduras, Indonesia, Jordan, Mexico, St. Lucia, Thailand.

Additional countries might be available in the future.

The series is to be used in conjunction with four other publications specifically designed to assist the U.S. geothermal industry in identifying and taking advantage of geothermal activities and opportunities abroad, namely:

- The *"Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities."* Final Report, August 1987. Prepared for Los Alamos National Laboratory.

- The *"Summary Report"* of the above publication.

- *"Equipment and Services for Worldwide Applications,"* U.S. Department of Energy.

- The *"Listing of U.S. Companies that Supply Goods and Services for Geothermal Explorers, Developers and Producers Internationally,"* August 1987, prepared by GRC.

Copies of these publications can be obtained from the Geothermal Technology Division of the U.S. Department of Energy. Correspondence should be addressed to:

Dr. John E. Mock
Geothermal Technology Division (GTD)
1000 Independence Avenue
U.S. Department of Energy
Washington, DC 20585
(202) 586-5340

NOTE

Data presented in this document are based on several U.S. government official publications as well as international organizations, namely:

- Background Notes (U.S. Department of State)
- Foreign Economic Trends (U.S. Department of Commerce)
- World Development Report 1987 (World Bank)
- International Data Base for the U.S. Renewable Energy Industry, May 1986 (U.S. Department of Energy)

The country's geothermal resources write-up is a revision and update of the Appendix in the "Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities." LANL, August 1987.

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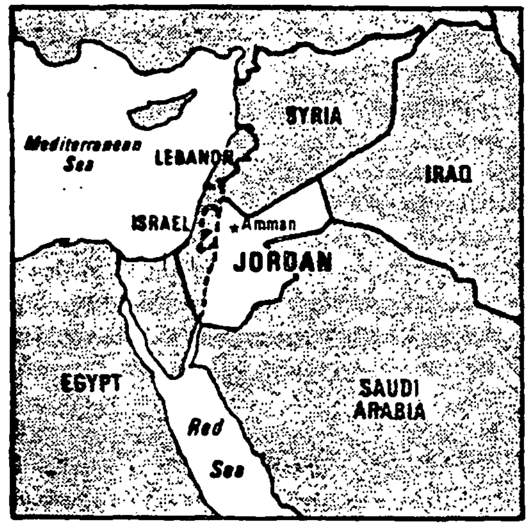
JORDAN



Official Name: Hashemite Kingdom of Jordan

Area: 98,000 sq. km. (35,000 sq. mi.)

Capital: Amman

Population (1985): 3.5 million

Population Growth Rate: 3.2%

Languages: Arabic (official), English

Economic Indicators:

Real GDP (1985): $3.450 billion
Real Annual Growth Rate (1985): 1.6%
Per Capita Income (1985): $1,560
Avg. Inflation Rate (1986): 30% change from 1980 base year

Trade and Balance of Payments:

(1985) Exports: $789 million; Major Markets: Iraq, Saudi Arabia, India, Romania
(1985) Imports: $2.733 billion; Major Suppliers: U.S., UK, FRG, Japan, Syria, Saudi Arabia

(1984) Official Exchange Rate: 1 Jordanian Dinar = US $2.60

Energy Profile: (Based on 1982 data unless otherwise indicated)

- Commercial Fuel Energy Consumption:

  Total: 1.917 million ton of oil equivalent (mtoe)
  1-Yr. Growth: 12.3%

- Commercial Fuel Breakdown:

  Liquid Fuels Pct: *
  Solid Fuel Pct: *
  Natural Gas Pct: *
  Electric Pct: *
  Commercial Fuel Consumption Growth Rate (1970-1980): *

* Not available

- Electricity Generation Capacity:

  (1982) Total Installed Elec. Capacity: 642 MW
  Hydro: 0%
  Hydro Potential: * MW
  Steam: 29%
  Gas Turbine: 33%
  Diesel: 21%
  Other: 18%

- Electricity Sales:

  Total: * GWh
  Residential: *
  Commercial: *
  Industrial: *
  Government: *
  Other: *
  Average Electricity Price: *

- Geothermal Power Generation:

  Reservoir Potential (MW): *
  Temperature Range: *

- Development Status: Preliminary assessments only.

- Countries Actively Involved: U.S.

- General Need for Assistance: All initial stages, mainly feasibility studies, exploratory drilling and reservoir modelling.

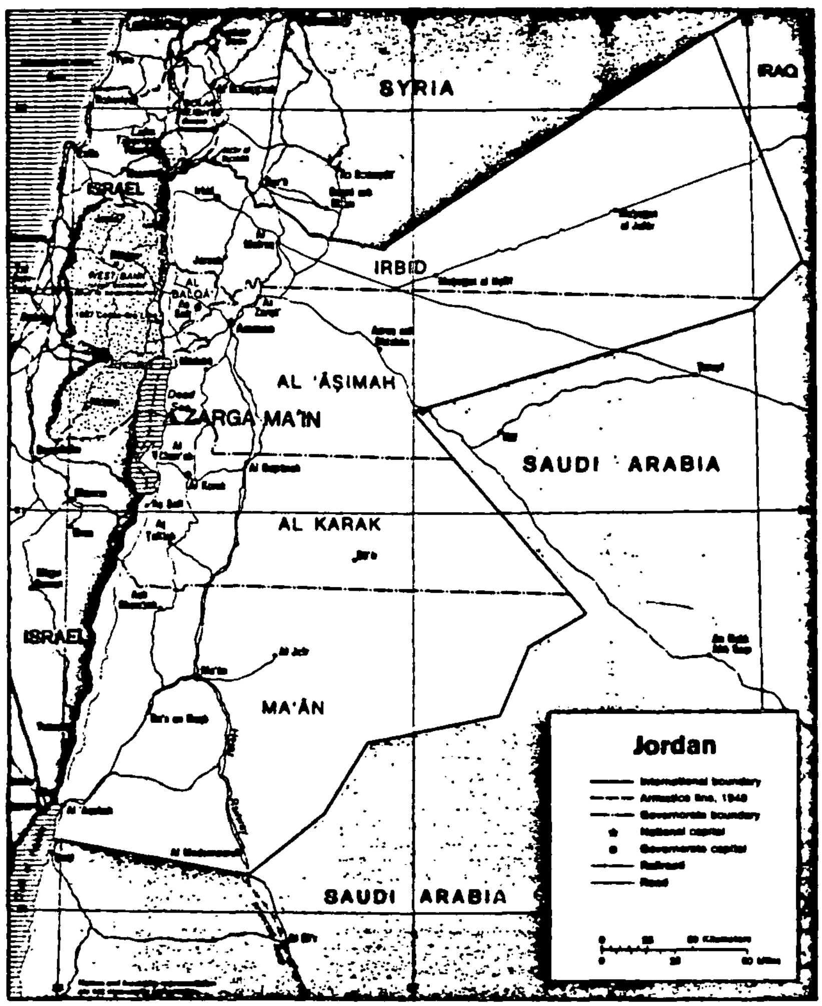
- Geographic Locations: Central-east region

- International Funding: $94,200 (UN/DTCD)

* Not available

GEOTHERMAL RESOURCES

The geothermal resources of Jordan, which are associated with active faulting along a transcurrent structure, were assessed as part of a U.S. Agency for International Development (AID) sponsored study to identify potentially exploitable minerals and plan a national minerals exploration program in Jordan. The project was performed on behalf of the Jordanian Natural Resources Authority (NRA) through AID by the U.S. Geological Survey and U.S. companies. It consisted of airborne geophysical surveys to define areas of potential interest. From these studies, the thermal area at Zarga Ma'in was proposed for further investigations in order to assess the area's geothermal potential. NRA has reportedly made recent plans to drill two 1,500 m geothermal exploratory wells.



Bibliography:

Perera, J., 1986; "Jordan Stepping up Activities in Several Solar Energy Fields," International Solar Energy Intelligence Report, January p. 16.

Stalla, S.A., and Ajamich, M.A., 1981 Project Evaluation Summary - Minerals Development, U.S. Agency for International Development, Bureau for Near East - Jordan, EN. PES no. 278-81-4, 6 p.

REFERENCES

AND

KEY CONTACTS

A. Business Climate Sources of Information

The following references are suggested for timely information on the business climate in Jordan.

U.S. GOVERNMENT PUBLICATIONS

U.S. Department of Commerce

- Foreign Economic Trends (FET) and their Implications for the U.S.
- Overseas Business Reports (OBR)

U.S. Department of State

- Background Notes

NON-GOVERNMENT PUBLICATIONS

- International Series, published by Ernst and Whinney
- Businessman's Guide to......., published by Price Waterhouse and Co.
- Information Guide: Doing Business in ......, published by Price Waterhouse and Co.
- Task and Trade Guide, published by Arthur Andersen
- Task and Investment Profile, published by Touche Ross and Co.

B. Geothermal-Related Sources of Information

The following reports and documents are suggested for further information regarding geothermal energy and export opportunities overseas:

Los Alamos National Laboratory:

- Review of International Geothermal Activities and Assessment of U.S. Industry Opportunities

U.S. Department of Energy

- Equipment and Services for Worldwide Applications
- Guide to the International Development and Funding Institutions for the U.S. Renewable Energy Industry
- Federal Export Assistance Programs Applicable to the U.S. Renewable Energy Industry
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California Energy Commission (CEC)

- Foreign Geothermal Energy Market Analysis
- Small Scale Electric Systems Using Geothermal Energy: A Guide to Development

U.S. Department of Commerce - International Trade Administration

- A Competitive Assessment of the U.S. Renewable Energy Equipment Industry

U.S. Export Council for Renewable Energy

- International Renewable Energy Industry Trade Policy

C. KEY CONTACTS

Jordan

Chamber of Commerce
P.O. Box 287
Amman, Jordan
Telex: 21543

U.S. Embassy
Jebel Amman
Tel: 644371-6
Attn: Lewis P. Reade
Officer in Charge
USAID
Tel: 604171/604868

Agency for International Development

- Bureau for Science and Technology

Dr. James Sullivan
Director, Office of Energy
Bureau for Science & Technology
Agency for International Development
Washington, DC 20523
(703) 235-8902

- Bureau for Private Enterprise

Mr. Sean P. Walsh
Director, Office of Investment
Bureau for Private Enterprise
Agency for International Development
Washington, DC 20523
(202) 647-9843

Mr. Russell Anderson
Director, Office of Project Development
Bureau for Private Enterprise
Agency for International Development
Washington, DC 20523
(202) 647-5806

- Bureau for External Affairs

Ms. Rhea Johnson
Director, Office of Public Inquiries
Bureau for External Affairs
Agency for International Development
Washington, DC 20523
(202) 647-1850

- Bureau for the Near East

  Robert Ichord
  Chief, Energy and Natural Resources Division
  Office of Technical Resources
  Agency for International Development
  Washington, DC 20523
  (202) 647-8274

- Publications

  Ms. Dolores Weiss
  Director, Office of Publications
  Bureau for External Affairs
  Agency for International Development
  Washington, DC 20523
  (202) 647-4330

U.S. Department of Commerce/International Trade Administration

- Office of International Major Projects

  Mr. Leo E. Engleson
  Office of International Major Projects
  Room 2015-B
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-2732

- Foreign Industry Sector

  Mr. Les Garden
  International Trade Specialist for Renewable Energy Equipment
  Office of General Industrial Machinery
  Room 2805
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-0556

- Trade Development

  Mr. Friedrich R. Crupe
  Director, Information Industries Division
  Office of Service Industries
  Room 1116
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-3575

- International Economic Policy

  Mr. Louis F. Laun
  Assistant Secretary for International
  Economic Policy
  Room 3864
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-3022

- Office of Trade Promotion

  Mr. Saul Padwo
  Director
  Office of Trade Promotion
  Room 1332
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-1468

- Export Development

  Ms. Laverne Branch
  Latin America, Middle East and Africa
  U.S. and Foreign Commercial Service (USFCS)
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-4756

- Minority Business Development Centers

  Minority Business Development Agency
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-1936

  or contact:

  Regional Offices:

  Atlanta, GA (404) 881-4091
  Chicago, IL (312) 353-0182
  San Francisco, CA (415) 556-7234
  Dallas, TX (214) 767-8001
  New York, NY (212) 264-3262
  Washington, DC (202) 377-8275 or 8267

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  U.S. Government Printing Office
  Washington, DC 20402
  (202) 783-3238

U.S. Department of Energy

Dr. Robert San Martin
DAS/RE
Office of Conservation and Renewable Energy
CE-030
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-9275

Dr. John E. Mock
Director, Geothermal Technology Division (GTD)
Office of Conservation and Renewable Energy
CF-342
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-5340

Export-Import Bank

- International Lending

Mr. James R. Sharpe
Senior Vice President, International Lending
Export-Import Bank
811 Vermont Avenue, NW
Washington, DC 20571
(202) 566-8187

- Africa and Middle East Division

Mr. Clayton Norris
Vice President, Africa and Middle East Division
Export-Import Bank
811 Vermont Avenue, NW
Washington, DC 20571
(202) 566-8011

Geothermal Resources Council

Mr. David N. Anderson
111 Q Street, Suite 29
P.O. Box 1350
Davis, CA 95617-1350
(916) 758-2360

International Trade Commission

Office of Publications
International Trade Commission
701 E Street, NW
Washington, DC 20436
(202) 523-5178

Office of the U.S. Trade Representative

Mr. Fred Ryan
Director, Private Sector Liaison Division
Office of the U.S. Trade Representative
600 17th Street, NW
Washington, DC 20506
(202) 456-7140

Overseas Private Investment Corporation

- Insurance Department

Mr. B. Thomas Mansbash
Managing Director, Africa & Middle East,
Europe and South Asia Division
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7045

- Energy Program

Mr. R. Douglas Greco
Manager, Natural Resources
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7044

- Finance Department

Ms. Suzanne M. Goldstein
Managing Director, Financial Services and Product Development
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7192

Mr. John Paul Andrews
Managing Director, Major Projects
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7196

- Office of Development

Mr. Michael R. Stack
Development Assistance Director
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7135

Small Business Administration

Mr. Michael E. Deegan
Director, Office of International Trade
U.S. Small Business Administration
1441 L Street, NW, Room 100
Washington, DC 20416
(202) 653-7794

Trade and Development Program

- Middle East and Caribbean Basin

Mr. Van Dyne McCutcheon
Regional Director
320-21st Street, NW
Washington, DC 20523
(703) 235-3660

United Nations

- United Nations Development Program

Mr. A. Bruce Harland
Director, UNDP Energy Office
One United Nations Plaza
New York, NY 10017
(212) 906-6090

- United Nations Department of Technical Cooperation for Development

Mr. Edmund K. Leo
Chief, Energy Resources Branch
Department of Technical Cooperation for Development
One United Nations Plaza
New York, NY 10017
(212) 963-8773

Mr. Nicky Beredjick
Director
National Resources and Energy Division
Department of Technical Cooperation for Development
One United Nations Plaza
New York, NY 10017
(212) 963-8764

Mr. Mario Di Paola
Technical Adviser on Geothermal Energy
Energy Resources Branch
Department of Technical Cooperation for Development
One United Nations Plaza
New York, NY 10017
(212) 963-8596

Mr. Joseph V. Acakpo-Satchivi
Secretary
Committee on the Development and Utilization of New
and Renewable Sources of Energy
United Nations
New York, NY 10017
(212) 963-5737

- Publications

Development Business
P.O. Box 5850
Grand Central Station
New York, NY 10163-5850
(212) 963-4460

<u>World Bank</u>

Mr. Anthony A. Churchill
Director
Industry and Energy Department
Sector Policy and Research
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 477-4676

Mr. Gunter Schramm
Division Director
Energy Development Division
Industry and Energy Department
Sector Policy and Research
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-3266

Mr. Robert J. Saunders
Division Director
Energy Strategy, Management and
Assessment Division
Industry and Energy Department
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-3254

Mr. Abderraouf Bouhaouala
Technical Director
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2707

Mr. Mohammad Reza Amin
Technical Adviser
Industry and Energy Division
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 477-5979

Mr. Everardus J. Stoutjesdijk
Country Director, CD III
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2707

Mr. Vinay K. Bhargava
Division Director, CD III
Industry and Energy Operations Division
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2600

- Public Affairs Office
  The World Bank
  1818 H Street, NW
  Washington, DC 20433
  (202) 477-1234

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  Grand Central Station
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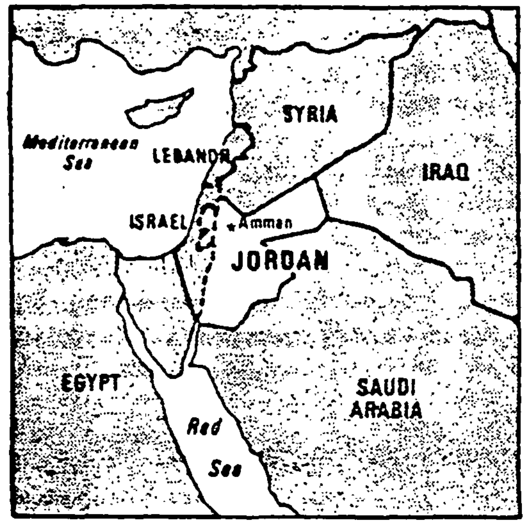

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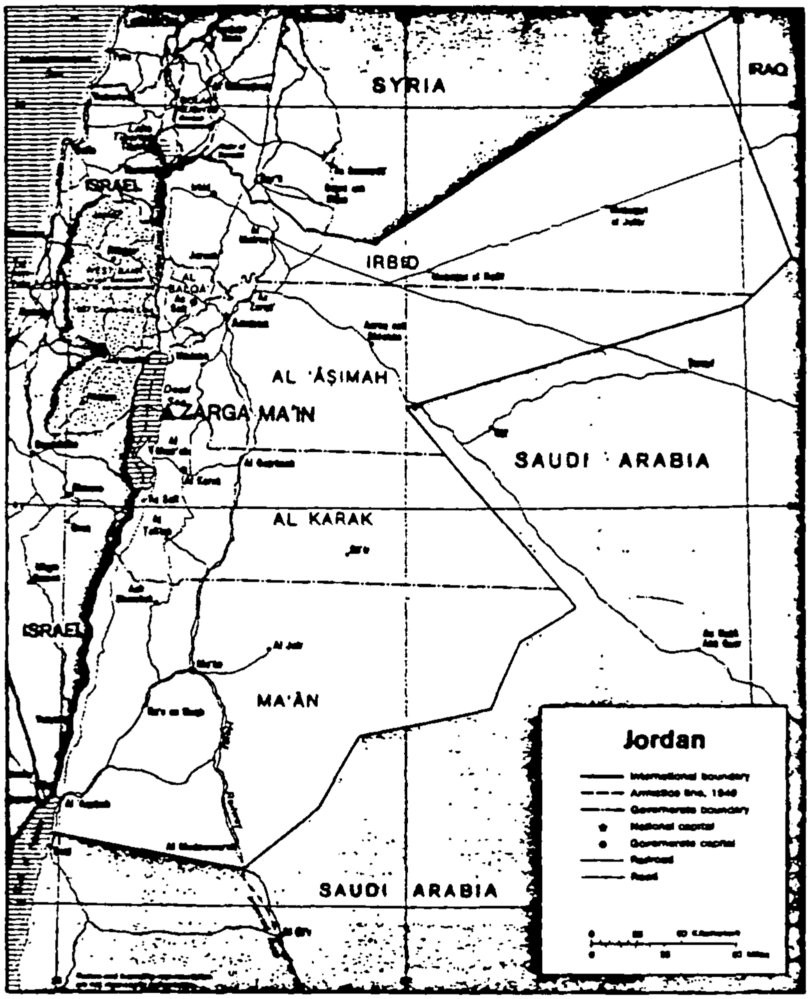

Bibliography:

Perera, J., 1986; "Jordan Stepping up Activities in Several Solar Energy Fields," International Solar Energy Intelligence Report, January p. 16.

Stalla, S.A., and Ajamich, M.A., 1981 Project Evaluation Summary - Minerals Development, U.S. Agency for International Development, Bureau for Near East - Jordan, EN. PES no. 278-81-4, 6 p.

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KEY CONTACTS

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- Bureau for the Near East

  Robert Ichord
  Chief, Energy and Natural Resources Division
  Office of Technical Resources
  Agency for International Development
  Washington, DC 20523
  (202) 647-8274

- Publications

  Ms. Dolores Weiss
  Director, Office of Publications
  Bureau for External Affairs
  Agency for International Development
  Washington, DC 20523
  (202) 647-4330

<u>U.S. Department of Commerce/International Trade Administration</u>

- Office of International Major Projects

  Mr. Leo E. Engleson
  Office of International Major Projects
  Room 2015-B
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-2732

- Foreign Industry Sector

  Mr. Les Garden
  International Trade Specialist for Renewable Energy Equipment
  Office of General Industrial Machinery
  Room 2805
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-0556

- Trade Development

  Mr. Friedrich R. Crupe
  Director, Information Industries Division
  Office of Service Industries
  Room 1116
  International Trade Administration
  U.S. Department of Commerce
  Washington, DC 20230
  (202) 377-3575

U.S. Department of Energy

Dr. Robert San Martin
DAS/RE
Office of Conservation and Renewable Energy
CE-030
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-9275

Dr. John E. Mock
Director, Geothermal Technology Division (GTD)
Office of Conservation and Renewable Energy
CF-342
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585
(202) 586-5340

Export-Import Bank

- International Lending

Mr. James R. Sharpe
Senior Vice President, International Lending
Export-Import Bank
811 Vermont Avenue, NW
Washington, DC 20571
(202) 566-8187

- Africa and Middle East Division

Mr. Clayton Norris
Vice President, Africa and Middle East Division
Export-Import Bank
811 Vermont Avenue, NW
Washington, DC 20571
(202) 566-8011

Geothermal Resources Council

Mr. David N. Anderson
111 Q Street, Suite 29
P.O. Box 1350
Davis, CA 95617-1350
(916) 758-2360

- Office of Development

Mr. Michael R. Stack
Development Assistance Director
Overseas Private Investment Corporation
1615 M Street, NW
Washington, DC 20527
(202) 457-7135

Small Business Administration

Mr. Michael E. Deegan
Director, Office of International Trade
U.S. Small Business Administration
1441 L Street, NW, Room 100
Washington, DC 20416
(202) 653-7794

Trade and Development Program

- Middle East and Caribbean Basin

Mr. Van Dyne McCutcheon
Regional Director
320-21st Street, NW
Washington, DC 20523
(703) 235-3660

United Nations

- United Nations Development Program

Mr. A. Bruce Harland
Director, UNDP Energy Office
One United Nations Plaza
New York, NY 10017
(212) 906-6090

- United Nations Department of Technical Cooperation for Development

Mr. Edmund K. Leo
Chief, Energy Resources Branch
Department of Technical Cooperation for Development
One United Nations Plaza
New York, NY 10017
(212) 963-8773

Mr. Nicky Beredjick
Director
National Resources and Energy Division
Department of Technical Cooperation for Development
One United Nations Plaza
New York, NY 10017
(212) 963-8764

Mr. Abderraouf Bouhaouala
Technical Director
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2707

Mr. Mohammad Reza Amin
Technical Adviser
Industry and Energy Division
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 477-5979

Mr. Everardus J. Stoutjesdijk
Country Director, CD III
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2707

Mr. Vinay K. Bhargava
Division Director, CD III
Industry and Energy Operations Division
Europe, Middle East and North Africa Region
The World Bank
1818 H Street, NW
Washington, DC 20433
(202) 473-2600

- Public Affairs Office
  The World Bank
  1818 H Street, NW
  Washington, DC 20433
  (202) 477-1234

- Publications

  Development Business
  P.O. Box 5850
  Grand Central Station
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  (212) 754-4460

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PHILIPPINES PROPOSAL CONSIDERATIONS

GENERAL QUESTIONS

1. Is there a limit to the amount that we can pay consultants or subcontractors?

2. The proposal invites us to expand the scope of work. However, there is already too much to do for the money. Is there any need to suggest other work? Are they looking for something?

3. Is it feasible to count on PNOC counterparts to do a large percentage of the work? Will they be able to write the sections of the development strategies that we would have a difficult time with?

4. How necessary will it be to have a continued presence in the country? Will they expect this, or will they be content with us coming and going, doing most of the work in the U. S.?

5. Will the work with PNOC be on a friendly basis, or do they resent the need to justify their work before NPC and the funding agencies will proceed?

6. What is the quality of the data that they will generate and expect us to work with? Will it be possible to actually arrive at meaningful development scenarios based on the 2-4 holes they will have along with the other surface data? Will they be able to furnish good copies of data?

7. What is the field like? Are these areas all rugged and inaccessible, or are some reasonable accessible?

8. Would there be the opportunity to influence their program of data collection and drilling? Would they be open to suggestions?

9. What are their facilities like in Manila and elsewhere in the country? Should we expect adequate office space? Do they have good FAX facilities? Will there be any computer support? Do they have PCs. What is the status of their computer capabilities and software?

10. How likely is it that they will actually follow their schedule for drilling and delivery of data?

11. How many of the PNOc people speak English? Is communication a barrier?

12. The RFP says that the PNOC will provide transportation, meals and lodging while we are in the country. Will their be extras that we have to budget?

13. How about our team? What are we lacking in the way of needed

talent? Suggest names.

14. How important is the study of 50 MW plants vs 20 Mw plants? Are they already settled and want verification of their decision to use 20s?

15. How can we address parts of the development strategy that have to do with "existing regional and local conditions" and "environmental considerations"?

16. What sort of environmental restrictions exist in the Philippines?

17. Does Koenig or any other U. S. company have an edge at the present time?

18. What kind of innovations might they be looking for in technology transfer?

19. What is the level of corruption among the PNOC people? Will they expect things under the table from us?

20. Why do the PNOC people think that they can not do good development strategies? What is their problem?

21. Where does PNOC leave off and NPC start?

22. What does it mean "client shall pay local transportation lodging meals etc?" what is local?

GENERAL COMMENTS ON PROPOSAL PREPARATION

1. Stress coordination with NPC engineers in the development strategy.

2. Stress communication with PNOC, especially on scheduling.

3. Because of the limitations on substitution of personnel, we must chose carefully.

4. Examine our insurance carefully to see that it will comply with contract requirements.

5. Statement needed that the proposals will be valid for a period of 3 months after submission.

CONTRACT

1. Who wrote the contract, TDP or PNOC? Can the contract be modified to state things more clearly, or are we stuck with it as is?

2. What is the meaning and intent of 3.8 -- Standards of Conduct? Specifically, the second paragraph, which states that

"the Consultant shall disqualify itself from business arrangements or work which conflicts with the objectives of this contract". What is the intent?

3. What is the meaning of 3.9 -- Liability.

4. Are the termination clauses in 5.1, 5.2 and 5.3 adequate?

5. In the TDP Mandatory Clause, Article VII, 7.1, what is the total list of TDP-reserved rights?

6. Article XII, Prohibition on Association. What does this mean?

7. Article XVI, Indemnifications. This clause is too one-sided. It does not offer UURI adequate protection. Can it be modified?

Walther
670-3454

Meeting w/ Barber-Nichols — 15 June 89

ITEMS NEEDED

1.

2.

3.

4. will send resumes on 5 1/4" floppy

5. Space/office needs — minimal to nil

6. Counterpart personnel: —
   - NPC plant people and/or plant people from PNOC
   - B-N has ME's, so need counterpart ME's — (or 2)
     and 1 CE.
     (for whole proj, ask for 1 Environ Engineer).
     ME should have power-plant background.

13. SOW — place where B-N might be weak would be pure CE stuff — roads, etc.

14. Contract →
Ralph Blakemore will look at it.

15.

16. Philippine involvement
- have done no work there in past
-

9. Possibly some CE on records missing.
~~The~~ B-N feels comfortable w/ gathering system as well as power plants.

8. will give std rate sheet. USURCI will take first cut at hrs/budget and get back to them by FAX.

7. Tech xfer (offering) -
- no canned classes / short courses -
- ~~x~~ are now in process of training people in Spain, Chinese (in past)
- Bill will write words for this.
- 2:1 prep time ratio is prob needed.

- Topics -
  - given a resource, what type of plant should one install
  - how to size plant

Bill will send us a xfer course outline.

10 E. Anticipated Problems
- maybe they want to know how flexible we are
- maybe they don't mean technical probs in this.

In our favor, we are all pretty small orgs, and adaptable.

— In schedule, put in proj review meetings.

- Talk about proj managmt — how we would deal with problems, etc.
- How will our teams ~~differ~~ deal w/ shifts in manpower loading from anticipated
- - i.e. internal managmt.

w/ Hutter

1. we will press deal w/ Leonard etc --
   they will have strong ideas
   check every point
   — rubber stamp -

2. Take advantage — Latin culture -
   know where to draw the line -

3. — quality of data is good -
   - validity will need to be checked -- been
     awfully taken by less exp people.
   - plenty of data, but maybe not all that we
     need
   - If something is not evaluable due to
     insufficient data — bring this out.
     May recom proj not ready to proceed.

4. — resources are big and spectacular --
   so on basis of 2-4 holes, can do job.
   Anyone in contiguous / nearby words -- etc.
   Hedge words --
     won't follow strategy anyway —

Phone 801-527-4734

- Recharge and longevity may be another prob. - check w/ LENOCAC people on this.

5. We could prob have input to program -- they have pride and education, but. do tactfully

- Everything DNOC has IBM or UNAC - call Embassy to make sure of machine

6. don't specify computer type.

B-M Management

- All projects have
  [Proj Manager
  Proj Engineer]

Engineer is resp for schedule/costs. For probs, PE deals w/ PM, who only gets involved if there are probs. PE and PM may be same person.

10. will furnish a letter to us.

15. Personnel –

B-M will name 4 people –
Ken + Bill as primary
Bob + Mike Forsha -- help in Denver.

16.

w/ Heltner – how much will PROC help?

1. We will be expected to do develop strategies, but they will help.
   - 5 days w/ PROC after being on site needed.

2. Counterparts – may wind up being our helpers.
   -- He had access to any discipline he wanted to talk about.

3. PROC have good attitude to learning – esp the Indians -- the chiefs don't know what's going on
   – they are young, bright, want to learn and show their knowledge

4. Travel to US for some of PROC people -- ?
   maybe service trade missions, etc.?
   Ivo. people would not be the ones to go to U.S.

5. Have FAX – spartan quarters –
   ask for part-time typist, copying
   desk space, etc.
   English is the language =

6. Time over there -
allocate ±10 days, etc for first project.
weeks at a time -

- living costs - not bad -

ITEMS NEEDED FROM BARBER-NICHOLD AND S-CUBED

1. Background, organization and experience of firm.

2. Letters of testimonial on previous work. will provide references, etc.

(3.) Philisophy of how the project should be done and technical approach. will provide this.

✓4. Background, employment records and detailed professional experience of experts. — resumes

B-N- min space file cabinets?

✓5. Estimate of office space needs, vehicles, equipment etc. that we want them to furnish in the Philippines.

✓6. Suggested make-up of counterpart personnel.

✓7. Technology transfer offerings.

time & material rate sheet.

✓8. Costs for services, including all rates. ←

✓9. Opinion of completeness of team -- have we got all of the bases covered?

✓10. Anticipated project problems, interpretation of problems and solutions to problems.

11. Letters that each sub is willing to serve in a subcontract role on the project.

12. Estimation of just what can be done with the data that PNOC says will be available, i.e., will it actually be possible to do what they ask in terms of reliable assurance of the resource and determination of optimal development strategies with the wells they plan to drill?

B-N fills in gaps only

13. Need to go through the SOW with each sub and determine what in-house capabilities they have for handling each item.

14. Do any of the subs have any problems with the contract? Our contract with them will indicate that the PNOC-UURI contract is part of each subcontract by reference.

15. Will any of the subs have trouble assuring that the personnel they propose will be available for the work?

(No for B-N)

16. Are any of the subs involved or will they be involved in the Philippines or with PNOC now or during the expected term of the project?

PB
6-15-89

Bill — re: your request for comments

p12 2.1 $ US

p13 2.2 (15) days

p14 3.4 client decides suitability of personnel
dispute - if consultant disagrees
personnel replacement cost high? travel, ~~[illegible]~~ etc?

p15 3.8 conflicting opportunity problem (client data or representation)
p15 3.9 except in instance of client influence or negligence
p15 3.10 ins. requirement is for both
general liability (including customer goods)
and professional liability

~~[how to settle disputes?]~~

p19 5.3 b suggest that "reasonable costs" be defined
(should be entitled to overheads and fee
on termination work)

p 19 VI should address on consultants behalf
compensation for damages resulting
from events of Force majeure

p 22 XI "great escape" clause
suggest elimination of same or
define fully "legal requirements
and procedures"

p 22 XII vague - too restrictive - last sentence
suggests consultant can't provide
any goods and services without
client consent - limit to
Philippines

p 22 XIV

insert

"... any information, marked confidential, which is disclosed to them ..."

"... any information, marked confidential, as to the ..."

this clause should contain:

i) public domain provision

ii) prior knowledge provision

iii) previous development provision

iv) third party (non-breach) disclosure

p23 XVI except in instances of client negligence including influence, data errors, mis-representations

or alternatively: only those acts for which the Consultant is directly responsible for

[illegible]

PNOC ENERGY DEVELOPMENT CORPORATION
PNOC ENERGY COMPANIES BLDG.
PNPC COMPLEX, MERRITT ROAD
FORT BONIFACIO, METRO MANILA, PHILIPPINES
P. O. BOX 1208, MAKATI COMMERCIAL CENTER
TEL. NO. 85-89-61 TO 73

11 June 1987

Dr, Phillips M. Wright
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

Dear Dr. Wright,

The Geothermal Division of the Philippine National Oil Company is actively engaged in personnel development, aimed primarily at having our technical staff acquire state-of-the-art knowledge along their respective areas of specialization, both for purposes of application to the problems besetting our own geothermal fields and of becoming active contributors to this rapidly expanding field. To realize this objective we have negotiated with several funding agencies (e.g. Colombo Plan, UNDP) to finance our staff during their overseas training or graduate studies.

We understand that included among your research interests are some aspects of geothermal energy development. In this connection, we would be very grateful if you could indicate to us whether it would be possible for any of our staff to come and work with you (or your group) either as a research trainee or as a graduate student. If so, it would be our pleasure if you could provide us with some documents indicating your areas of research interests (e.g. programs, research articles).

Looking forward to your favorable reply.

Yours truly,

Rodolfo M. Castillo

MEMO TO: DENNIS NIELSON

FROM: MIKE WRIGHT

SUBJECT: TRIP TO BARBER-NICHOLS

June 16, 1989

The following items were discussed with Bill Batten yesterday pertaining to the Philippines proposal. This is in addition to the stuff I have already given you.

1. They use WordPerfect 5.0, and should be able to send stuff on disk to us in that format.

2. They do not anticipate any special space or equipment needs in the Philippines. They believe that most of the work can be done at their shop in Arvada.

3. Counterpart people. They will want to interface closely with plant people, which may mean people in NPC rather than PNOC. Perhaps PNOC will also have a plant person for liaison. We should specify both in the proposal. They have in mind 1 or 2 Mechanical Engineers who have power-plant experience and possible 1 Civil Engineer. We should also ask for an Environmental Engineer to interface some with B-N and with other team members.

4. Bill feels comfortable with all of the aspects of the work that we would have them do except possibly some of the more CE things such as road building. They can handle simpler aspects of this also. My feeling is that we may want to wait until we get into the project, and if a real need for a CE comes up, we can probably pick one up for the small amount of work we would anticipate at this point.

Bill in particular said that they can handle all aspects of the gathering system as well as the power plant.

5. Their guy Ralph Blakemore has quite a few problems with the contract as given. My feeling is that we can wait to iron out these if we get the project rather than try to make an issue of it at this point.

6. B-N has had no Philippine projects to date, and do not expect any during the term of our project.

7. Tech Transfer. They have no prepared material that is suitable, and would need some prep time for lectures. Bill felt that they might need a ratio of 2:1 prep time:lecture time. They have done some training of people to run their equipment, and can site that as experience. They have worked with both Chinese and Spaniards on this. Bill with write some words on what they would propose to cover in tech transfer lectures.

8. In the schedule, there should be domestic travel for coordination and working meetings.

9. In the project management section, there should be discussion about how we would handle coordination among team members and how any conflicts would be handled. We should also discuss how we would build in flexibility to deal with changes in project that PNOC might request.

10. The way B-N usually handles projects is with two responsible people. They assign a Project Manager and a Project Engineer. The PE is responsible for the work, schedules and costs. If any problems arise, the PE deals with the PM, who only gets involved at need. Sometimes the PE and PM are the same person, but they usually try to avoid this.

11. They plan to use four different people on the project. Ken Nichols and Bill Batten will be the primary people, and Bob Barber and Mike Forsha (pronounced Forshay) will be secondary and back-up. Ken, Bill and Bob bill at the Senior Engineer rate, while Mike bills at the next lower rate. Mike will probably be used in the office to do more routine calculations, etc.

UNIVERSITY OF UTAH RESEARCH INSTITUTE
GEOTHERMAL PROJECTS

INJECTION RESEARCH

Development of chemical tracers for use in geothermal reservoirs. Development of injection-backflow techniques for determining chemical reactions in and physical properties of the reservoir.

GEOLOGICAL AND GEOCHEMICAL RESEARCH

Development of geologic and geochemical models of geothermal systems. Studying the nature of fluid flow in fractured systems, water/rock interactions (hydrothermal alteration), trace element chemical zoning, chemical and physical evolution of geothermal systems. Using: petrology, petrography, and X-ray diffraction; major, minor, trace element, and isotope geochemistry; fluid inclusions; remote sensing. Currently working at: Valles Caldera, New Mexico; The Geysers, Coso, Salton Sea, East Mesa and Heber, California; Meager Creek, British Colombia; Los Azufres, Mexico.

GEOPHYSICAL RESEARCH

Development of geophysical techniques and interpretation methods and of geophysical models of geothermal systems. Currently concentrating on development of magnetotelluric (MT) and borehole geophysical methods. In MT, constructing a state-of-the-art field data acquisition system. In borehole geophysics, using computer modeling to help design a field system for borehole-to-surface and cross-borehole resistivity and electromagnetic work. Currently working at Coso and Long Valley, California.

CASCADES RESEARCH

Assisting the U.S. Department of Energy in the cost-shared drilling of 4000-5000 ft exploration coreholes with companies. We make the data available to the public. Also performing research on and writing case histories of the projects. Four project areas.

ASCENSION ISLAND PROJECT

Exploring Ascension Island, South Atlantic Ocean, for geothermal resources on behalf of the U.S. Air Force. Have mapped geology, performed geophysical surveys, drilled 6 temperature gradient holes and one deep reservoir test well.

CONTINENTAL SCIENTIFIC DRILLING

We are one of two lead organizations for CSD in the Valles Caldera, New Mexico. Drilling designed to scientifically explore the magma-hydrothermal system.

Rodolfo M. Castillo

Dear Mr. Castillo,

Thank you for your letter requesting information on our geothermal programs and the possibility of some of your people working with our group. We are funded primarily by the U.S. Department of Energy to perform geothermal research in the earth sciences. Our group consists of geologists, geochemists and geophysicists at the B.S., M.S. and PhD. levels. We have a laboratory for chemical analyses that specializes in geothermal rock and fluid samples. We also have a supermini-computer, a Prime 2655, that is available for calculations related to geophysical and geochemical interpretation. Our remote sensing group has the latest NASA software for processing and interpretation of satellite and airborne imagery. The attached sheet gives a summary of our current research projects.

The University of Utah Research Institute is a non-profit organization that is owned and controlled by the University of Utah, but is not part of the University. We are a separate corporation that does contract research. We receive no financial support from the University, and we perform no teaching functions.

We would be very happy to have one or several people from PNOC come to the United States and work with us. You would be able to get involved with almost any of our projects. We could offer your people the position of research trainee, and we understand that your people would have salary and expenses paid by funds that you have obtained. In addition, it may be possible for members of your group to apply to the University of Utah for admission to graduate school and work with UURI as graduate students. We, of course, could not guarantee acceptance into the graduate program at the University.

If these arrangements are interesting to you, I would be happy to answer any further questions.

Sincerely,

PNOC ENERGY DEVELOPMENT CORPORATION
PNOC ENERGY COMPANIES BLDG.
PNPC COMPLEX, MERRITT ROAD
FORT BONIFACIO, METRO MANILA, PHILIPPINES
P. O. BOX 1208, MAKATI COMMERCIAL CENTER
TEL. NO. 85-89-61 TO 73

Mike
For your info.
MA

25 May 1987

Mr. Michael Adams
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
U.S.A.

Dear Mike,

Our trip to the United States was exhausting but enjoyable. The most interesting part of it I think, was our trip to Salt Lake City. Thanks for your hospitality. I really learned a lot during my short stay at your Laboratory. Now I'm back to my old job doing geothermal.

I have brought up with our management the idea of a possible joint project with your institution on geothermal tracers. The consensus is that the cooperative project is feasible, but details have to be worked out. My initial impression is that the Company is willing to have the field tests done on our wells, but the cost of the chemicals and the international air tickets for you or your staff will have to be shouldered by an outside agency. Maybe you could give me some feedback on this.

Right now, we don't have ongoing tracer studies, but there will be one in the near future. We continue to use disodium fluorescein as tracer, but then, many of our well fluids have temperatures in excess of 250°C where you noted a thermal breakdown of the tracer. I would appreciate very much if you could send me data (or copy of published paper) on the thermal stability of fluorescein which you obtained in the laboratory, as you mentioned while I was in Salt Lake City.

I'm enclosing an invitation to our annual geothermal conference in the hope that you might just be able to come to our country at about this time. While this is mainly a local conference, we do have foreign visitors from time to time. It would be an opportunity for you to see our geothermal development, too.

By the way, I mentioned to Jeff Hulen that I was aware of a recent paper on molybdenum in geothermal waters, but I forgot the details at that time. Please tell Jeff that the paper I was referring to is: S. Arnorsson and G. Ivarsson (1985) Molybdenum in Icelandic geothermal waters. Contrib. Mineral, Petrol. 90, 179-189.

Extend my regards to Jeff, Mike Wright, Dennis Nielson and all the rest. Again, thanks for the hospitality you have extended to me during my visit there.

Sincerely yours,

Joselito R. Ruaya

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TEL. NO. 815-89-61 TO 73

08 April 1987

Mr. Michael Adams
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, Utah
U.S.A. 84108

Dear Mr. Adams:

The Technical Review Committee is now soliciting papers for our 9th Annual PNOC-EDC Geoscientific Workshop and Geothermal Conference which is tentatively scheduled on 24-27 November 1987 in Tongonan, Leyte. Deadline for the submission of abstracts is on 02 July 1987.

Authors of accepted papers are required to submit their manuscripts not later than 21 August 1987. Only papers with manuscripts will be considered for oral presentation.

The main theme of the Conference is "Tongonan after 15 years" but all other papers on geothermal are equally welcome.

Abstracts should be not more than 300 words with illustrations and mathematical equations avoided or kept to a minimum. Titles of abstracts should be submitted to:

Ms. T.A. VICTORIA
PNOC-EDC Geothermal Division, Room 4201, Bldg. IV-A
PNPC Complex, Merritt Road, Fort Bonifacio, Metro Manila
Philippines

We will cover your accommodations and meals for the duration of the conference. However, our company cannot shoulder your round-trip international airfares. We suggest you seek the assistance of your office or some funding institutions like UNDP.

We look forward to your presence and active participation in this conference.

Very truly yours,

Joselito R. Ruaya

JOSELITO R. RUAYA
Chairman
Technical Review Committee

JRR/ASJB:mrf

REPORT ON A DEFINITIONAL MISSION TO
DETERMINE THE SCOPE AND ESTIMATE THE
COST OF A GEOTHERMAL ENERGY
FEASIBILITY STUDY OF SITES ON
LUZON ISLAND IN THE PHILIPPINES

By:

GERALD W. HUTTRER
Geothermal Management Company, Inc.
Box 2980, 27972 Meadow Drive, Suite 340
Evergreen, Colorado 80439

For:

U.S. Trade and Development Program
Room 309, SA-16
Washington, D.C. 20523

November 8, 1988

Conclusions and Recommendations

1. A definitional mission to determine the scope and estimate the cost of geothermal energy feasibility studies at four sites on Luzon, Philippines was conducted by Geothermal Management Company, Inc. from October 12-26, 1988.

2. In Manila and at project sites, meetings were held and information was collected from the U.S. Embassy, Philippine National Oil Company (PNOC) and Asian Development Bank (ADB) representatives.

   The senior staffs met and/or interviewed included:

U.S. Embassy:	Ted Velinsky - Commercial Director
	Cleo A. Alday - Sr. Commercial Specialist
PNOC:	Pedro S. Santos - Vice President
	Arturo Alcaraz - Consultant
	Leonardo M. Ote - Division Manager
	Samson P. Javellana - Manager, Planning
	Ramon B. Balane, Jr. - Manager, Planning & Evaluation
	Carli M. Ricio - Manager, Geoscientific Department
	Conrado C. Panem - Mining Engineer, Geologist
	F.C. Delfin - Geologist
	Jim Johnson - Geologist
	Joselito R. Ruaya - Geochemist
	Numerous field engineers and geologists.
Asian Development Bank:	Michael Charleson - Senior Project Engineer

3. PNOC has several active geothermal projects on Luzon including Bac-Man II, Del Gallego (formerly called Mt. Labo), Bulusan, Pinatubo and Natib. Though TDP may fund feasibility studies on four projects, an additional project was reviewed in order to increase project flexibility.

4. PNOC has conducted geologic, geochemical, and geophysical studies of a very high professional caliber at all of the projects under consideration. The data gathered to date, when coupled with information to be gleaned from

exploration drilling and testing will be adequate to permit valid feasibility studies.

5. The scope of the feasibility studies will include: (a) Review of Resource Assessments done at each project by PNOC, and (b) Design of a Development Strategy for each project.

6. The estimated cost for PNOC to hire an independent third party consultant to conduct these feasibility studies is U.S. $403,922 to be spent over a period of 15-18 months beginning in January 1989.

7. All of the projects reviewed have excellent potential for generation of electric power using geothermal steam. Funding of a grant to PNOC by TDP is recommended in light of the low-risk nature of the projects and future financial benefits to U.S. firms which might accrue, directly or indirectly, because of U.S. assistance in the development of these projects. The possible value of these benefits is close to $350 Million.

Contents

1.0 DETAILED PROJECT BACKGROUND INFORMATION

1.1 Introduction

The Philippine National Oil Company (PNOC) is the primary entity in the Philippine Republic responsible for exploration and development of geothermal resources. PNOC comprises two basic division: the Oil and Gas Division and the Energy Development Corporation (EDC) which originally included coal, geothermal and uranium programs. Because coal and uranium now receive a very low level of effort, EDC is primarily dedicated to geothermal work. The Vice President of PNOC-EDC is Pedro Santos, the Division Manager is Leonardo Ote, the Geoscientific Manager is Carli Reccio, and the Geothermal Exploration Manager is Hermes Ferrar. More than 100 geologists, geophysicists, geochemists, and technicians work indirectly under Mr. Ferrar's supervision.

Since the late 1970s, PNOC alone and in collaboration with consultants from New Zealand, the U.S., Italy, France and Japan, has been exploring and developing Philippine geothermal resources. Funds for this work have been received from World Bank, Asian Development Bank, A.I.D. programs from several nations, and from internal budgets. To date, PNOC has taken to the power producing stage projects at Tongonan, Leyte and Palimpinon, Negros. (See Figure 1 Index Map).

During the latter years of the Marcos regime, economic development in the Philippines stagnated and the demand for electric power generation increases did likewise. Since the start of the Aquino presidency, Philippine economics have improved, and all agencies have been directed to increase electric power producing capacities. Accordingly, geothermal exploration has resumed and accelerated.

Currently, PNOC, funded by World Bank, has been exploring geothermal resources all over the archipelago. Demand for power will be greatest on Luzon, however some increased demand can be promoted on the Visayan and Mindanao Island groups. In order to accommodate these anticipated smaller power increments, the National Power Corporation (NPC) has requested bids on twenty (20), small

(20 MWe) turbine generator sets for delivery as soon as possible. The availability of these units will give the geothermal program speed and flexibility and will enable economic development of several fields previously considered to be too small to use.

1.2 PNOC Exploration and Development Techniques

On its own and via guidance provided by consultants and geothermal school directors, PNOC has developed a systematic approach to geothermal exploration and development which is technically sound and at the same time cost effective. The work is split into three main phases:

I. Exploration
II. Resource Assessment
III. Development Strategy

1.2.1 Exploration includes:

a) Geologic mapping, on a semi-detailed scale, of lithologies and structure using air photos and traditional field techniques. The main objective of the mapping is the delineation of prominent faults, caldera boundaries, loci of anomalous hydrothermal alteration and of all thermal manifestations and the characterization of the local and regional rock types, their ages and relative relationships.

b) Hydrogeochemical studies of thermal and non-thermal surface, spring and well waters in and around interest areas. The purpose of this work is to learn the chemical signatures of the various waters sampled. This information can then often be used for geothermometric calculations by which equilibration temperatures of thermal waters can be estimated, to decide if the water source is in an upflow zone or an outflow area, if the geothermal resource is vapor or liquid-dominated and whether the sampled water represents the actual geothermal reservoir or is a secondarily heated surface water.

c) Geophysical studies; mainly Schlumberger Resistivity Traverses (SRT) and Vertical Electric Soundings (VES) but also including gravity and seismic methods on a few occasions. Resistivity studies seek areas in which the conductivity of rocks and interstitial fluids are increased, i.e., resistivities decrease to levels of 10-20 ohm-meters or less. Such areas are often characteristic of geothermal fluid concentrations. Gravity and seismic surveys are used to help locate and/or identify buried structures such as grabens, caldera boundaries, buried intrusive bodies and loci of active faults. This information is often helpful in creation of a realistic geologic and geothermal model of the prospect area.

d) Drilling of up to three (3) production-scale exploration wells at sites determined by congruence of geologic, geochemical and geophysical anomalies as modified by environmental and logistical considerations.

1.2.2 <u>Resource Assessment</u> can begin when the exploration drilling program starts. The assessment input includes all information gleaned from drilling (lithology, alteration, mineralization, structure, lost circulation, fluid production zones, chemistry of produced fluids and gasses, temperatures, pressures and geothermal production and/or injection capacities). This work has been done most recently by PNOC staff, but in the past it was done by consultants and jointly by PNOC and consultants.

The results of the Resource Assessments are used by PNOC to make a preliminary commitment to NPC for provision of enough steam to fuel the generation of a certain number of megawatts of power. Because NPC must be sure that such PNOC commitments are realistic, NPC normally commissions an impartial third party to review the PNOC and Resource Assessment. If the power plants to be build by NPC are funded by a non-Philippine lending agency, it is not unusual for the lending agency to employ the third part reviewer of the Resource Assessment.

Resource Assessment can begin by review of exploration data and proceed on a well-by-well basis, creating resource models and then modifying them as new well data are generated and interpreted. In this way, the Resource Assessment can be finished soon after the last exploration well has been drilled and tested. (Wells usually take 6-8 weeks to drill to 2500-3000 meters and are tested following completion for up to 3 months.)

1.2.3 Development Strategy is not PNOC's strongest suit by its own admission, hence this work has mainly been conducted by outside consultants. The work is critical and synthesizes all aspects of the Resource Assessment with environmental, transmission, plant type and size, permitting and power demand/timing parameters. Alternative development scenarios are designed and ranked in preference order which is based, to a great extent, on NPC priorities. Outside consultants collaborate with PNOC and NPC scientists, engineers, lawyers and economists to optimize their development strategy.

1.3 Recommended Projects and the Scope of Activities for the Feasibility Study for which TDP funding is being considered

1.3.1 Projects Involved

Though PNOC is currently exploring geothermal prospects on islands other than Luzon, the current project is to address only Luzon areas of interest. The recommended projects are:

1. Bacon-Manito II (Bac-Man II) - Albay Province
2. Del Gallego (Mt. Labo) - Camarines Norte Province
3. Bulusan - Sorsongon Province
4. Mt. Pinatubo - Zambales, Tarlac, Pampanga Provinces
5. Mr. Natib - Bataan Province

Though TDP funding for four (4) Luzon projects has been anticipated, five (5) areas are addressed herein in case one does not survive Resource Assessment and does not therefore require a Development Strategy. Figures 2 and 11 depict the Bataan and Bicol peninsula regions in which all five referenced projects are located.

1.3.2 Scope of the Feasibility Study

PNOC prefers to conduct Resource Assessment on all of its projects using in-house personnel. However, PNOC will welcome and requests that an independent third party consultant review their Resource Assessments for each area. As previously stated, PNOC believes that such a review can: (a) lend credibility to its steam commitments to NPC, (b) help PNOC in its continuing efforts to optimize the abilities of its professional geothermal staff, and (c) constitute an assessment acceptable to project lenders.

Additionally, PNOC seeks third party, consultant assistance in designing the Development Strategies for each area. PNOC can, of course, do this in-house, but they are best at resource-related matters and would appreciate assistance with the non-resource related tasks.

In summary, the author of this report, after extensive consultation with PNOC officers, managers and staff, recommends that the "geothermal resource assessment and feasibility study of four sites on Luzon in the Philippines" (Page 1, Item A "Objective", Lines 4-7 of Order for Supplies or Services on TDP Project No. 88-397) comprise the two following primary tasks:

1. Review of the Resource Assessment to be conducted by PNOC on the results of their geothermal exploration at four of the following Luzon prospect sites: Bac-Man II, Del Gallego, Bulusan, Pinatubo, and/or Natib, and
2. Design of Development Strategies for the four geothermal prospects chosen from the list above.

2.0 PROJECT STATUS SUMMARIES

2.1 Introduction

Presented below are summary descriptions of the exploration activities conducted to date at each project, the interpretations of the recorded data and the PNOC plans for October 1988 through December 1989. These summaries are synthesized from information gathered during: (a) reviews of detailed reports, maps, tables and figures, (b) comprehensive discussions with PNOC field and managerial personnel, and (c) site visits to Bac-Man and Pinatubo on October 20 and 21, 1988.

2.1.1 Bacon-Manito II (Bac-Man II)

The Bac-Man geothermal prospect is located 30 km southeast of Legaspe City, Albay Province in the central part of the Bicol Peninsula of Souther Luzon (Figure 2). Exploration of Bac-Man was begun by PNOC, using its own funds, in 1976 and to date, more than 88 MW worth of steam has been drilled out and tested. NPC now plans to install two 55 MWE power plants at Bac-Man I by 1991, therefore PNOC is planning to drill three more wells with which to fuel these plants.

PNOC exploration in the Bac-Man areas covered 500-600 square km so as to study the overall geothermal environment. Geologic mapping delineated a highly fractured area just north of the Pan-Philippine fault zone (Figure 3) as being the most promising. The fractured area was adjacent to craters at Palayang-Bayan and Cawayan and near prominent domes at Pangas and Osaio (Figure 4).

Resistivity studies in the geologically promising area revealed an east-west elongated, ameboid shaped region of 20-30 ohm-meter resistivities at depth. The anomaly includes Masakrot, Cawayan, Mt. Pangas, and is mainly south of Palayang-Bayan (Figure 5).

Geochemistry of surface waters indicated that sulphate waters, in a postulated upflow area, were located in the eastern part of the overall anomaly. Other springs, with higher chloride content (outflows) were sampled in the west and northwestern parts of the interest area (Figure 6).

Bac-Man I wells drilled into the upflow area were very hot (>300°C) and some, drilled toward Mt. Pangas, suggested that the main heat source might be well to the east. Accordingly the Pangas vicinity was designated as Bac-Man II.

Exploration targeted at Bac-Man II began with two wells designated Osaio-Pangas (O-P #1 and O-P #2), deviated northeast and east from Bac-Man I. The results of these wells were disappointing (high temperatures, low permeabilities) therefore the eastern limits of Bac-Man II were moved westward. To compensate for the loss of prospective area, Bac-Man I wells drilled in the Masakrot and Cawayan areas were dedicated to Bac-Man II. Finally, a newly prospective area adjacent to Palayang-Bayan (northeast of Bac-Man I) was also integrated into Bac-Man II.

Bac-Man I will use fairly standard 55 MWe size power plants but because of the decentralized sites of the Bac-Man II wells, the new 20 MW, well-head turbine generators will be most cost effective.

PNOC plans to finish drilling O-P #3 by the end of October. The Resource Assessment is due 12/15/88 and the Development Strategy for Bac-Man II is due 3/30/89. Thus, if TDP elects to fund the project, it is possible that the contractor selected will have time to review the resource assessment and participate in the Development Strategy design.

Bac-Man is one of the better PNOC projects and the construction of both the 100 MWC Phase I and the 60 MWC Phase II is almost certain.

2.1.2 Del Gallego (Previously called Mt. Labo)

The Del Gallego geothermal project is located on the southwestern flank of Mt. Labo, the northwestern-most volcano in the chain of peaks forming the spine of the southern Luzon Bicol Peninsula. The project is in Camarines Norte Province, about 35 km southwest of Doet, the provincial capital (Figure 7).

Exploration of the Mt. Labo region was initiated in 1983 by the French company Total and Philippine Oil and Geothermal Energy, Inc. Much of the geologic mapping and air photo analysis was contracted to an Italian firm. For unspecified reasons, the group discontinued their work without ever drilling a well.

PNOC began work at Del Gallego in late 1984, redoing the geologic mapping of 190 square km, sampling 12 groups of surface waters, running Schlumberger Resistivity Traverses over 600 square km (337 stations) and doing Vertical Electric Soundings at 39 sites over 300 square km.

The Italians believed that a series of andesite domes are concentric around Mt. Labo and that they erupted along a caldera boundary with Mt. Labo as a resurgent central dome. PNOC geologists do not see this caldera and prefer to model the target area as a prominent northwest trending graben transected by northeast striking faults (Figure 8).

The hydrochemical studies done by PNOC revealed $Cl+HCO_3$ SO_4, SO_4+HCO_3, HCO_3+Cl, and SO_4+Cl water groups. The high chloride waters tend to be in the western and southwestern lowlands, in an outflow zone, while the high sulfate waters are higher up and are considered to be just downstream of the upflow zone. Geothermometric calculations for resource equilibration temperatures are 180-200°C, but these may be on the low side due to mixing with meteoric waters.

The several electrical resistivity surveys run showed an ovoid area of about 20-30 square km extent in which resistivities are less than 10 ohm-meters. This anomaly covers the part of the graben that is strongly fault-dissected and which is immediately upstream of some high sulfate springs and solfaterically altered ground.

PNOC has plans to drill three wells from two pads at Del Gallego in early 1989. Access roads were being built to pad A, but in August 1988 progress was stopped by local insurgents who commonly interfere with government projects. Demands for radios and/or money are being negotiated and PNOC believes that road building will resume in time for drilling to start in April or May 1989. All work to date by PNOC has been funded in-house.

2.1.3 Bulusan

The Bulusan geothermal project is located in Sorsogon Province at the southern-most end of the Bicol Peninsula of southern Luzon. The area of interest is about 35 air km due south of the Bac-Man project area and is accessible via the Pan Philippine highway and local roads.

PNOC began exploring Bulusan in July 1985 and completed geologic mapping, hydrogeochemistry and geophysical studies by December 1986.

Geologic mapping disclosed three major ages of volcanic rock depositions:

1. a pre-caldera series of andesite and basalt flows outcropping primarily beyond the caldera limits,
2. widely distributed pumecious, non-welded, nuees ardentes flows which overlie the older rocks, and
3. a group of andesitic cones which are concentric about the youngest cone, the active Mr. Bulusan.

The area of interest is transected by northeast and northwest trending faults many of which emanate radially from Mt. Bulusan. Thermal features comprise springs at 30-60°C localized around the caldera rim. These springs are mixed waters with higher chloride contents in the low-land outflow area and higher sulfate in the suspected upflow areas near the Malpaso and Makrot conductive anomalies and at Pinirincipe northeast of Mt. Agoho.

The electrical resistivity surveys (SRT and VES) revealed anomalies at Banyo, Gabao and San Roque initially (Figure 9). Later, follow-up VES work found profound anomalies at Mapaso and Makrot (Figure 10). Both of these new anomalies are deep (below 800 m) and of less than 10 ohm-meter intensity.

The initial evaluation of Bulusan was not very positive, citing low temperature springs, low geothermometric predictions (150°C) and paucity of acid-sulfate alteration. However, in light of the fact that Mt. Bulusan is active, with an obvious heat source, reevaluation was indicated.

The review of data emphasized the relevance of the geochemistry. All indications are that only mixed waters are being sampled since nowhere do representative geothermal resource waters reach the surface. Most likely, all of the springs are meteoric waters that are heated by steam boiling off the true geothermal reservoir.

Work at Mt. Bulusan is being renewed now, in October 1988. Current plans are to drill three exploration wells in 1989, probably upstream of the Mapaso and Makrot anomalies, near Mt. Agoho. The wells will be deviated and designed to intersect northwest and northeast faults.

Though there is some rebel activity in the Bulusan area, PNOC work has not been interrupted and it is anticipated that road building through the moderately forested highlands will be completed efficiently.

2.1.4 Pinatubo

Pinatubo is located near the boundaries of Zambales, Tarlac and Pampanga Provinces about 12 km west of Clark Air Force Base near the west coast of central Luzon (Figure 11). It is accessible via reasonably well maintained roads by a two hour drive from metro-Manila. Vegetation on the mountain is dense while the lowlands are largely grass-covered.

PNOC began exploration of Mt. Pinatubo in 1983 using in-house personnel and consultants from New Zealand. Geologic mapping disclosed andesitic cones erupted around the rim of a 4 km x 3 km caldera. Mt. Pinatubo is a resurgent dome with solfateras and acid-sulfate springs near its summit (Figure 12). The area is underlain by Eocene age ophiolites to the west and by Miocene-Pliocene age sediments on the north and northeast. North-south and conjugate east-west dip slip faults, typically less than 5 km long, transect the region.

Hydrogeochemistry is somewhat sparse, however, two distinct hydrothermal systems are indicated: one at Marunot northwest of Pinatubo and the other (smaller and older) at Mt. Negron, southeast of Mt. Pinatubo. Both systems are characterized by lower level chloride springs and higher level sulfate springs and solfateras. The PNOC geologists believe the Marunot region to be the upflow zone, while the New Zealanders prefer the Mt. Donald McDonald region between Mt. Pinatubo and Mt. Negron.

Electrical resistivities in the region are higher than those recorded at the prospects in the Bicol Peninsula with values below 50 ohm-meters being anomalous. Both the Marunot and the Mt. Donald McDonald anomalies are below the 50 ohm-meters threshold.

As of October 1988, a vertical well, PIN-1, had been drilled to 2580 meters and a second well, P-2D, had been spudded (Figure 13). PIN-1 temperature (unequilibrated) was about 250°C; permeability appears to be low to moderate. No attempts have been made, as of October 19, 1988 to flow PIN-1. P-2D will be deviated due west and will test the upper Marunot anomaly. A third well, P-3D, will follow P-2D and will be drilled southward beneath Mt. Pinatubo toward the Mt. Donald McDonald anomaly.

The PIN-1 well was the first of the exploration wells to be drilled under World Bank funding. All of the exploration wells on all of the Luzon prospects will likewise be drilled with World Bank funds.

2.1.5 Natib

Natib is located on the Bataan Peninsula due west of Manila, at the south end of the Zambales Range. Access is via the Pan Philippine highway north from Manila, thence west and south on adequately maintained local roads (Figure 11). The interior Natib region is very steep, heavily vegetated terrain with access limited to scattered logging roads and tribal trails. Insurgents are not a problem.

PNOC conducted geologic mapping hydrogeochemical sampling and geophysical exploration of the Natib (and adjacent Mariveles area) between February and December 1987. All work was done by PNOC staff with in-house funding.

The geologic mapping (Figure 14) revealed two coalescing andesitic strato-volcanoes, a large, western, older caldera, a young (<30,000 YBP) eastern crater of Mt. Natib, and well developed northwest trending faults that transect both the caldera and the adjacent Natib crater, and which are the loci of most of the local thermal phenomena (Figure 15).

Hydrochemical studies made of ten surface water sources (thermal and non-thermal) show that most Natib area waters are mixtures of meteoric and geothermal fluids. Most of the warm springs discharge neutral chloride-sulfate-bicarbonate waters with acid-sulfate waters and fumaroles notably absent. Geothermometric temperatures are only 180°C but they are not reliable due to the admixture of non-thermal waters in unknown amounts.

Electrical resistivity traverses and vertical electric sounding over more than 450 square km show an extensive 10 ohm-meter anomaly over both the caldera and the Natib crater (Figure 16). Within the older caldera, the anomaly is related to the warm springs and altered ground while in the crater, it may be indicative of thermal upflow along major faults.

The very young age of Mt. Natib and adjacent cones and the alignment of thermal features along northwest faults together create a viable objective for geothermal drilling. Currently, a road is being built in to eastern edge of the caldera where a pad will be created in time for the drilling of at least two wells in early 1989. The wells will trend west southwest and south southwest so as to test the fault networks, the caldera boundary and the Natib crater regimes.

3.0 PRELIMINARY TECHNICAL AND FINANCIAL ANALYSIS

3.1 Introduction

Technical and financial analyses supporting the recommendation whether or not to proceed with the proposed project are presented in the following two sections of this report. The technical analysis is based on the author's 16 years of experience in evaluating similar projects; the financial analysis concerns future benefits to U.S. firms and the U.S. economy anticipated to result from the financing and facilitization of these projects.

3.1.1 Technical Analysis

PNOC and its predecessors have been exploring for and developing Philippine geothermal resources for almost 20 years and have a professional staff of collage educated geoscientists and engineers with a strong background in geothermics. In the past, PNOC has collaborated primarily with New Zealand consultants (thanks to A.I.D. funding by that nation) and to a lesser degree with experts from the U.S., France, Italy and Japan. With all of this assistance and regular attendance at geothermal schools and colloquia, PNOC talents are kept up-to-date.

All of the projects on Luzon which are being considered for feasibility studies by a specialized U.S. consultant are being undertaken in a systematic, professional manner by PNOC. Though there are alternative exploration techniques available for use, PNOC's 20 years of in-the-field experience has taught them the most cost-effective methods for their topography, climate, resource type and budget limitations.

Accordingly, in recommending that TDP fund the feasibility studies, I can say that the geologic mapping, the hydrogeochemistry and the geophysical work accomplished on each of the Luzon geothermal projects has resulted in very adequate collection, interpretation, and documentation of relevant and required geoscientific information.

Except for the critical information which can be gleaned only from the exploration well drilling program, almost all of the input necessary for resource assessment and development strategy is available at PNOC's Manila offices. The few parameters which have not yet been documented are those in the development strategy which depend, to some degree, on changing priorities of the National Power Corporation (NPC) and/or Federal government policies.

3.1.2 Financial Analysis

Implementation of feasibility studies on these geothermal development projects will have the following positive financial impacts for U.S. firms: (1) monies expended as grants by TDP will, to a large degree, be earned by an American consultant group, (2) the overall cost for installing geothermal power plants is at least $1900/kw. This means that between $418 Million and $760 Million will be the value of the hardware needed for the 220-400 MWe planned at the four Luzon projects. A significant portion of this may be available through U.S. firms, and (3) there should be indirect, unquantifiable financial benefits to U.S. companies as a strong track record is established for hard goods providers.

In summary, there should immediately be about $400,000 worth of consulting work available for American consultants and later, there should be opportunities to bid on at least $355 Million worth of supplies and services (85% of $418 Million).

If the U.S. does not assist PNOC, the New Zealanders and/or Japanese will probably do so, thus decreasing financial benefits for the U.S.A. and U.S. based companies.

4.0 DETAILED SCOPE OF WORK FOR A FEASIBILITY STUDY

4.1 Resource Assessment

4.1.1 Introduction

Because PNOC has in-house capability for conducting Resource Assessments, they prefer to do so and to make initial estimates of reserves and preliminary commitments regarding the amount of steam which they can supply for power generation by the National Power Corporation (NPC). However, NPC and the international lending agencies currently involved in the financing of power plant construction routinely require review of PNOC's resource assessments and steam supply commitments by a qualified, impartial third party consultant.

It is for these reviews of the PNOC resource assessments that TDP funding is recommended and as the first part of the feasibility study for each Luzon project, it is recommended that the selected consultant firm be prepared to address, at a minimum, the subjects listed below:

4.1.2 Recommended Minimum Scope of Resource Assessment Review

- I. Conclusions and Recommendations
- II. Geology
  - A. Surface Geology
    - 1. Stratigraphy and lithology
    - 2. Structures and permeability
    - 3. Relative ages of units
  - B. Subsurface
    - 1. Lithology
    - 2. Structures
    - 3. Alteration
      - a. Types
      - b. Extent and trends
      - c. Interpretations
  - C. Overall Geologic Model

III. <u>Geochemistry</u>

A. Surface waters (thermal and non-thermal)

1. Interpretations regarding geothermal reservoir

B. Geothermal reservoir

1. Liquids

a. Examples from well tests

2. Gases

a. Examples from well tests

C. Reinjection chemistry

1. Potential problems

a. Non-condensible gases

b. Scaling

c. Corrosion

d. Other

2. Mitigation Possibilities

IV. <u>Geophysics</u>

A. Summary of surveys

1. Anomalies and Causes

2. Implications regarding reservoir extent.

V. <u>Geothermal Reservoir</u>

A. Temperature

1. Isotherm distribution

2. Trends and interpretation

B. Geometry

C. Rock Properties

D. Fluid Properties

E. Permeability

F. Reservoir Pressures

G. Reservoir Model

VI. <u>Reserve Estimation</u>

A. Explanation of calculation method(s) used

1. Volumetric method, lumped parameter, other

2. Modeling

a. Type, confidence levels, limitations

b. Results

c. Other topics as required

3. Calculation of gross heat in place
4. Calculation of heat losses
5. Recovery percent
6. Effects of reinjection
   a. Temperature changes
   b. Pressure changes
   c. Other
7. Potentially extractable heat and steam and reserve estimate

VII. Reservoir Management Strategy Recommended in Order to Realize Full Predicted Resource Potential

1. Scale prevention
2. Corrosion prevention
3. Reservoir depletion
4. Other

4.2 Development Strategy

4.2.1 Introduction

PNOC is stronger in its in-house resource assessment capabilities than it is in its abilities to design Development Strategies. Therefore, as the second part of the TDP-funded activities, it is recommended that the third party consultant firm be responsible for the full design of Development Strategies for each of the Luzon projects.

In the past, the National Power Corporation (NPC) has installed 55 MWe units (usually in sets of two). These plants were large, required significant acreage, access to all present and planned wells via reasonably short gathering systems, and were environmentally and logistically difficult to site. Because NPC is now planning to use relatively small 20 MWe power plants, site location and many attendant problems will be significantly reduced and well-field design will have more flexibility.

With this in mind, the scope of the Development Strategy, as recommended and presented below, stresses the well field and not the power plant related matters though coordination with NPC engineers will still be required.

4.2.2 Recommended Minimum Scope of Development Strategy Design

- I. Conclusions and Recommendations
- II. Existing Regional and Local Conditions
  - A. Topography
  - B. Vegetation, climate, demography
  - C. Roads, power lines
  - D. Parks, Reservations, etc.
  - E. Power stations, wells, gathering systems
- III. Environmental Considerations
  - A. Regulatory agencies
  - B. Applicable regulations
  - C. Site specific constraints
  - D. Recommended procedures
- IV. Development Strategy Options
  - A. Overview
  - B. Preferred Strategy
- V. Recommended Development Strategy
  - A. Well field development
    - 1. Drilling sequence
    - 2. Well stimulation
    - 3. Environmental considerations
      - a. Cuttings disposal
      - b. Sumps
      - c. Effluents, gases
      - d. Mud, chemicals
  - B. Gathering systems
    - 1. Separators
    - 2. Pipelines
    - 3. Expansion accommodations
    - 4. Environmental considerations

VI. <u>Fluid Disposal</u>

A. Separated fluids

1. Chemistry and temperature

2. Volume

3. Reinjection options

a. Potential problems

b. Mitigation possibilities and costs

4. Surface disposal

a. Temporary basis

b. Potential problems

c. Mitigation possibilities and costs

B. Condensate

1. Cooling tower use

2. Holding ponds

3. Make-up water

VII. <u>Power Plants</u>

A. Sites

1. Access to transmission grids

a. Substations

b. Towers or poles

2. Foundations

3. Materials disposal

4. Drainage

5. Typhoon and earthquake considerations

6. Gathering system access

7. Roads and maintenance

8. Fresh water availability

9. Sanitation

B. Turbine-Generator Options

1. Basic parameters

2. Turbine types and sizes

3. Steam inlet facilities

a. By-passes

b. Protective mechanisms

4. Non-condensible gas considerations

VIII. <u>Schedules</u>

A. Power plant

1. Planning and lead-times
2. construction
3. Start-up and shake down
4. Firm production on line

B. Well Field

1. New well drilling and testing
2. Injection facilities
3. Gathering system
4. Stand-by facilities

C. Future Well Drilling

1. Infill
2. Replacement

IX. <u>Estimated Development costs</u>

A. Well field development costs

1. Wells (drilling and testing)
   a. Production
   b. Injection
2. Operation and maintenance
3. Replacement reserves

B. Power plant costs

1. Capital expenses
2. Operation and maintenance

C. Parameters to which costs are sensitive

1. Well field
2. Power plant

D. Unit cost comparison with other Philippine power generation alternatives

5.0 SCHEDULE, MILESTONES AND DELIVERABLES

5.1 Schedule

The schedule for doing the resource assessment review and the development strategy design depends entirely on the PNOC schedule for drilling and testing their exploration wells at each project.

Resource assessment can actually start, albeit at a slow pace, while the first well is being drilled and its intensity increases with the next two wells. The most advanced assessment can only be made after the final (in some cases the second or fourth) exploration well has been flow tested.

Figure 17 is a diagrammatic schedule based on the October 18, 1988 PNOC drilling schedule for the Luzon projects. The figure does not show:

(a) that three exploration wells at Bac-Man II have been drilled and tested prior to 1989

(b) that two wells have been finished at Pinatubo, or

(c) whether a third well will be drilled at Bulusan.

Surprisingly, four more exploration wells (the fourth through seventh) are scheduled at Bac-Man II. PNOC has committed to finish its Resource Assessment for Bac-Man II by December 15, 1988 and a Development Strategy by March 31, 1989. Accordingly, intense immediate activity on both these tasks will be required of a third party consultant firm.

The drilling and testing at Del Gallego is scheduled to end by April 30, 1990, therefore, the total anticipated duration of the feasibility studies to be considered for TDP funding may be up to 18 months. if one of the five projects is canceled, the contract period could be shortened by about 3 months.

5.2 Milestones

Milestones for these feasibility studies are the due dates for the Resource Assessment Review and Development Strategy design reports. The former has been set at the end of the testing period for the last exploration well while the latter is set six weeks later.

5.3 Deliverables

For each Luzon project, the two deliverables are:

1. The Resource Assessment Review Report
2. The Development Strategy Report

6.0 ESTIMATED FEASIBILITY STUDY COSTS

The cost for feasibility studies of four Luzon geothermal projects, over a period of 15-18 months has been estimated. Included have been allowances for: management, professional and secretarial salaries while in the Philippines and in the U.S., travel costs from a western U.S. city (since most potential geothermal consultants are located in the west), computer modeling costs, insurance, overhead, profit, and contingencies. The cost estimate is $403,922 which figure could be reduced $35-40,000 if late stage cost effectiveness increases, or increased if Philippines policies, schedules or project scope change significantly.

7.0 RECOMMENDED TEXT FOR CBD ADVERTISEMENT

The Philippine National Oil Company (PNOC) of the Republic of the Philippines is seeking a qualified U.S. consulting firm to carry out detailed feasibility studies of four geothermal fields on the island of Luzon, Philippines. PNOC will be the executing agency for the study.

The selected firm will be required to conduct each feasibility study in two phases. Phase 1 will be a detailed review of a resource analysis which will be done for each field by PNOC staff. Geologic, geophysical (electrical resistivity), geohydrological data and information from exploration wells will comprise input for the review.

If the resource assessment review confirms the viability of the project then, as Phase 2, the selected firm will be required to design a comprehensive strategy for field development. The consultant will address all relevant topics including existing local conditions, environmental considerations, strategy options, the recommended strategy, fluid disposal, power plants, schedules and estimated development costs.

It is expected that Phase 1 and 2 activities on the four projects may overlap and that the entire study will require 15-18 months.

The selected U.S. consulting firm will be paid in U.S. dollars from a grant of $400,000 provided to PNOC by the U.S. Trade and Development Program (TDP).

All documents will be prepared in English.

Interested U.S. firms should submit a Prequalifications Statement, including the requisite TDP qualifications forms 254 and 255. Forms 254 and 255 are available from TDP, telephone (703) 875-4357.

All Prequalifications Statements should be submitted within forty-five (45) days from the publication of this notice to:

Leonardo M. Ote
Division Manager
PNOC-EDC
Geothermal Division
PNPC Complex, Merritt Road
Fort Bonifacio, Metro Manila
Philippines

Based on the evaluation of prequalification packages, PNOC will develop a shortlist of qualified firms which will be provided detailed Terms of Reference for submitting technical and cost proposals.

PNOC reserves the right to reject any or all proposals. Firms agree by their response to this announcement to abide by the procedure established for this procurement. PNOC will not be obligated to pay any costs involved in the preparation and submission of proposals.

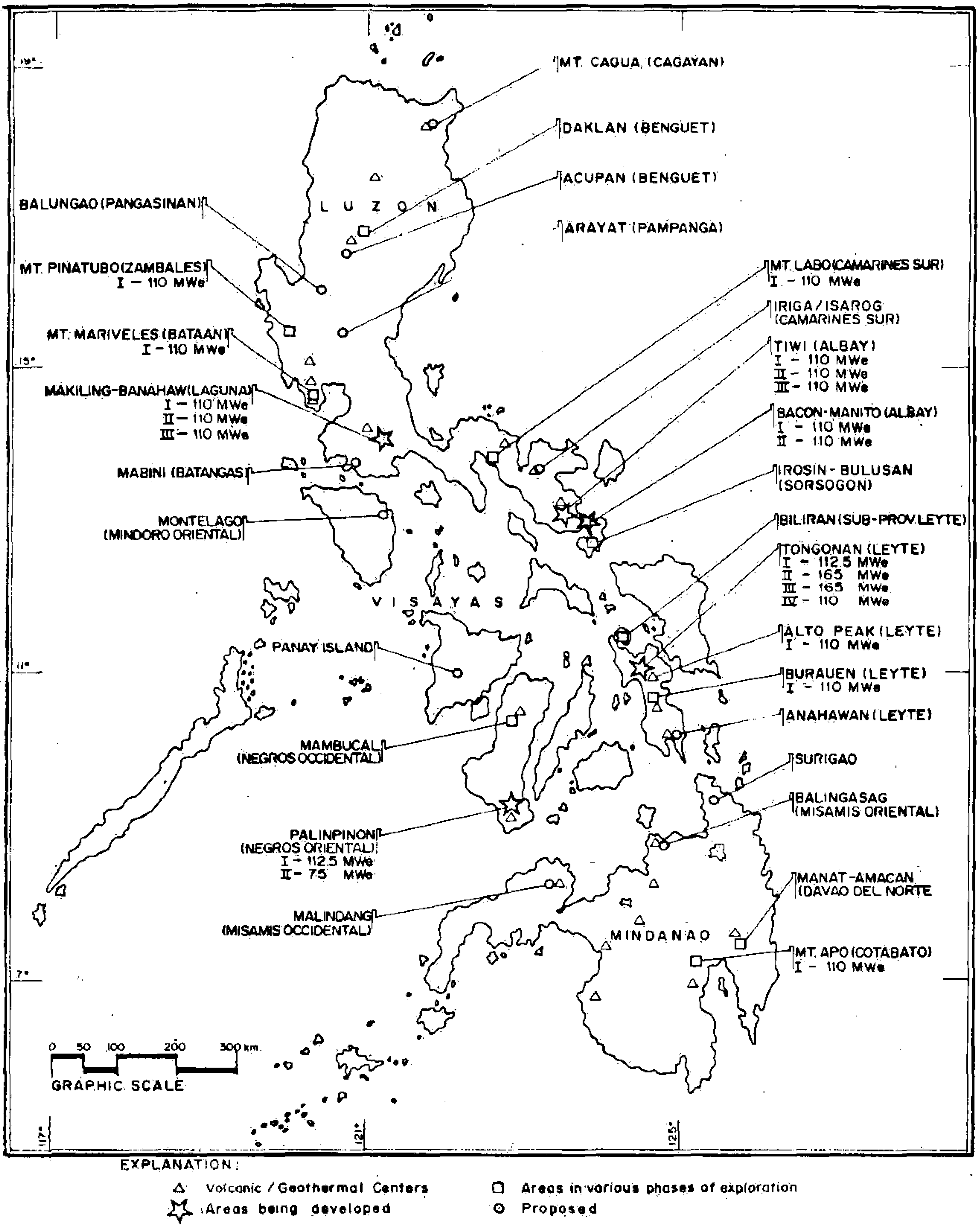


Fig. 1 PHILIPPINE GEOTHERMAL AREAS UNDERGOING EXPLORATION & DEVELOPMENT

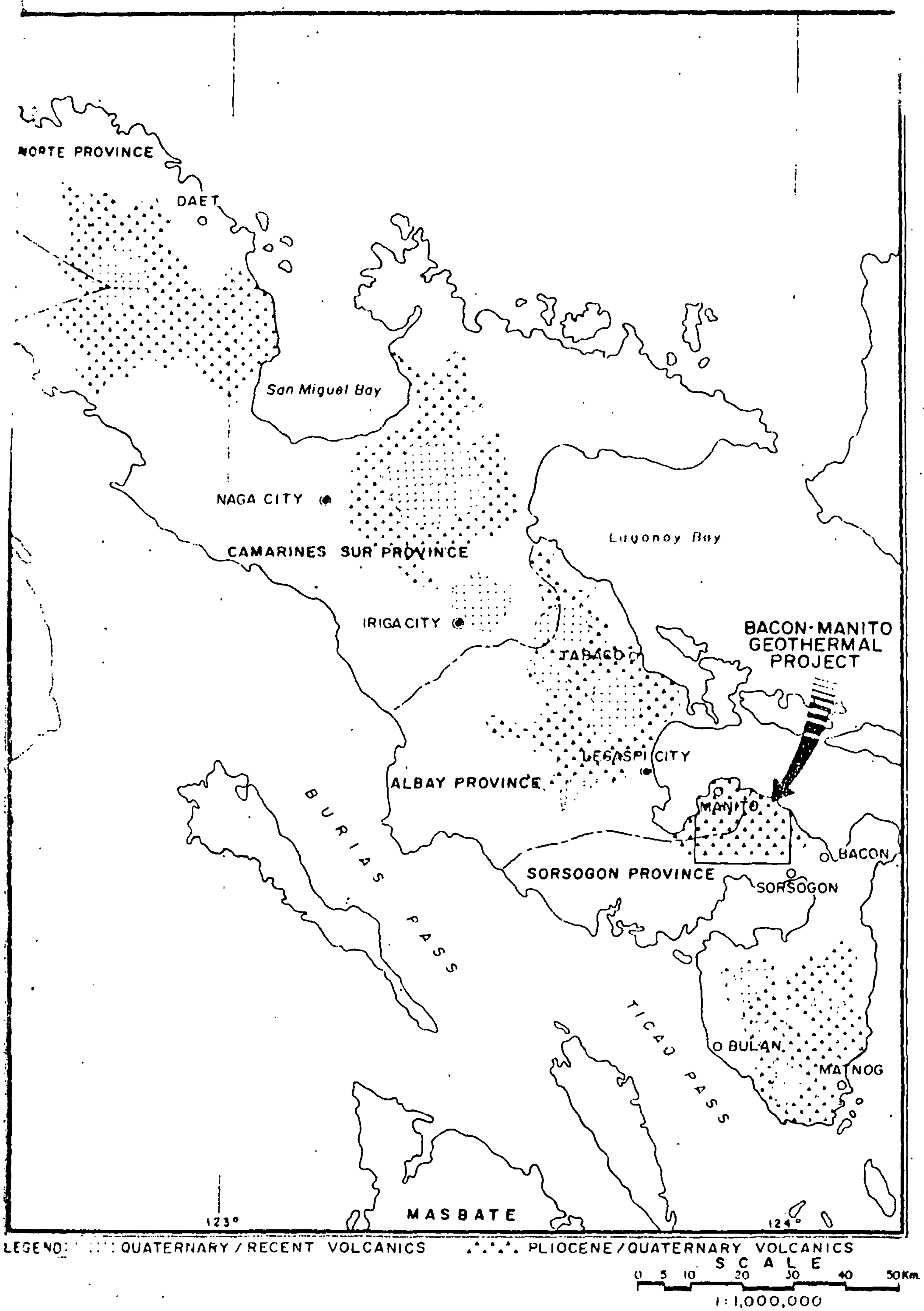


Figure 2 LOCATION MAP OF BACON-MANITO GEOTHERMAL PROJECT

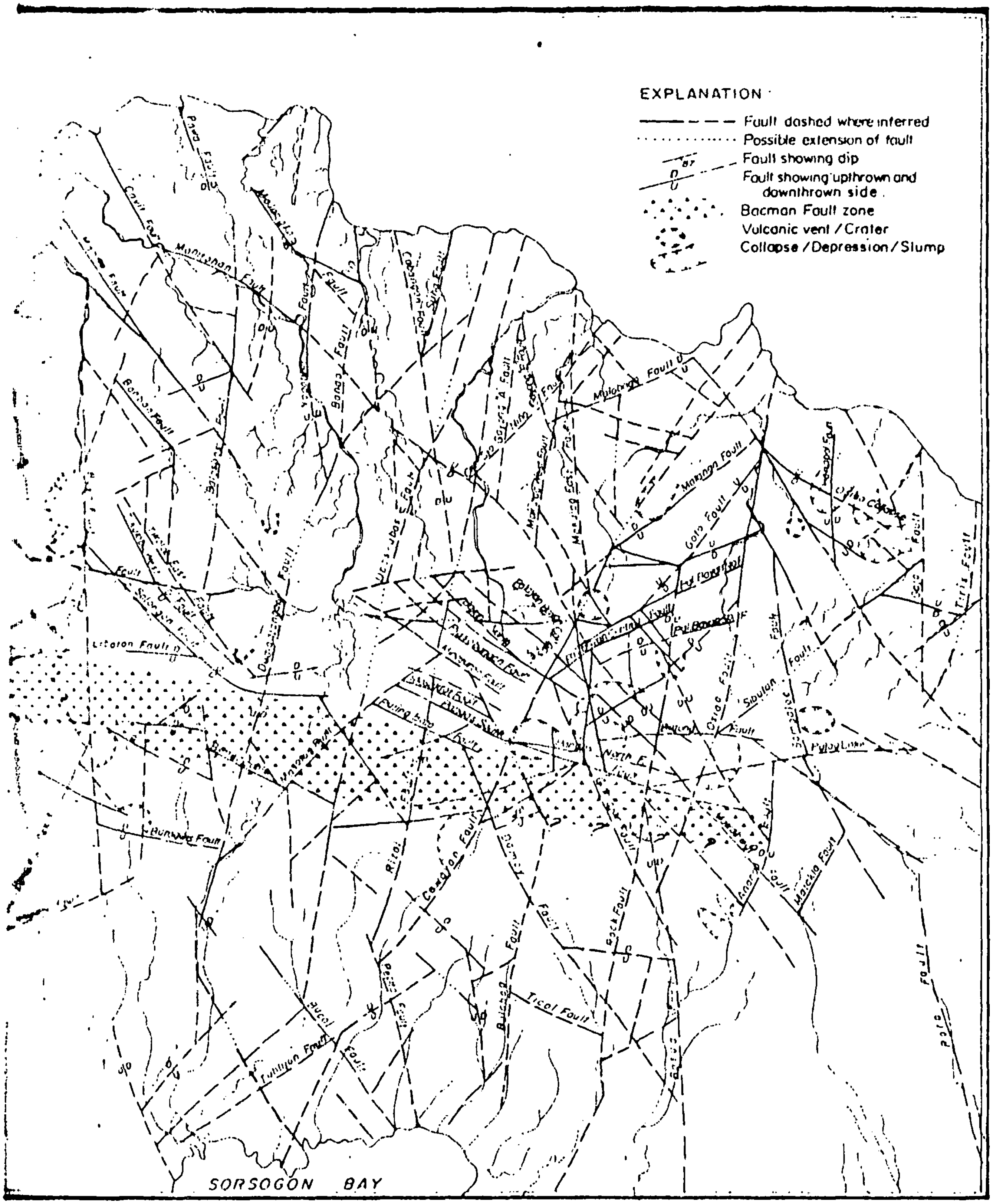
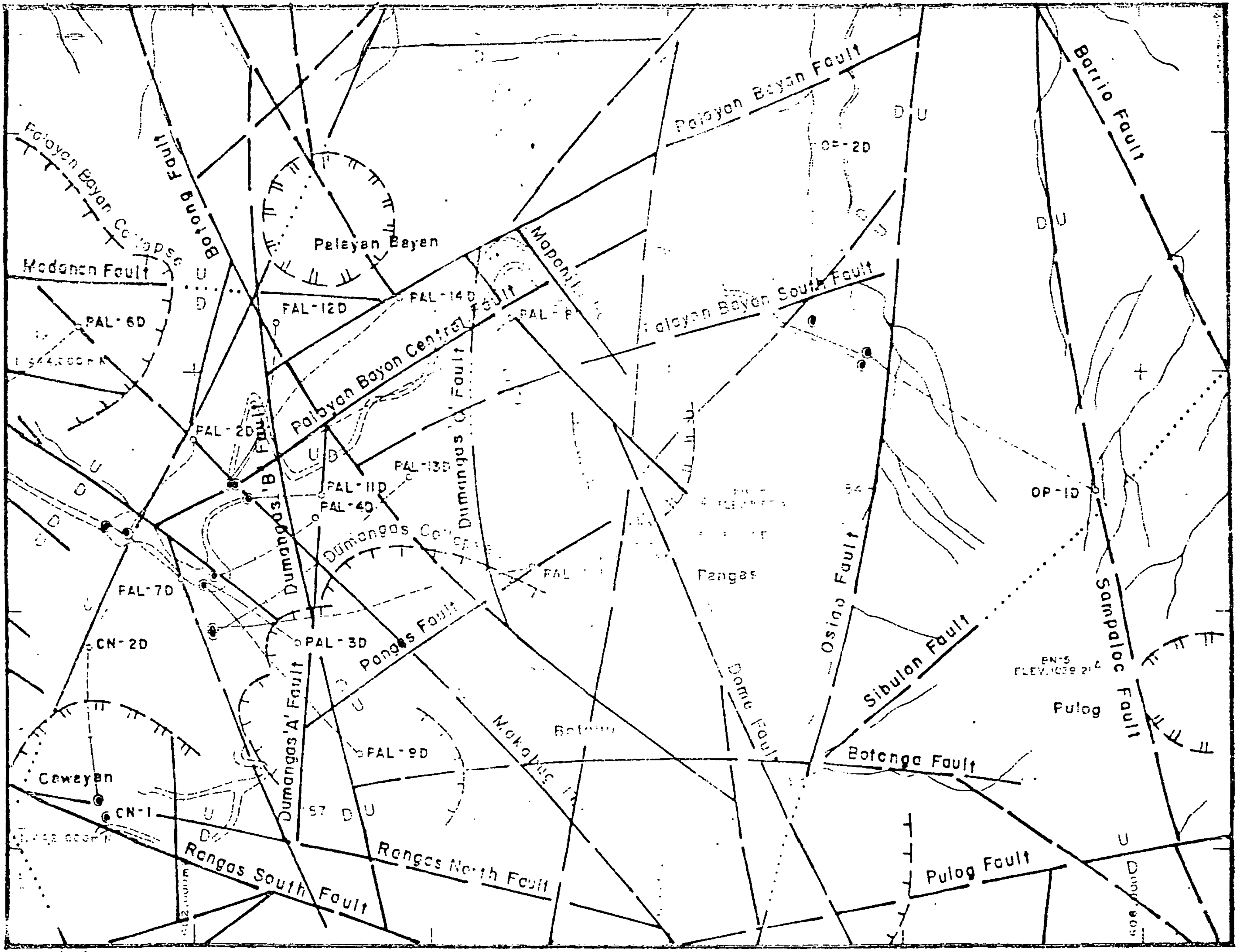


Figure 3 STRUCTURAL MAP OF BACMAN GEOTHERMAL FIELD
BACON-MANITO GEOTHERMAL PROJECT

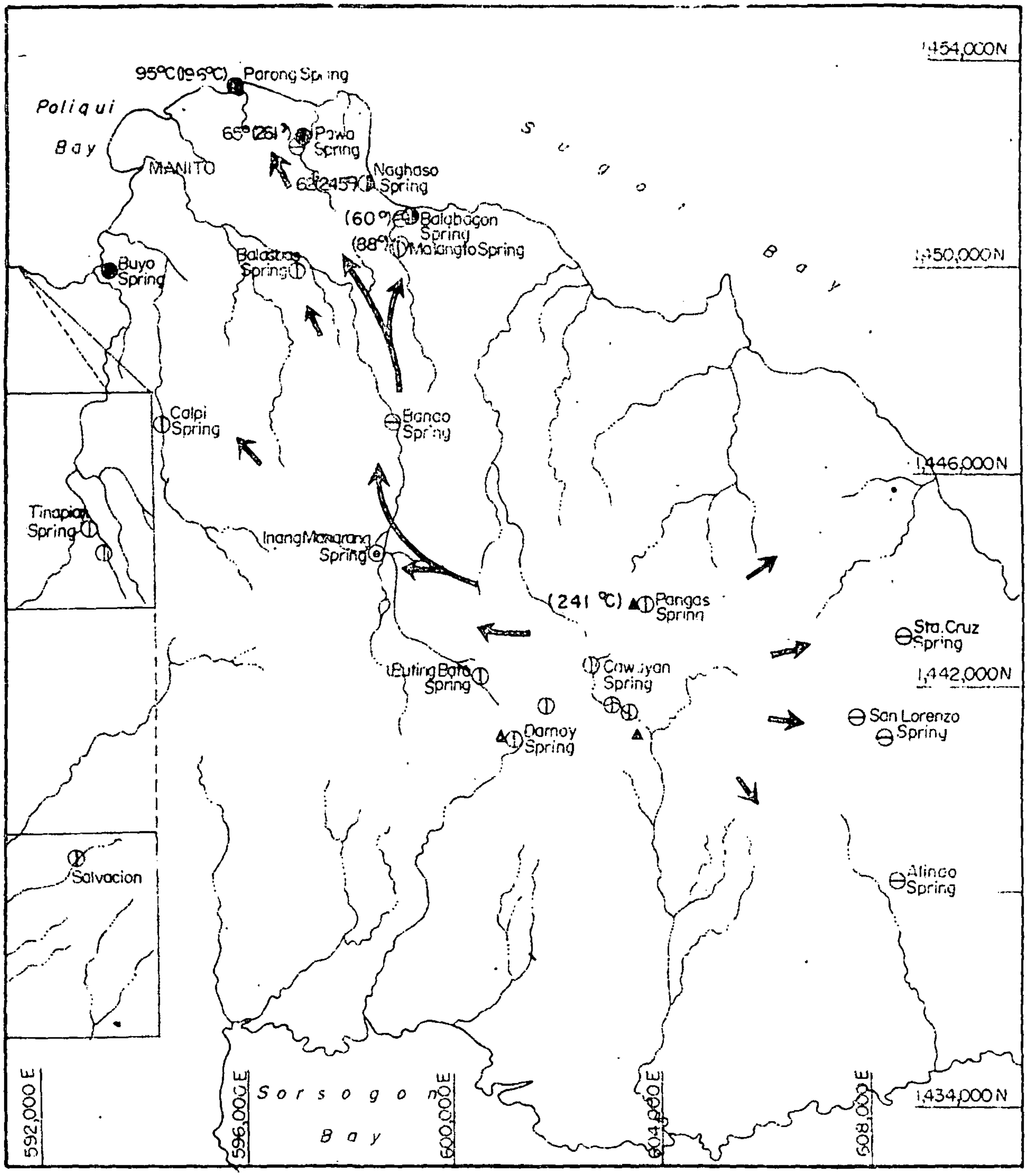
GRAPHIC SCALE



Palayan Bayan Fault
Barrio Fault
Palayan Bayan Collapse
Botong Fault
Palayan Bayen
Madanan Fault
PAL-12D
PAL-14D
PAL-6D
PAL-8
Palayan Bayan Central Fault
Palayan Bayan South Fault
OP-2D
Maponti
Dumangas 'C' Fault
Dumangas 'B' Fault
PAL-2D
PAL-13D
PAL-11D
PAL-4D
OP-1D
Dumangas Collapse
PAL-7D
Rangas
Rangas Fault
Dumangas 'A' Fault
CN-2D
PAL-3D
Osiao Fault
Sibulan Fault
Sampaloc Fault
Dome Fault
Makabug
Pulog
PAL-9D
Botanga Fault
Caweyan
CN-1
Rangas South Fault
Rangas North Fault
Pulog Fault

4

Figure 5 ISO-RESISTIVITY MAP AT AB/2 = 500 m.
BACON-MANITO GEOTHERMAL PROJECT



LEGEND

- Acid Sulphate spring
- Neutral Na - SO_4 - HCO_3 spring
- Bicarbonate spring
- Acid Chloride - Sulphate spring
- Neutral Chloride spring
- Solfatara
- Chloride spring
- Probable Hydrological flow

95 °C - Sampling Temperature
(261 °C) - Na/K Geoth.
((241°C)) - T -Dan

Figure 6. HYDROGEOCHEMICAL MAP OF BACON-MANITO GEOTHERMAL FIELD

0 500 1000 2000
SCALE 1:30,000 M

8104

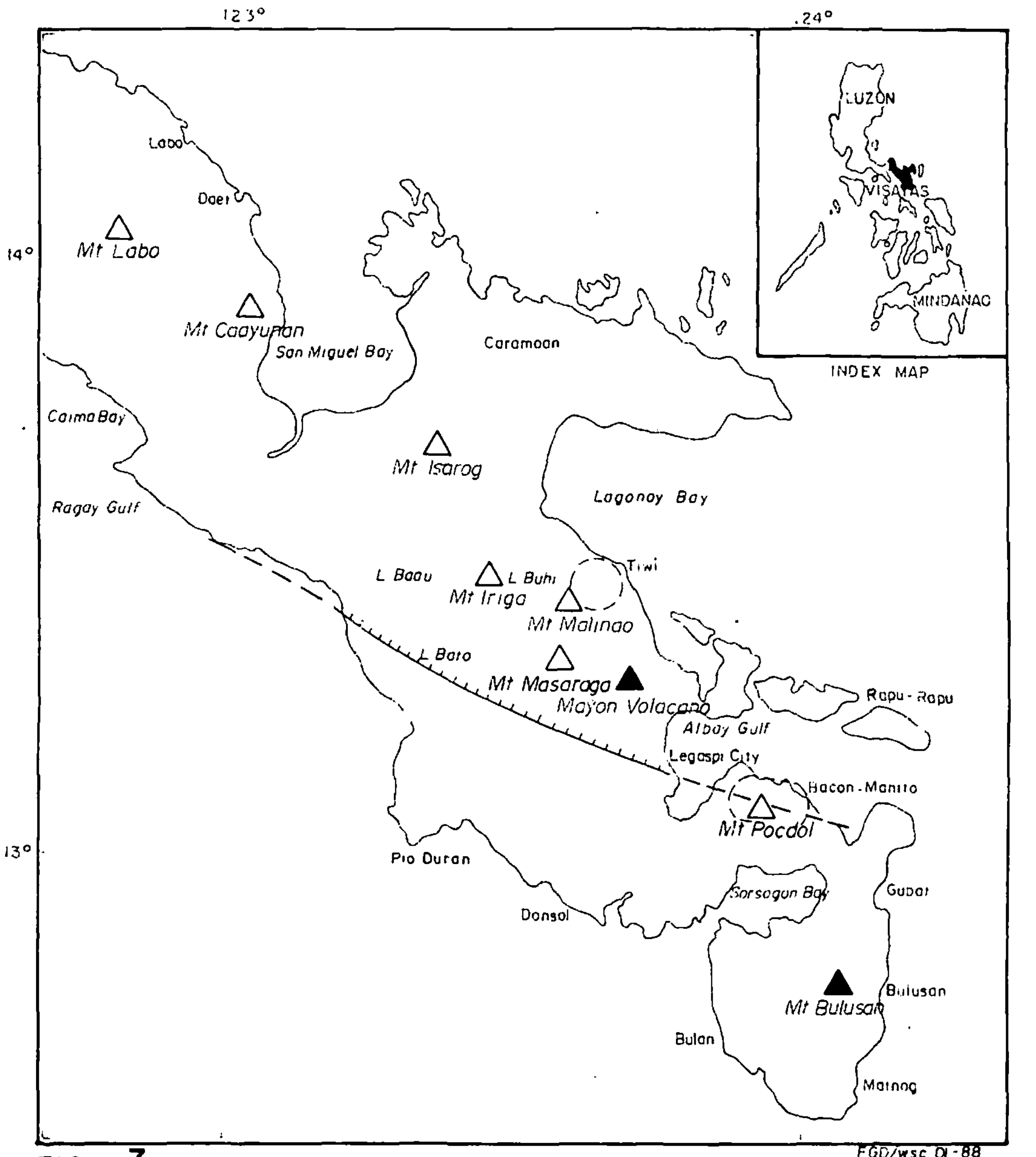


FIG. 7

QUATERNARY VOLCANOES AND GEOTHERMAL FIELDS IN THE BICOL PENINSULA

▲ Active Volcano
△ Inactive Volcano
Geothermal Field
Normal Fault

0 10 20 30 40

BAR SCALE

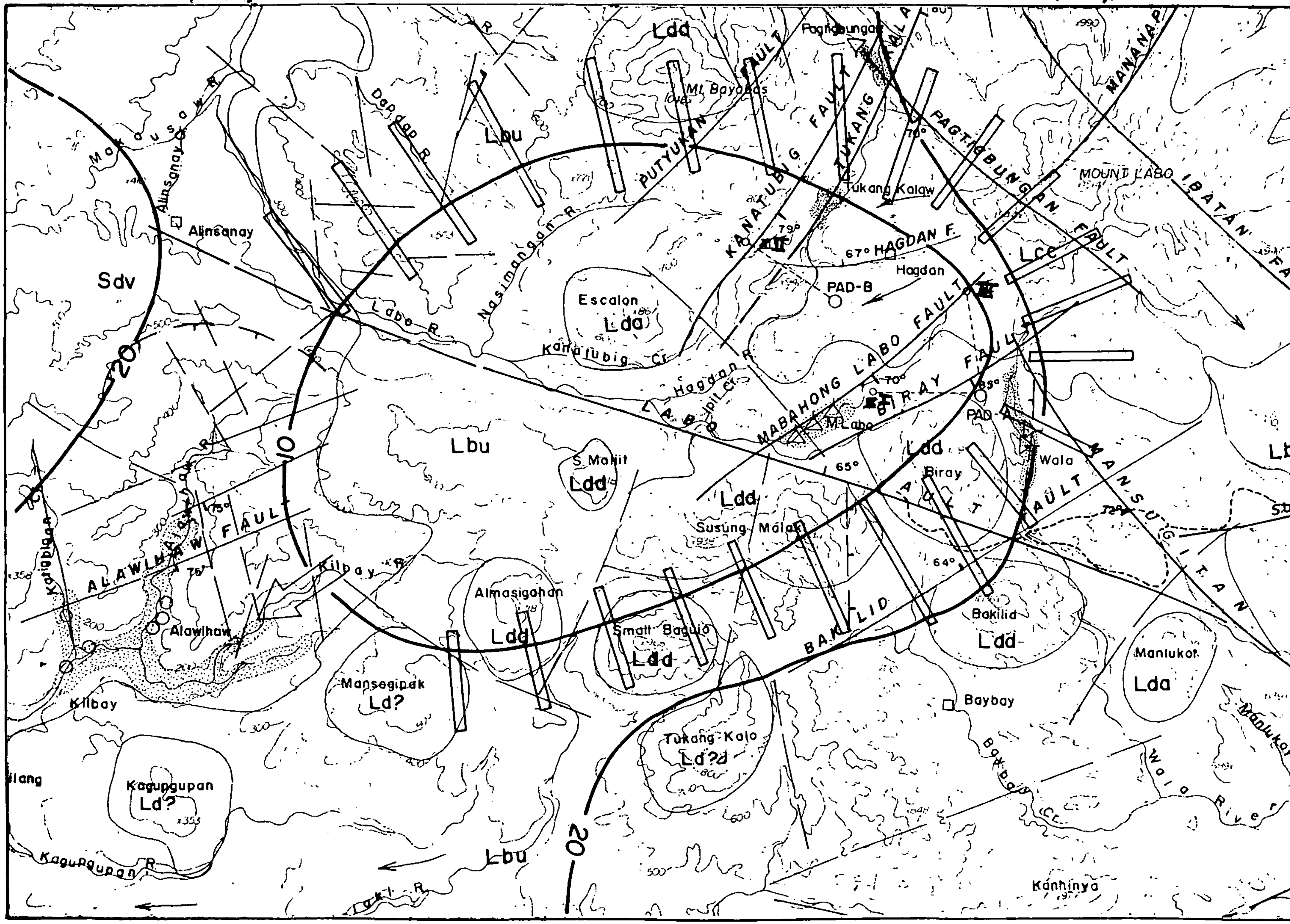


Figure 8 PROPOSED PAD LOCATIONS AND WELL TRACKS
DEL GALLEGO (MT. LABO) GEOTHERMAL PROSPECT

SCALE: 0 1 1.5 2 (in KM.)

LEGEND:

- Isoresistivity of bottom layers at about 500 to 800 m below surface
- Provisional geothermal resource boundary
- Direction of outflow
- Proposed exploratory well

NOTE: For other legends, refer to geologic map

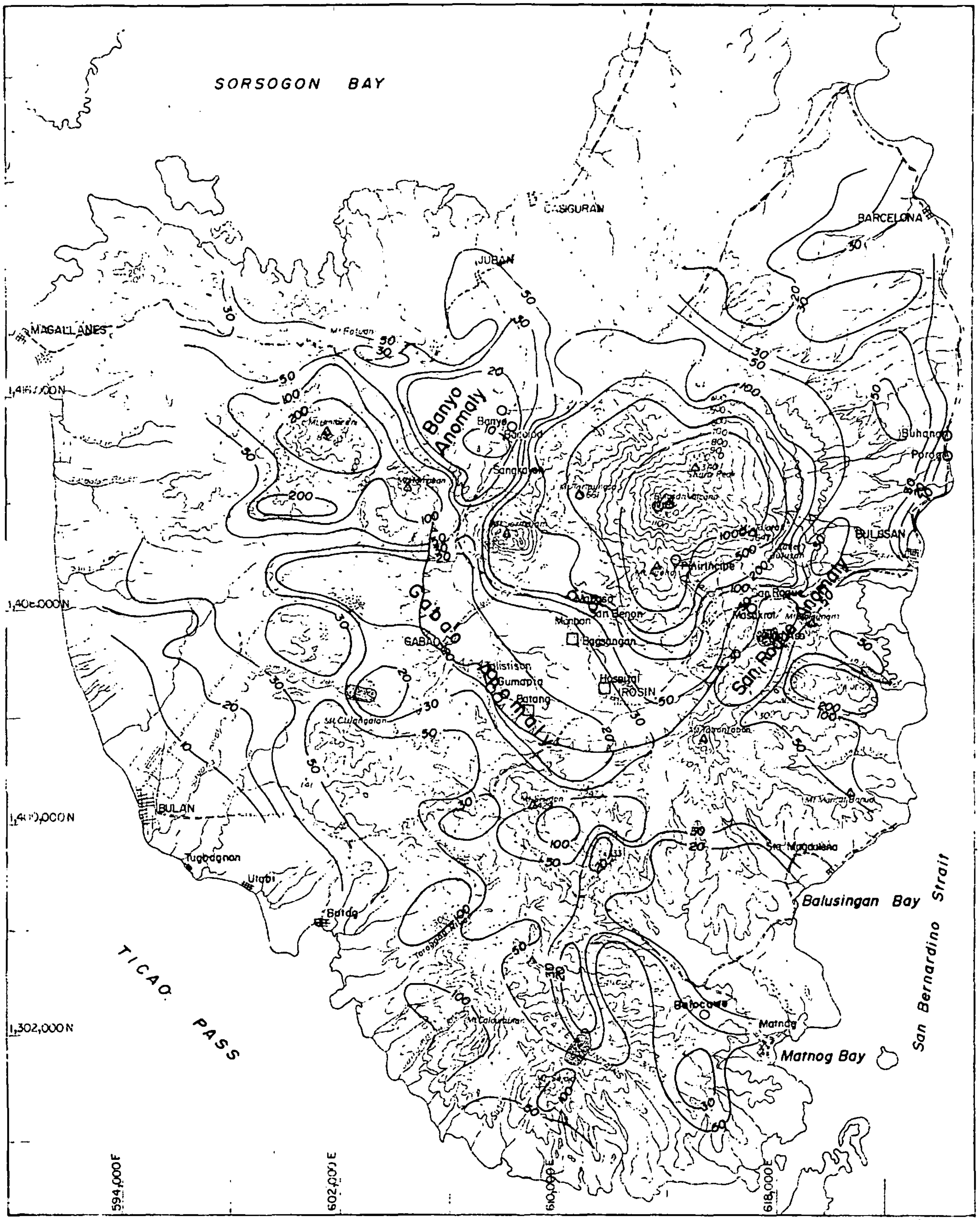


FIG. 9. APPARENT ISORESISTIVITY MAP AT AB/2 = 500 m

MT. BULUSAN GEOTHERMAL PROSPECT

Bar Scale

LEGEND:

- CALDERA RIM
- Δ ERUPTIVE CENTER
- SOLFATARA
- O HOT/WARM SPRING
- □ SHALLOW WELL
- ALTERED GROUND

PNOC-EDC
May 1987

FIG. 10 ISORESISTIVITY OF BOTTOM LAYERS AT ABOUT 500 TO 800 BELOW SURFACE
MT. BULUSAN GEOTHERMAL PROSPECT

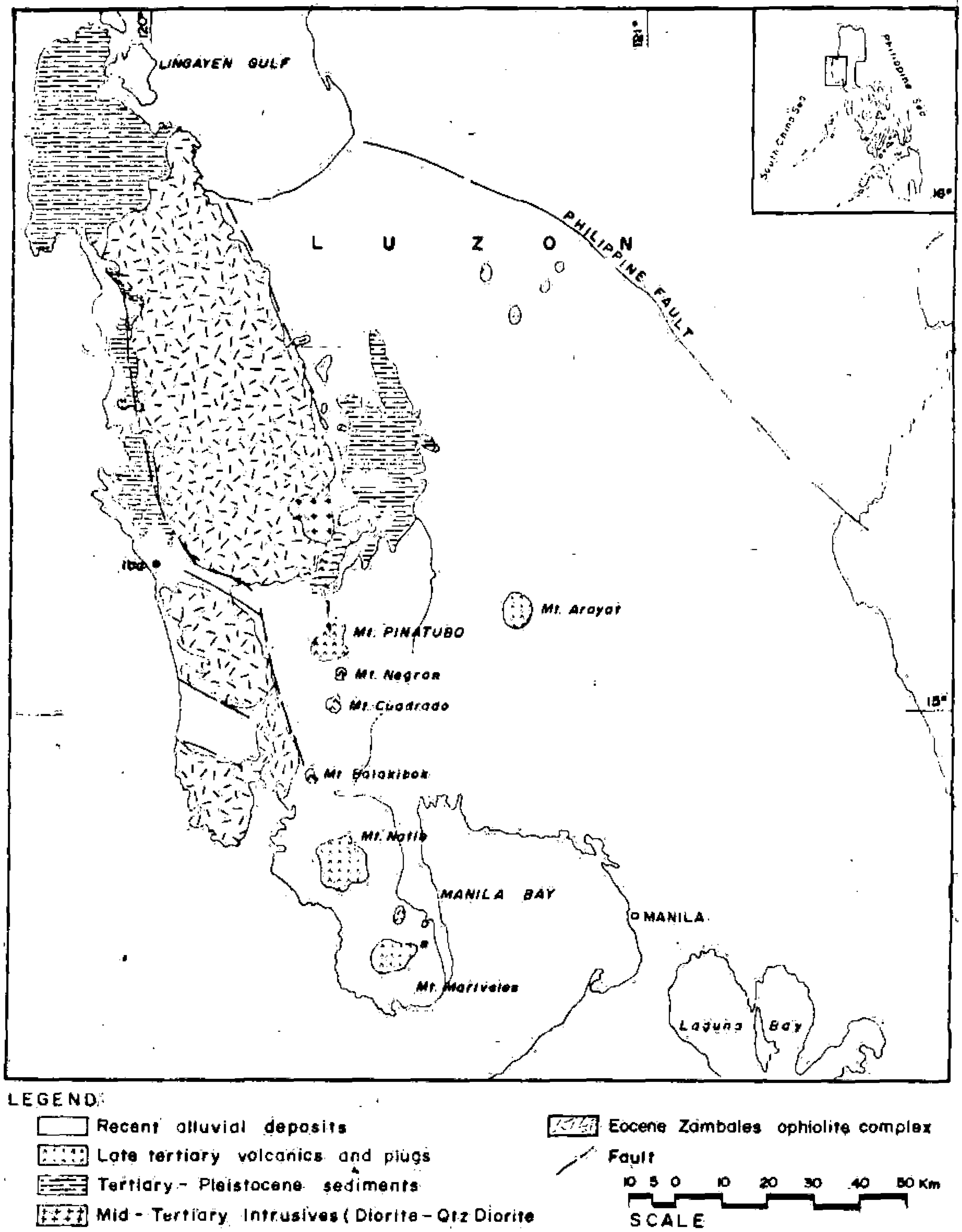
LEGEND:

- CALDERA RIM
- ERUPTIVE CENTER
- SOLFATARA
- HOT / WARM SPRING
- SHALLOW WELL
- ALTERED GROUND

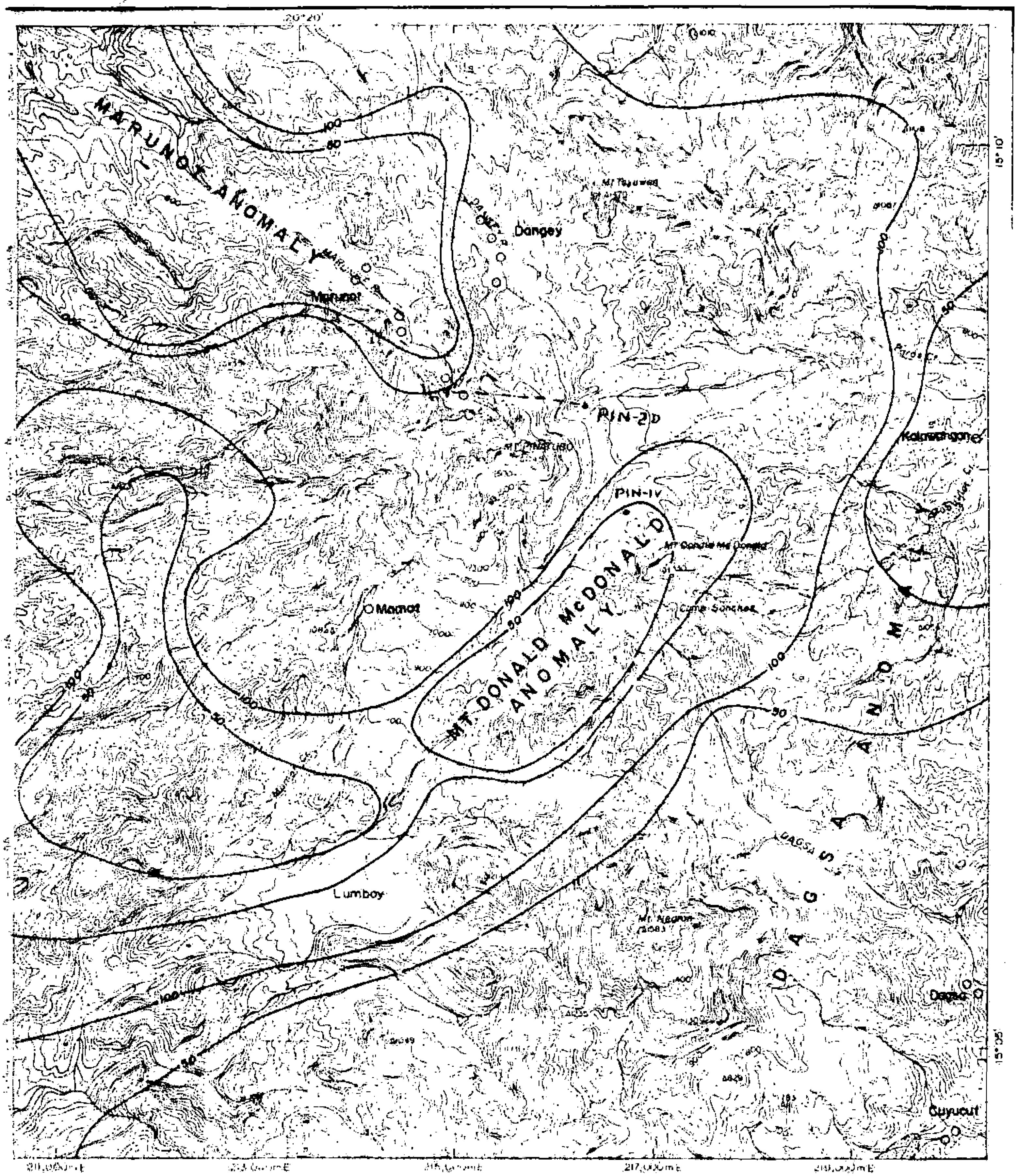
A - B cross-section A-B.

PNOC - EDC
May 1987

July '88 Reevaluation w/ new VES stations



REGIONAL SETTING OF MT. PINATUBO GEOTHERMAL PROSPECT
(Modified from PBM (1963) and PSAR (1977)



—50— Apparent resistivity contour at AB/2 = 500 m

O Thermal spring

Altered ground

Figure APPARENT ISORESISTIVITY MAP AT AB/2 = 500m
MT. PINATUBO GEOTHERMAL PROSPECT

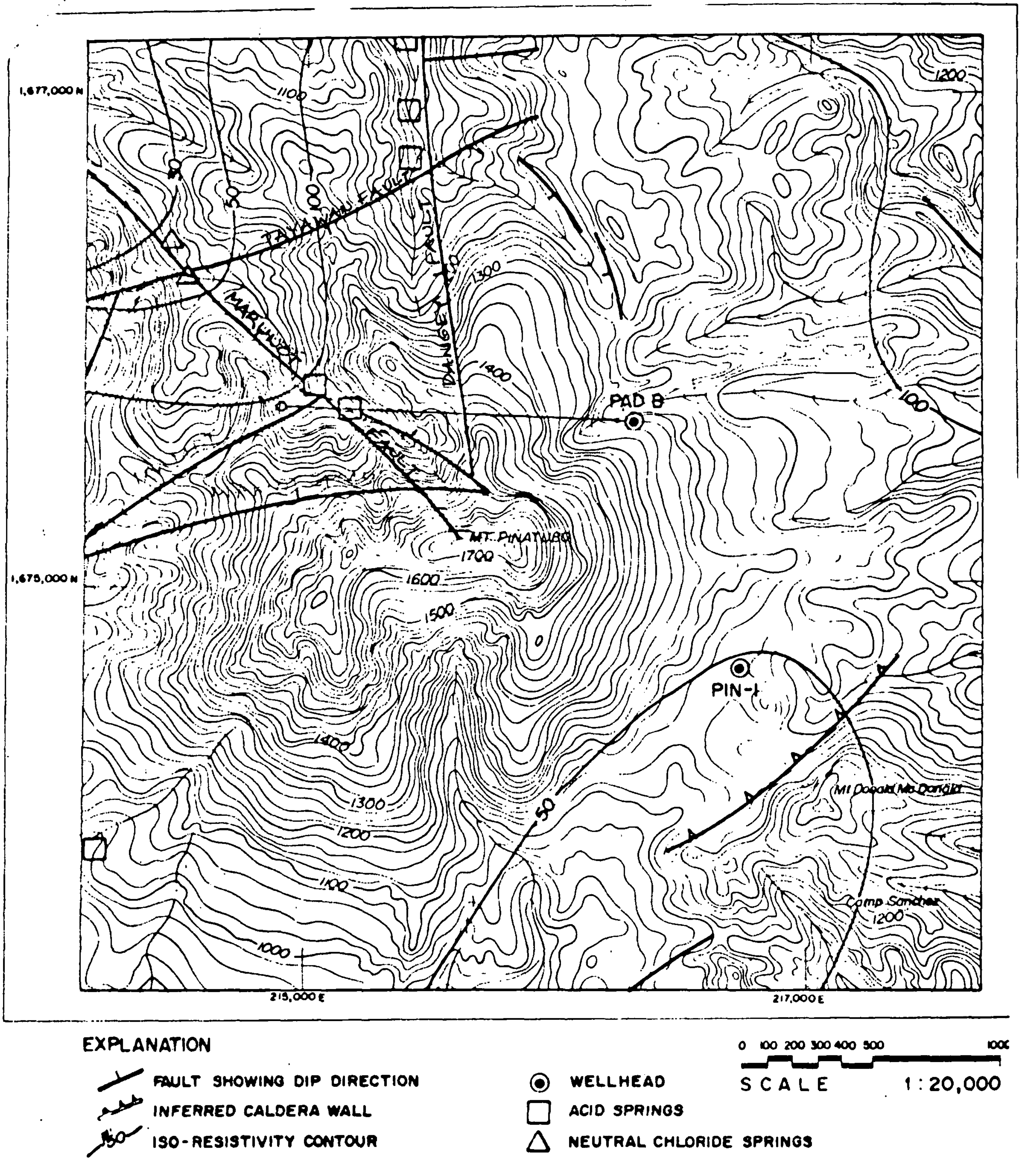


Figure 13 LOCATION MAP OF PINATUBO-2D
MT. PINATUBO GEOTHERMAL PROSPECT

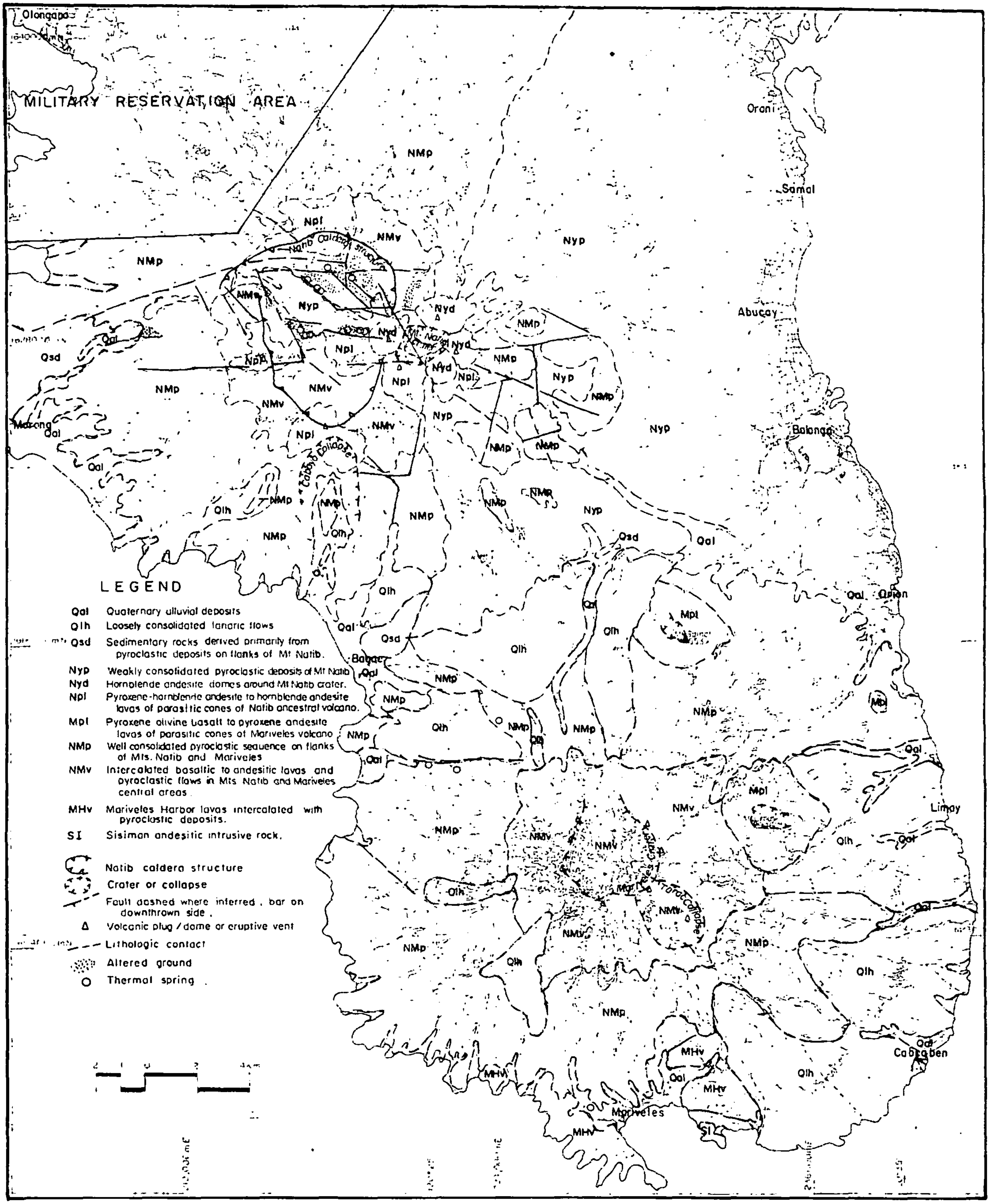
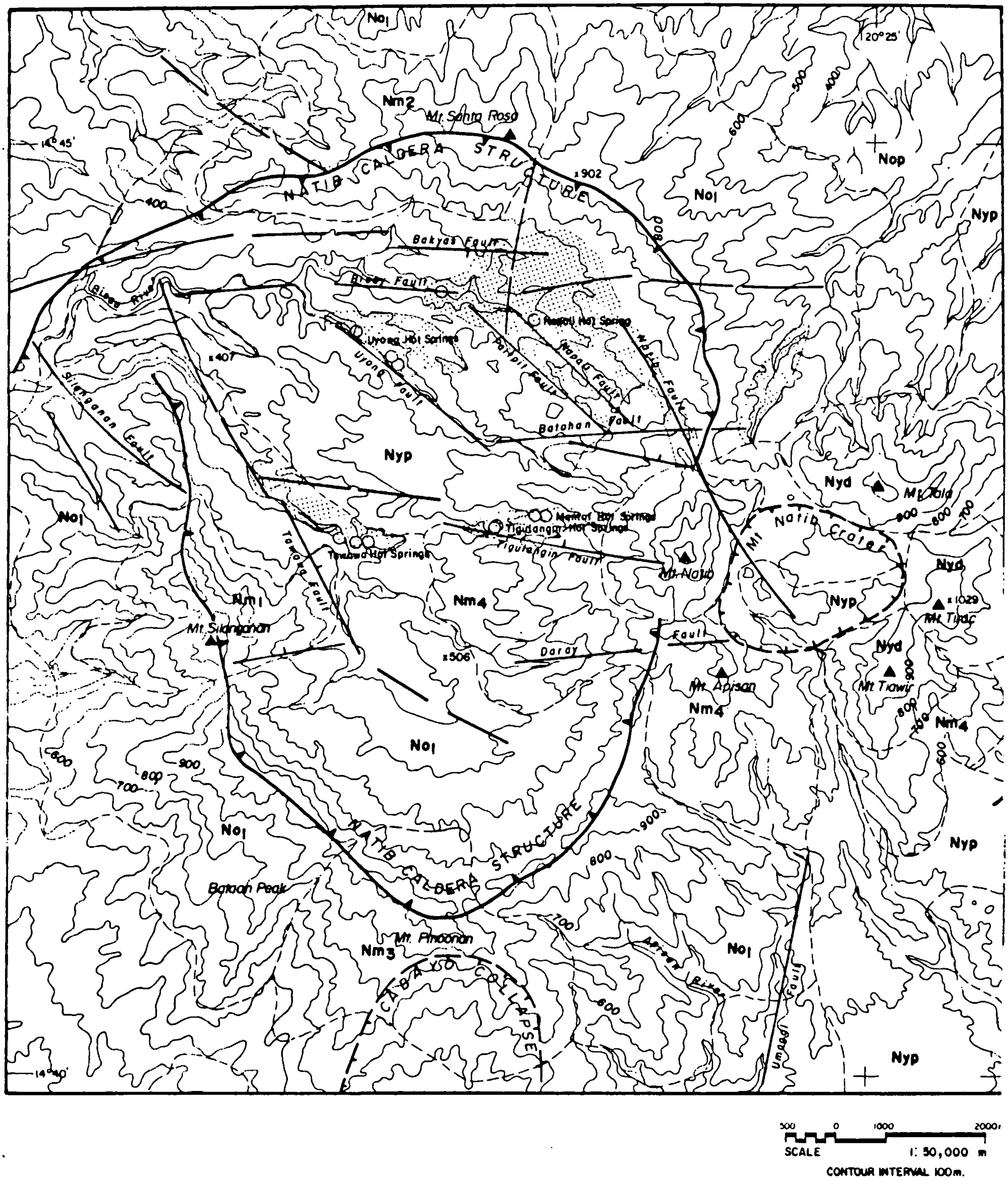


Figure 14 GEOLOGICAL MAP OF NATIB-MARIVELES GEOTHERMAL PROSPECT



STRUCTURES AND HYDROTHERMAL FEATURES

- Natib Caldera Structure.
- Fault dashed where inferred, bar on downthrown side.
- Collapse or Crater
- Lithologic Contact
- Altered Ground
- Thermal Springs

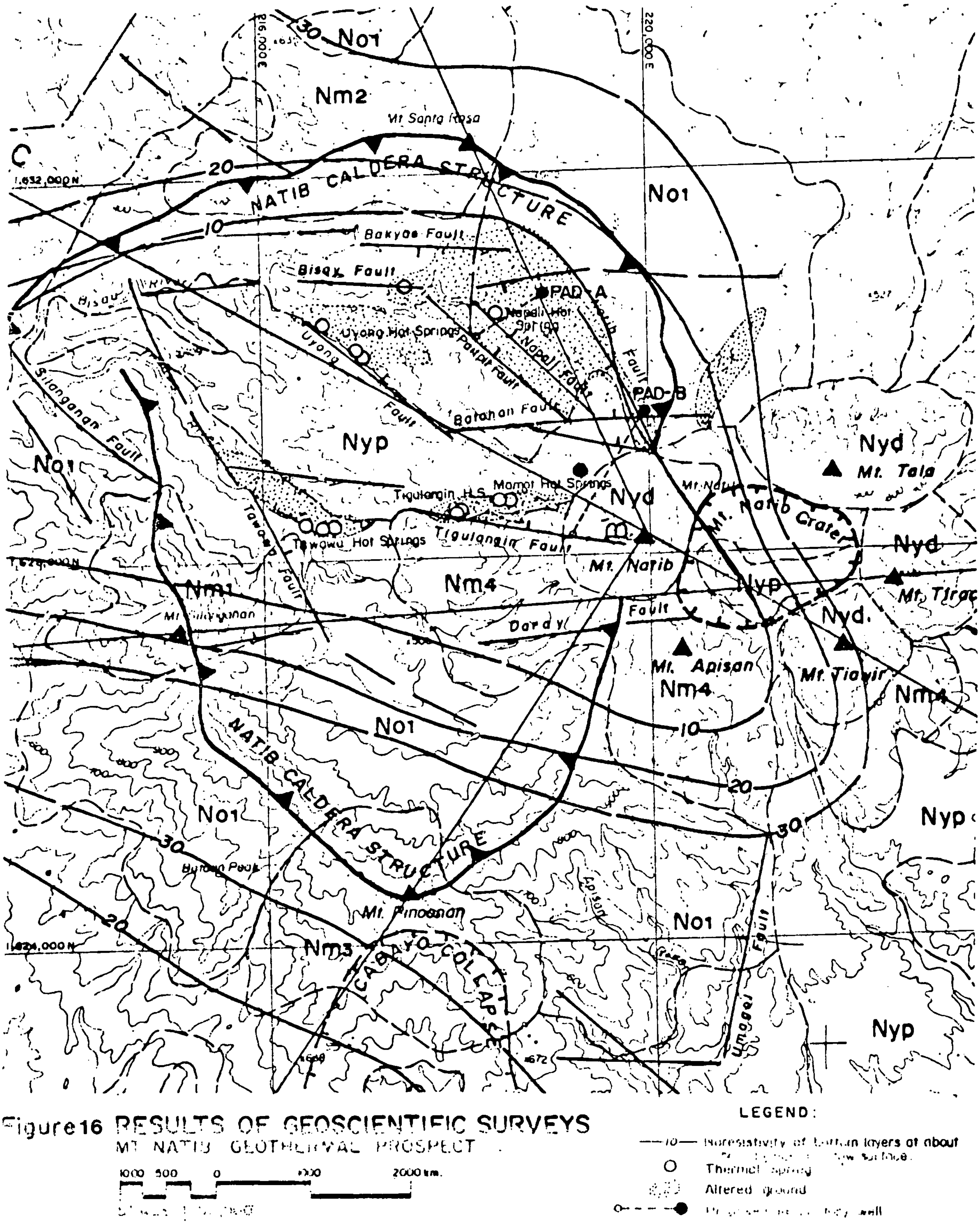


Figure16 RESULTS OF GEOSCIENTIFIC SURVEYS
MT NATIB GEOTHERMAL PROSPECT

SCHEDULE AND MILESTONES FOR 1989-1990
LUZON, PHILIPPINES GEOTHERMAL FEASIBILITY STUDIES

GEOTHERMAL MANAGEMENT Co., Inc.
P.O. Box 2980 Evergreen, CO. 80439-2980 (303) 670-3454

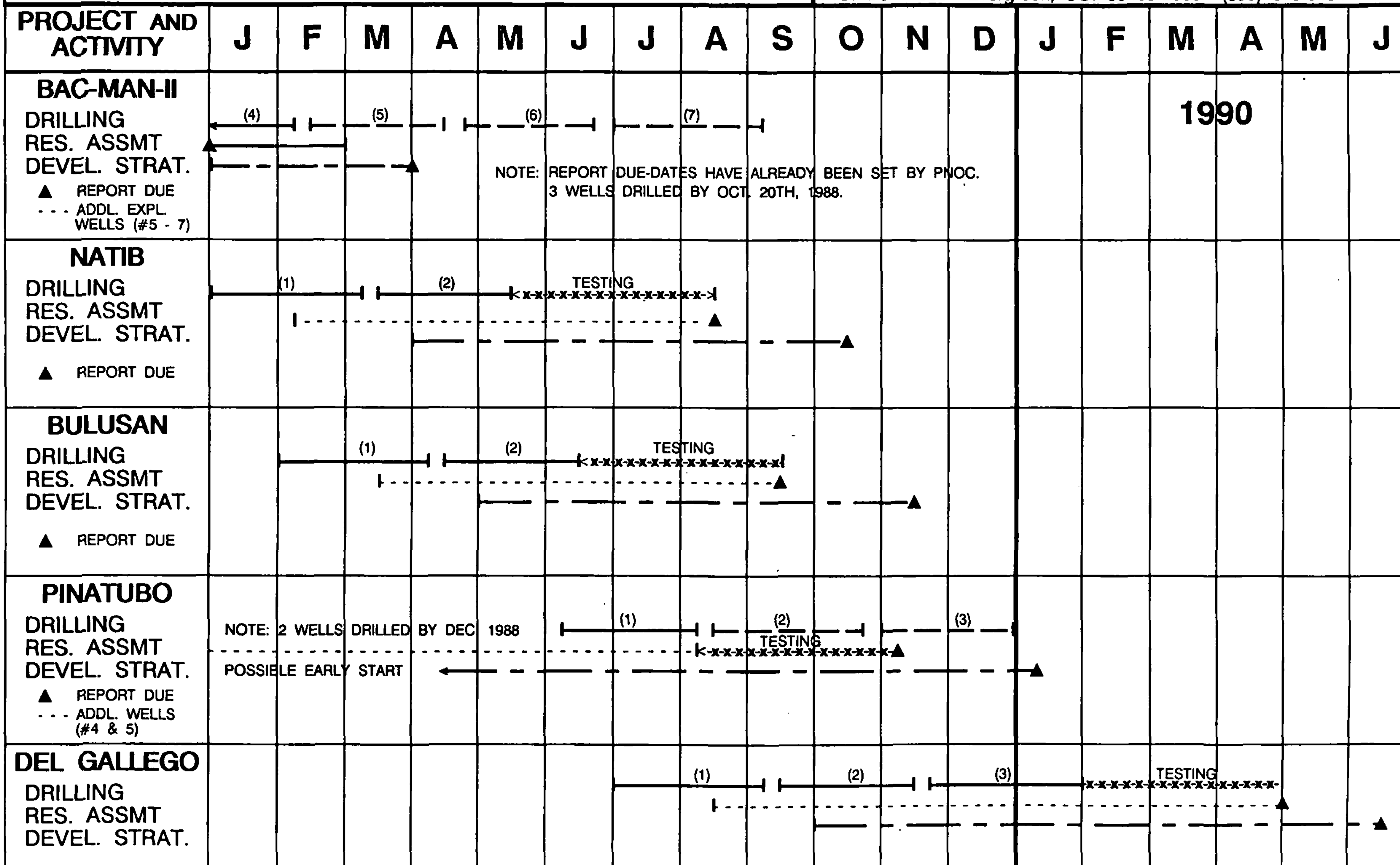


FIGURE 17

PHILIPPINES, LAND OF ASHES

Editors Note: The following article was reprinted from "IMAGE", February 2, 1992. It has been reprinted here because it probably provides an accurate picture of the situation in this country.

BY A. LIN NEUMAN

Manila, these days, is a city rotting away from the inside.

It's not the filth or the bitter air. It isn't the squatter colonies erupting like oozing sores on every unguarded lot, or the thousands of people reduced to garbage-picking and petty theft for survival. It's not the Pasig River, the once-majestic waterway that flows past the presidential palace, now a choked and fetid sewer. It isn't even the pathetically long lines that form outside the United States Embassy every day as more and more Filipinos just give up on the place.

It is something deeper, less tangible. The Philippines, today, feels like a country without hope.

I first came to this country as a church volunteer worker in 1977, during the dark days of the Marcos regime. But even then, when Ferdinand and Imelda were robbing the country blind and locking up their opponents, there was still a sense that things could get better. Even in the worst times, Filipinos always proposed solutions, dreamed of change: Marcos could be overthrown, reforms could be instituted. There was energy; there was hope. And when Corazon Aquino was swept into office in 1986 on a wave of "people power," the future of this desperately poor island nation seemed brighter than it ever had.

Now, almost six years later, the country is in a shambles. To call the Aquino presidency a "disappointment" is to understate the case. Considering the high hopes it inspired, it has been nothing short of a disaster.

Cory Aquino has utterly failed to transform her nation. Marcos looted it; she simply did nothing. Her administration hasn't even managed to pick up the garbage in Manila. She did not have the political clout to deliver a vote on the all-important treaty to allow U.S. bases to remain in the country--this despite the fact that 22 of the 23 members of the Philippine Senate were handpicked by her and won election handily on her coattails. Billions of dollars pumped into the country in aid from the United States., Japan and Europe over the last six years have gone unspent because the government is unable to formulate plans for necessary development projects. Diplomats complain that even the money rushed to the country to help it recover from the massive 1990 earthquake is still sitting in the bank while various government officials argue over its dispersal.

When Aquino delivered her state of the nation address last summer--presumably her last, unless she changes her mind and decides to seek a second term--she defended her regime's record by saying she had done her best and tearfully invoking the memory of her husband, Benigno Aquino, the opposition leader whose assassination in 1983 propelled her into a political career. It was a pathetic performance, a fitting coda to her inept presidency.

My wife is Filipino, I lived in Manila for most of the 80s. It is a city I consider a second home. On my recent trip, behind the usual noise and smoke and mirrors of the capital, I sensed something I never had before: a kind of hollowness. Again and again, in conversations with old and close friends, Filipinos of wit, intellect and creativity, they spoke in despairing terms of a country that had promised so much a few years earlier. "It's the families," says a woman who works as a government information officer. "They control everything in this system of ours, and it makes no difference who is there." Others just shrug. They can think of nothing to do. "Maybe the generals will just take over," says a business woman who was once a passionate Aquino supporter. Then she adds, wearily, "But they'll probably just steal even more."

In this atmosphere of poisonous stagnation and ennui, it somehow seems fitting that the very symbol of national kleptocracy, Imelda Marcos, recently returned--and not in disgrace, but almost triumphantly, as a kind of aging movie queen attempting a comeback. Political life here has become a black comedy: Standing on the steps of a Manila courthouse just minutes after being arraigned on corruption charges, Marcos announced that she was planning to run for president in May.

Corruption, confusion and incompetence. These are the bywords of the Philippines. And nowhere are they more clearly illustrated than in the two major issues facing the country: the horrendous eruption of Mount Pinatubo volcano last summer and the impending closure of the U.S. military bases.

Clark Air Base, about an hour north of Manila by car, used to look like a tropical Anysuburb, USA, with Burger Kings and Baskin-Robbins and a golf course, the atmosphere punctuated by the constant roar of fighter planes and hulking jet transports keeping American power in Southeast Asia well-projected. Then Mount Pinatubo exploded, and Clark became a wasteland. Massive warehouses are crushed and twisted under tons of volcanic debris. Abandoned cars stand on street corners, blasted by windblown volcanic sand. The vast subdivisions of the base are empty and in ruins. Roofs are collapsed, acres of trees stand dead and gray, and everywhere there is nothing but silence. The runway, once the finest in Asia, is covered with 6 inches of sand.

Nearby, tens of thousands of people are displaced and out of work. As villages were buried in mud and ash, refugees, many of then the tiny Aeta hill people, were forced into the lowlands, crowding into hastily constructed camps.

It is a scene of appalling devastation. But even in the face of this calamity, profits take priority over humanitarian assistance.

In one refugee camp, in the province of Zambales, I spoke with Dr. Koen van den Abeele, a Belgian doctor with the relief group <u>Medicins Sans Frontieres</u>. He says that the provincial governor, who owns the land being used for the camp, is using government funds to develop the property, building a market and a church and a school building, all permanent structures in a supposedly temporary camp. While these shiny new buildings are going up, the refugees are dying from a measles epidemic and for want of clean water. "They are very busy over there," the doctor says, pointing to the governor's improvement project. "But not with *the measles and the water-the things they should be doing."*

I catch up with the governor, Amor Deloso, as he sits with a couple of bodyguards in his newly built chapel. He is wearing a cap that says "Tent City." He begins complaining about his political opponents in various parts of the province, saying that they were not helping the people. He himself is building a "model community" for 728 families-this in a camp that holds more than 20,000 people. He admits that he is using public funds but claims that the wood and concrete structures are only temporary.

It is a familiar story in this country. This man has found a way to make personal gain out of human tragedy. When the refugees leave, he will have built a town on a previously worthless piece of family land and filled it with a few paying customers who will become voters.

Politics here is all connections, family, patronage. Not that it makes much difference-it could just as easily be another clan-but Gov. Deloso is a member of President Aquino's political party. He describes the president's powerful brother, Congressman Jose Cojuangco Jr., this way: "He is my boss; he is my padrino."

The nearby town of Olongapo, which was also hit hard by the volcano, faces an even greater calamity-one that threatens the entire country. Olongapo is home to the massive Subic Bay Naval Base, a U.S. base whose future in grave jeopardy. In September, the Philippine Senate voted not to ratify the treaty that would extend the United States' lease on the property for another 10 years. The Americans have been told to leave by October.

The loss of Subic Bay would be noting short of catastrophic. Never mind the $200 million annual rental the U.S. government proposed to pay to the Philippines in a new agreement. The base indirectly pumps hundreds of millions of dollars annually into the Philippine economy, supporting almost an entire region-storekeepers, taxi drivers, restaurant workers, entertainers. If the base closes, hundreds of thousands of people throughout the country would be affected.

Confronted with one of the most important policy decisions in the country's history, the Aquino government did what it usually does: nothing. Aquino herself never called for the removal or the retention of the bases until it was too late. At the 11th hour, she tried to get the treaty passed, but positions had already hardened. Nor did her government formulate any real plans for the conversion of the bases to civilian use.

It feels odd to defend the presence of the American bases. For years I was committed to the idea that the Philippines would be really free only if its people threw out the Americans and stood on their own feet. And there is no question in my mind even now that the nation's dependence on American largesse, and the connivance of generations of politicians in its subservient status, is a disgrace.

In theory, then, the bases should go. But theory will not put bread on the table for the countless thousands of Filipinos who depend on the bases for their living. With the country's economy in a state of crisis, with dozens of American cities fighting the closure of their own bases, the action seems insane.

One night, sitting alone in a hotel

restaurant in Olongapo, I listen to the regular evening singing group, Los Amores. After they finish dutifully performing for their only guest, I ask one of the young women in the group why the senate is opposed to the bases. "They don't like the bases in the Philippines," she replies, "because the bases are not in Manila.

Her answer points out what is perhaps most disturbing about the attitude of those who are opposed to the bases: hypocrisy. Those who clamor most loudly for Subic to be closed are the ones who will be the least affected by it.

On the eve of my departure, I have a brief chat with a woman I have always respected deeply. One of the drafters of the current constitution, she finds it hard to believe that I have changed my mine. "The bases should have gone-yesterday," argues my friend. "We will survive." We Filipinos have always been poor."

She is right: Most Filipinos have always been poor. But she is not poor. She has grown up sheltered by wealth and privilege. Her child was born in the United States, with the option of American citizenship. He husband is wealthy and powerful. Should things get really bad, she has an option denied most of the workers in Olongapo: She can leave.

The Filipino elite is fond of talking about "we Filipinos." In fact, the Philippines is really two countries. Eighty percent of the 60 million Filipinos are desperately, permanently poor, suffering from disease and malnutrition, living in squalor with little access to medical care. The birth rate soars because the Catholic church has effectively intervened with the devout president to slow down family-planning efforts. The poor provide the maids and drivers, clerks, factory workers, prostitutes and soldiers who serve the elite.

As for the elite, they live in a giant playpen of excess and wealth, which they seldom share. Power is passed around among a handful of families. When my wife and I lived in Manila, we has access to a measure of that power, and we used it. We had no choice. If you want a phone, for example, you wait for years unless you know someone-preferably a relative of the president, a branch of whose family owns the enormously profitable and notoriously inefficient phone company.

Today, the gap between rich and poor is widening. Walking down M.H. del Pilar Street, Manila's tourist-oriented red-light district, I can see how bad things have gotten. This was always a seedy neighborhood, but these days it is worse than I've ever seen it: a muddle of beggars and boarded-up storefronts punctuated by garish discos catering to the fat, unpleasant Germans and slovenly Australians willing to brave the country's tarnished reputation because the women are charming, and growing poverty has kept the price of sex down.

On the other side of town, at the home of some wealthy friends, there's light jazz on the CD player; good brandy is passed around after dinner. These are members of the "Makati crowd," the name taken from their exclusive neighborhood-rich folks bound together by private schools, inherited money and breeding. It's a light' skinned world. The Makati crowd are mostly mestizo: half Spanish, half American, or, in Aquino's case, a mixture of Spanish and Chinese blood. By contrast, the vast majority of Filipinos are dark skinned Malays.

The discussion is lively, the tone one of distracted concern. The man of the house-I'll call him Ricardo--says the politicians should all go to hell. But he admits, later, that he is making money, lots of it, in a family business dependent on political connections.

Maids hover at a discreet distance. Friends drop in for coffee. Someone's cousin is dating a niece of a former cabinet minister. Someone else is having an affair with a military officer. The banter is lively, informed, sophisticated. There is nothing "Third World" about these evenings. Dinners start late and go late, the music and food are first-rate, the conversation makes California seem provincial.

These are the people who fueled the revolt against the Marcoses in 1986, providing financing, ideas, logistical support. Now they see that it has all gone wrong. And they grumble about it, over their liquers. "It's all kanya-kanya-everybody for themselves. Here, it is everyone out for themselves," says Julie, Ricardo's wife, a stunning, light brown-haired beauty many years his junior.

In most of Asia, the elite have made some sort of compromise with thievery, preferring to reward productivity and efficiency. In the process, they have built booming economics and dynamic societies that manage to give some benefits to the poor. Not here. Alone among the countries in the region, the Philippines slides ever backwards.

Except, of course, for those at the top. Under Aquino, lots of rich people are making money. The scion of one of the wealthiest families in the Philippines is a close friend of mine. Once an ally of Ferdinand Marcos, he gave up on him in 1984 because he was bad for business. On this latest trip, my friend reiterated his continued support for Aquino. Why? The family business, a combination of agriculture and management, was prospering. "She's good for business," he said.

I sit in the spacious home of a general, a man I have seen rise through the ranks since Aquino came to power. The evidence of his sudden prosperity is everywhere: in the silk clothes, the Italian shoes, the ornate furniture. He remains a staunch critic of the regime that has served him so well. "This society is sick. There is a kind of malaise. The people are sick of the politicians," he says. For dinner, he serves fresh lobster the he has had flown in.

He and other generals have been approached recently by a loose coalition of businessmen who want the brass to impose order and avoid the chaos many fear will come with the May elections. I don't know what he will do: I want to trust him, but have no idea how his new wealth will affect his judgement.

There is no solution in sight. Even the communist left, once feared by the elite and the American embassy as a potential successor to Marcos, has disintegrated in a series of bloody internal feuds. The former commanding general of the Philippine Army, Rudolfo Canieso, once told me that the country needed the communists because and active insurgency scared the rich and provided a check on their excesses. I think he is right.

I came to the Philippines this time hoping to figure out why things had gone so wrong. I wanted to know why squabbling, infighting and greed seem to dominate the entire society. I wanted to find out whey the elite victimize the poor and the poor victimize each other. I came away with no answers-and with the taste of ashes in my mouth.

I traveled this time with another journalist, a man who has spent even more time here in the last 20 years than I have. He and I are even married into different branches of the same fami'·.

"I don't even want to come back," he says, "and I am glad to be leaving." For the first time, I feel the same way.

August 22, 1988

Revised Update From The Geothermal Energy Institute:

PHILIPPINES GEOTHERMAL

N.C. Vasquez, Vice President and General Manager of PNOC Energy Development Corporation (Manila), has kindly provided the following update on geothermal power plants in the Philippines:

YEAR FIRST UNIT	YEAR LATEST UNIT	NUMBER OF UNITS	TOTAL INSTALLED MWe	PLANNED CAPACITY MWe
1977	1983	23	894	1967.5*

	LUZON	
* 1990	Makiling Banahaw Luzon Geo	55
1991	Bacon-Manito I	40
1992	Bacon-Manito II	110
1994	Luzon Geo	440
1995	Tongonan Geo A	440
1996	Tongonan Geo B	440
	Sub-Total	1,635
	VISAYAS	
1992	Palinpinon Geo 4	37.5
1994	Palinpinon Geo 5	37.5
1996	Palinpinon Geo 6	37.5
	Sub-Total	112.5
	MINDANAO	
1993	APO-1 and APO-2	110
1994	APO Geo 3	55
1995	APO Geo 4	55
	Sub-Total	220

Grand Total 1,967.5 MWe

PNOC currently estimates that it can develop the required geothermal fuel reserve (30 years) and build a power plant within a 5-year time frame. Mr. Vasquez advises that the cost of a geothermal KWh at Tongonan is $.0305 and at Palinpinon is $.0330.

We estimate total worldwide installed and planned geothermal generating capacity at 10,810.4 MWe, and the U.S.A. at 3,631 MWe. Worldwide, the Philippines ranks as the second largest of eighteen countries developing geothermal power plants. The U.S.A. remains well established as number one.

Donald F. X. Finn, Managing Director
Geothermal Energy Institute
770 Lexington Avenue, New York, New York 10021
(212) 888-9201

Mike Wright

THE WHITE HOUSE

WASHINGTON

November 5, 1993

Mr. Ken Kerr
Senior Vice President
Magma Power Company
4365 Executive Drive
Suite 900
San Diego, California 92121

Dear Mr. Kerr:

Your recent letter regarding Magma Power Company's plans to help develop clean geothermal power in the Philippines has been received. I appreciate your enclosing your press release for my information.

Your keeping me informed of Magma Power Company's commitment to renewable energy, as well as a clean and healthy environment, is helpful as we move forward with the President's agenda. I have taken the liberty of forwarding your letter to the Department of Energy for further review.

Again, thank you for taking the time to write.

Personally,

Mack McLarty

Mack McLarty
Chief of Staff to the President

DOE

OT 12

Magma Power Company

September 5, 1993

Thomas F. McLarty
Chief of Staff
The White House
Washington, D.C. 20500

Dear Mr. McLarty:

As one of America's leading developers of clean, renewable power from natural geothermal steam, Magma Power Company has been working hard to boost U.S. exports of clean energy technologies. As President Clinton has stated, increasing American exports of renewable energy technologies can help reduce the world's reliance on fossil fuels, keep our environment clean, and create more jobs here at home.

We are pleased to announce that we have recently reached agreement to help develop clean geothermal power in the Philippines. In conjunction with the Philippine National Oil Company (PNOC), Magma Power will build and operate a 231 megawatt geothermal plant on the Philippine island of Leyte. Eleven years after power first comes on line (scheduled for 1996), we will shift ownership of the power plant to PNOC at no cost, thereby transferring clean renewable energy technologies to the Philippine people for their future use. We have enclosed a copy of a news release with more details on this announcement.

Geothermal power will help meet the growing need for electricity in the Philippines. Because it will produce practically no greenhouse gas or other air emissions, our facility will add to efforts to combat global warming. In addition, developing and increasing the Philippines' domestic energy supply will strengthen their national security.

Given the Clinton Administration's leadership on and support for renewable energy, we thought you would be interested in this new project. If you have any questions about Magma Power Company or about this development, please don't hesitate to contact me. We look forward to working with you to provide America with clean and renewable power and to find new ways to encourage U.S. renewable energy exports around the world.

Sincerely,

Ken Kerr

Ken Kerr
Senior Vice President

Encl.

4365 Executive Drive • Suite 900 • San Diego, California 92121 • (619) 622-7800

Magma Power Company

FOR IMMEDIATE RELEASE ***NEWS RELEASE***

September 23, 1993

MAGMA POWER COMPANY SIGNS AGREEMENT TO BUILD AND OPERATE 231 MW GEOTHERMAL POWER PLANT IN THE PHILIPPINES

San Diego, CA ...Magma Power Company (NASDAQ:MGMA) today announced that it has reached an agreement with the Philippine National Oil Company-Energy Development Corporation (PNOC) to build and operate a 231 MW (216 MW net) geothermal power plant on the Philippine island of Leyte.

The power plant will be built in two phases, with the first phase consisting of 77 MW (72 MW net) scheduled for start up in July 1996 and the second phase adding an additional 154 MW (144 MW net) for start up in July 1997. The project will be built under a "build, operate and transfer" (BOT) contract. Magma will build and operate the plant utilizing steam supplied by PNOC. Ownership of the plant will transfer to PNOC ten years after commencement of commercial operation of the second phase.

Paul M. Pankratz, Magma's chairman and chief executive officer, stated, "We are pleased to be participating in the geothermal developments in the Philippines to help meet the country's need for new generating capacity. Magma is committed to growing its geothermal power business through investments in the international markets and this agreement in the Philippines marks an important first step."

This agreement incorporates the 70 MW Philippine project announced earlier this year by Magma Power. The development of the project is subject to a number of conditions, including the arrangement of financing.

Magma operates seven geothermal power plants in Southern California on geothermal leaseholds and fee interests held by the Company, and holds additional geothermal leasehold and fee interests in other parts of California and Nevada.

# # #

Contact:
Investor Relations
(619) 622-7800

4365 Executive Drive • Suite 900
San Diego, California 92121
(619) 622-7800

philippines

ESRI

Earth Sciences and Resources Institute
(Formerly UURI)
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295
USA

Phone: 801-584-4422 FAX: 801-584-4453

Facsimile (FAX) Cover Page

From: Phillip M. Wright Date: February 28, 1995

To: Will Forsberg

Number of pages including this one: **4**

Message or Comments:

Wil-

Do you think this will "bust loose" the foreign travel requests in the Park Building?

Mike

DEPARTMENT OF ENERGY
WASHINGTON, DC 20585

FACSIMILE TRANSMISSION

DATE: February 28, 1995

TO: Dr. Phillip M. Wright
University of Utah, ESRI
391 Chipeta Way, Suite C
Salt Lake City, UT 84108-1295

TELEFAX: 801-584-4453

2 PAGES FOLLOW.

Please make any changes you think are useful, and fax these letters back to me for changes. If you think either is useful the way it is, please use it.

Marshall Reed
Geothermal Division
EE-122

202-586-8076

PLEASE NOTE NEW NUMBER
Telefax: 202-586-8185

Department of Energy
Washington, DC 20585

February 28, 1995

Dr. Phillip M. Wright
Senior Associate Director, ESRI
University of Utah
391 Chipeta Way
Salt Lake City, UT 84108

Dear Mike:

In Fiscal Year 1995, the Geothermal Division of the Department of Energy instituted a new initiative, GT-WORLD, to work with U.S. industry in joint, cost-shared research in geothermal developments outside the United States. In this way we are better able to support industry in all aspects of geothermal technology development. We have received a request for a DOE geothermal structural geologist to work with Unocal Geothermal Division in their core hole research project at the Tiwi geothermal field, Philippines. Unocal has asked that we provide Dr. Dennis Nielson of your laboratory to work jointly with Unocal geologists in this project. This research falls within the scope of work for your DOE contract, DE-AC07-90ID12929.

Please work with Mrs. Peggy Brookshier, DOE Idaho Operations Office, on the management of this DOE-Industry project. Funding for this activity was provided to the DOE Idaho Operations Office under Budget and Reporting number AM-10-01 in the FY-1995 Program Letter.

Unocal has asked for an initial visit to the Tiwi field between 5 April and 29 April, 1995. Since this foreign travel is coming up soon, I would appreciate it if you would arrange for the processing and approval of the Foreign Travel Request and other travel related activities as soon as possible. I would also appreciate a telefax copy of the Foreign Travel Request for my preparation of the DOE headquarters review.

Thank you for your continuing cooperation in our technological support of the U.S. geothermal industry.

Sincerely,

Marshall Reed

Marshall Reed, Program Manager
Geothermal Reservoir Technology
Geothermal Division, EE-122

cc: Mrs. Peggy Brookshier, Project Manager
DOE Idaho Operations Office
850 Energy Drive, MS-1220
Idaho Falls, Idaho 83401-1563

Department of Energy
Washington, DC 20585

February 28, 1995

Dr. Phillip M. Wright
Senior Associate Director, ESRI
University of Utah
391 Chipeta Way
Salt Lake City, UT 84108

Dear Mike:

In Fiscal Year 1995, the Geothermal Division of the Department of Energy instituted a new initiative, GT-WORLD, to work with U.S. industry in joint, cost-shared research in geothermal developments outside the United States. In this way we are better able to support industry in all aspects of geothermal technology development in other countries. The U.S. geothermal industry has requested our strong participation in the World Geothermal Congress, to be held in Florence, Italy during 18 May to 31 May, 1995. I would appreciate it if your laboratory could plan to send 6 geothermal researchers to this International Congress to present the results of your research and to support the U.S. industry in its endeavors to obtain a number of geothermal development contracts in other countries. This type of industry support would fall within the scope of work for your DOE contract, DE-AC07-90ID12929.

Please work with Mrs. Peggy Brookshier, DOE Idaho Operations Office, on the management of this International Travel. Funding for this activity was provided to the DOE Idaho Operations Office under Budget and Reporting number AM-10-01 in the FY-1995 Program Letter.

I would appreciate it if you would arrange for the processing and approval of the Foreign Travel Request and other travel related activities as soon as possible. I would also appreciate a telefax copy of the Foreign Travel Request for my preparation of the DOE headquarters review.

Thank you for your research support of the U.S. geothermal industry.

Sincerely,

Marshall Reed

Marshall Reed, Program Manager
Geothermal Reservoir Technology
Geothermal Division, EE-122

cc: Mrs. Peggy Brookshier, Project Manager
DOE Idaho Operations Office
850 Energy Drive, MS-1220
Idaho Falls, Idaho 83401-1563

MODE = TRANSMISSION START=FEB-28 16:18 END=FEB-28 16:19

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-U OF U RESEARCH -

MR. MARVIN HAWKINS
c/o.Mr. John Stodt
Univ. of Utah Research Insti.
Earth Science Lab.
Research Park
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Philippine Geothermal, Inc.

PHILIPPINE GEOTHERMAL

Marv has said it will cost $5½M over 5 yrs
Bodell says its underfunded

January 10, 1989

University of Utah Research Institute
Earth Science Lab.
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391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

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Like an echo for our conversation, each scientist felt that electrochemical probes could not accurately resolve constituents, particularly in 2-phase flow (steam and brine), or survive at the high temperatures, pressures, and flow velocities in geothermal pipelines. Others felt that periodic monitoring is more than adequate and that continuous data would be overkill. Also, there is concern about calibration and probe life -- basic maintenance of an electrochemical system. The production engineer is especially skeptical. In 1984 engineering conducted experiments with electrochemical probes to measure conductivity. The purpose was to determine TDS. The efforts failed because the probes fouled within days from silica scale, or were severely affected by $H_2S(g)$ and yielded unreliable data.

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None of these opinions are designed to discourage your general appeal for funding. On the other hand, I can not be encouraging that UNOCAL will support the research. As with any research proposal, the onus is on you to demonstrate benefit. Therefore, I have enclosed tables of constituents (Appendix) that are routinely measured concentration ranges, and other conditions to aid in your assessment. I also encourage you to review the geothermal literature on steam gathering facilities and geochemical monitoring; the proceedings from the New Zealand geothermal workshops are an excellent starting point. I would be interested in more details of your efforts, perhaps your published research. This could dispel some of the skeptism imparted by my inadequate details to my colleagues.

By way of encouragement, however, one particular condition would benefit from real-time, continuous analyses. That is monitoring of steam quality and purity in pipelines. This situation is limited in number of analytes, and the research would have wide appeal to developers and power plant operators. This is because scaling and turbine erosion occurs if steam delivered to a power plant contains brine carryover from separation facilities. This is known as an upset condition that results in power plant inefficiency.

The following are important to be analyzed:

	Constituent	Range (ppm)	Needed Accuracy
can do	Cl*	0.1 - 5.0	± 5%
hard	Na*	0.1 - 5.0	± 5%
hard	SiO_2*	0.2 - 1.0	± 5%
can do	CO_2 (g)#	0.0 - 7.5 wt %	± 5%
(can do) (but hard)	H_2S (g)#	0.0 - 1.0 wt %	± 5%

* currently use AAS or colorimetric spectrophotometry
\# currently use wetflow meter

The pipeline temperatures and pressures are from 450-500°F and from 80 to 125 psig, respectively. Steam flow velocities range from 75 to 200 ft/sec.

Let me know if I can help you further. My best wishes in your endeavors and regards to John Stodt.

Sincerely,

John M. Bodell

JMB:lbb
3698E

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Makati : G. M. Lyon/J. R. Hoagland/B. E. Wendt
Brea : D. L. Gallup
Indio : D. T. Rohrs
Santa Rosa : H. R. Crecraft/B. Koenig/J. R. Farison

Darrel Gallup - research chemist.
UNOCAL
Scientific and Technical Div
Union Oil
376 Velinoia Ave.
Brea Calif

APPENDIX

Attached are tables of constituents from geothermal waters (from Ellis, A. J. and W. A. J. Mahon, Chemistry and Geothermal Systems, Academic Press, N.Y., 1977, pp. 392.).

The ones we routinely measure and ranges are highlighted. Accuracy is ±5%. Other properties of interest are redox, Eh, hardness, and sulfides.

2.2 Analyses for Various Types of Fields[a]

Component[b]	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Temp.	248°	350°		200°	73°	~100°	85°	69.5°
pH	8.15	6.40	—	9.0	7.65	5.70	—	6.8
Li	5.2	15.5	—	4.5	3.3	15	—	4.4
Na	936	6429	82	1280	1718	13600	[c]	1190
K	131	1176	35	135	104	404	[c]	23
Rb	2.4	—	—	0.0	—	0.6	—	—
Cs	0.84	—	—	0.33	—	<0.5	—	—
NH_4	0.06	—	372	2.6	0.1	134	—	464
Ca	12.3	347	305	2.5	102.5	12200	6.5	20
Mg	0.19	18.6	23	0.2	46.5	275	2.2	55
Fe	0.08	—	—	0.09	0.1	0.1	—	0.0
Mn	0.01	—	—	0.0	—	7.0	—	0.1
F	4.65	—	—	23.7	2.4	1.6	—	1.0
Cl	1474	11735	7.5	117	617	44000	23	644
Br	3.4	—	—	1.2	1.4	238	—	1.6
I	0.26	—	—	—	—	56	—	3.2
SO_4	136	15	2858	770	1662	16	23	598
HCO_3	46	303	—	1860	2100	80	1575	3250
B	19.7	11.6	780	26.2	1.0	50	—	620
SiO_2	665	1133	109	325	68	63	—	42
Reference	Koga (1970)	Molina and Banwell (1970)	Nasini (1930)	Chemistry Division	Ovchinnikov (1955)	White (1965)	Boldizsar (1970)	White *et al.* (1973)

[a] Key: (a) well 9 (550 m), Otake, Japan; (b) well 8 (1300 m), Mexicali; (c) Larderello steam-heated pool; (d) well 1A (430 m), Kizildere, Turkey; (e) main spring, Carlsbad, Czechoslovakia; (f) oil well (3650 m), Leda formation, Kings County, Calif.; (g) well, Szentes, Hungary; (h) Geyser Spring, Sulphur Bank, California.

[b] Concentrations are in ppm (mg/kg) in waters collected at atmospheric pressure, and pHs are as measured in cooled waters.

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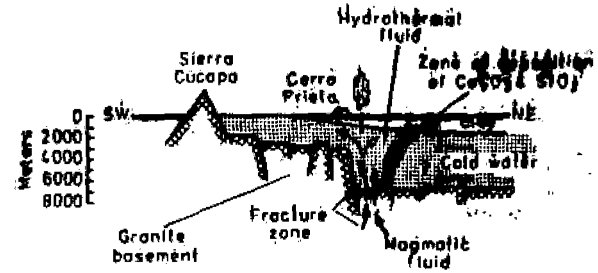


Fig. 2.4 Schematic cross section of the Mexicali geothermal field, from Mercado (1967).

this sandwich-type sequence is terminated by an outcrop of the granitic basement at Sierra Cucapá, whereas the sediments stretch east to the Colorado River. The Cerro Prieto volcano within the field is basalt and pyroclastics, with associated fumarolic activity to the southwest. The regional structure corresponds to a tectonic trench which rises in a series of stepped blocks toward Sierra Cucapá to the west and descends abruptly to the east of Cerro Prieto where the basement crystalline rocks are displaced downward by about 3000 m. The basement is broken by a series of northwest-southeast faults which provide upflow channels for high-temperature water.

The geothermal system is capped by approximately 700 m of plastic clay which acts as a barrier, forcing the hot fluids to flow horizontally away from the fractured upflow zones. Hot water flows mainly toward the west due to flat stratification and good permeability in the sandstone. To the east the sedimentary strata are more compacted, and the lower permeability is considered to be due to precipitation of calcite and silica in a zone of interaction between the hot fluids and the cold water front. This type of self-sealing may be common in high-temperature geothermal systems.

An inflow of colder water at depths of 1000–2000 m causes cooler temperatures at deeper levels in wells on the eastern and western edges of the field.

Figure 2.5, from Mercado (1970), shows an interpretation of water flow patterns and temperatures in the central part of the production field. Temperature differences are shown in terms of the Na/K ratio in the hot waters, which shows an inverse relationship to temperature (Chapter 4). The highest temperatures in the central upflow zone are approximately 375°, while temperatures fall rapidly to the northeast to 150°, and less rapidly to the southwest where high-temperature water sweeps through the sandstone layer.

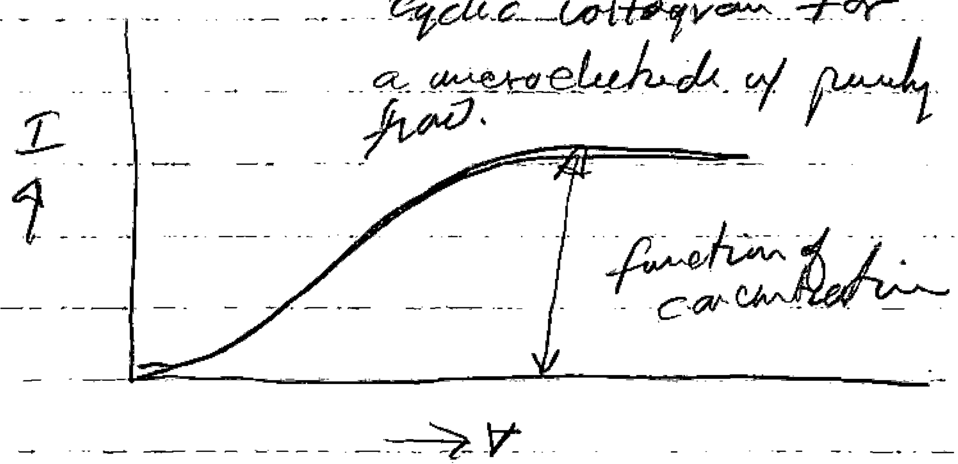
Marvin Hawkins

"Microelectrodes" is a buzzword

Classical Electrochemistry - passing current thru a system -- Problems IR drop -- so limited to highly cond slns w/ limited or no side reactions.

begin 1980, theory behind microelectrodes known -

cyclic voltagram for a microelectrode w/ purely radial diffusion proc.



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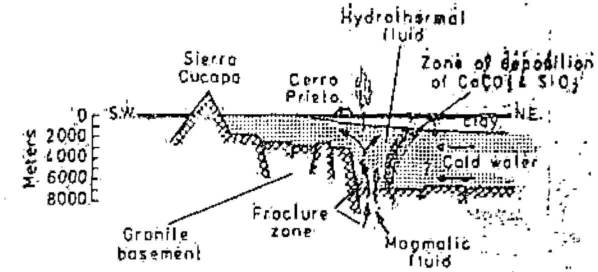

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Chapter 3

THE CHEMICAL NATURE OF GEOTHERMAL SYSTEMS

The first two chapters emphasized the wide variety of natural hydrothermal systems in many different geological situations. The remainder of the book concentrates principally on high-temperature geothermal systems—their physical and chemical characteristics, and the chemical problems associated with their utilization. The authors have been associated mainly with these systems and with projects directed toward utilizing geothermal fluids for the development of electric power. To date, appreciable quantities of electricity have been produced only in areas where there is water or steam at temperatures in excess of about 180°C within 1–2 km of the surface. This selected coverage is not meant to imply that high-temperature geothermal systems and electric power generation are the only areas of significance. Indeed, because of their wider occurrence, warm water systems may prove in the long term to be of greater economic importance in connection with community heating projects.

3.1 WATERS

Classification

Most chemical types of water found in high-temperature geothermal areas can be classified under the general headings that follow (White, 1957; Ellis and Mahon, 1964). The classification can be applied to high-temperature spring and well waters in nonvolcanic as well as volcanic areas, and is more for convenience in discussion than for defining origins of waters. Examples of the compositions of various types of hot water are given in Table 3.1.

TABLE 3.1

Analyses Typical of Each Water Classification Group[a]

	Source	pH	Li	Na	K	Rb	Cs	NH_3	Ca	Mg	Fe	Mn	F	Cl	SO_4	HCO_3	B	SiO_2	Ref.[b]
a.	Geyser 238, El Tatio, Chile	7.32	45	4340	520	6.7	12.6	3.8	272	0.5	0.1	0.4	3.1	7922	30	46	178	260	1
b.	Taumatapuhi Geyser, Tokaanu, N.Z.	7.8	22.6	1710	168	0.9	3.3	1.3	32	0.2	0.01	—	1.7	3021	63	2	90	270	1
c.	Green-black hot pool, explosion crater, Waiotapu, N.Z.	2.8	—	43	11	—	—	6.2	27	3.5	8.2	—	—	32	347	0	2.5	239	2
d.	Yellow hot pool, explosion crater, Waiotapu, N.Z.	2.8	—	405	74	—	—	65.5	40	7.5	5.0	—	—	612	666	0	10.1	370	2
e.	Well 205, Matsao, Taiwan, 1500 m deep	2.4	26	5490	900	12	9.6	38	1470	131	220	42	7.0	13400	350	0	106	639	1
f.	Crater Lake, Ruapehu, N.Z.	1.20	1.6	740	79	0.4	0.1	11	1200	1030	900	34	260	9450	10950	0	13.8	852	3
g.	Well 5, Wairakei, 471 m deep	8.6	1.2	230	17	—	—	0.2	12	1.7	—	—	3.7	2.7	11	680	0.5	191	4

[a] Concentrations in mg/kg (ppm) in waters reaching the surface; pHs measured in cooled waters.
[b] References: 1, Chemistry Division, DSIR; 2, Wilson (1963a); 3, Giggenbach (1974).

TABLE 3.2

Composition of Thermal Waters from Springs and Drill Holes

Source and reference[a]	Approx temp. (°C)	Depth (m)	pH (20°)	Li	Na	K	Rb	Cs	Mg	Ca	Mn	Fe	F	Cl	Br	I
				Concentrations (mg/kg) for water collected at atmospheric pressure from discharge												
Spring, Reykjavik, Iceland (a)	88	0	9.4	0.00	159	1.4	—	—	0.3	1.9	0.00	0.00	1.0	30	0.9	0.1
Drillhole, Reykjavik, Iceland (b)	100	600	8.6	<0.1	95	1.5	<0.02	0.02	—	0.5	—	—	—	31	—	—
Spring, Hveragerdi, Iceland (b)	100	0	9.3	—	—	—	—	—	0.8	2.5	—	—	1.1	186	—	—
Hole G-3, Hveragerdi, Iceland (b)	216	650	9.6	0.3	212	27	0.04	≤0.02	0.0	1.5	0.00	0.1	1.9	197	0.45	[illegible]
Spring, Pauzhetsk, Kamchatka, USSR (c)	100	0	8.4	—	1010	88	—	—	10	64	—	0.04	0.8	1684	3.2	[illegible]
Pauzhetsk drill holes, Kamchatka, USSR (d)	170–195	300–400	8.7	—	Na + K 940		—	—	7	119	—	—	—	1470	—	—
Jubilee Bath, Ngawha, N.Z. (e)	50	0	6.5	11	870	79	0.3	0.5	2.5	8	—	—	0.3	1336	—	—
Drillhole 1, Ngawha, N.Z. (e)	230	585	7.4	12.2	950	80	0.8	0.4	Ca + Mg 28		0.02	0.1	0.8	1625	—	[illegible]
Ohaki Pool, Broadlands, N.Z. (e)	95	0	7.05	7.4	860	82	0.1	1.2	Ca + Mg 2.6		—	—	5.2	1060	3.0	[illegible]
Drill hole 2, Broadlands, N.Z. (e)	260	1030	8.3	11.7	1050	210	2.2	1.7	0.1	2.2	0.009	≤0.01	7.3	1743	5.7	[illegible]
Champagne Pool, Wairakei, N.Z. (e)	99	0	8.0	10.8	1070	102	1.1	2.7	0.4	26	—	—	6.6	1770	4.0	0.7
Drill hole 24, Wairakei, N.Z. (e)	250	830	8.3	13.2	1250	210	2.9	2.5	0.04	12	0.015	≤0.01	8.4	2210	5.5	0.3
Spring 6, Rotokaua, N.Z. (e)	65	0	2.5	7.8	990	102	—	—	11.3	11	—	—	<1	1433	—	—
Drill hole 2, Rotokaua, N.Z. (e)	220	880	7.8	10.2	1525	176	—	—	—	50	—	—	6.6	2675	—	[illegible]
Spring, Tahuangtsui, Tatun, Taiwan (f)	91	0	—	3.0	611	25.9	—	—	2.8	3.5	2.5	1.7	7.3	387	—	—
Hole E103, Tahuangtsui, Tatun, Taiwan (f)	200	1000	3.2	—	282	54	—	—	89	0	—	1368	—	1223	—	—
Shofuso Hotel, Matsukawa, Japan (g)	78.5	0	3.1	—	40	9.6	—	—	8.2	31.6	—	8.6	—	3.0	—	—
Hole 1, Matsukawa, Japan (g)	~300	945	4.9	—	264	144	—	—	8.7	22.9	—	508	—	12.4	—	—
Spring 22, Mexicali, Mexico (h)	—	0	—	11.6	4250	535	—	—	24	310	—	—	—	8600	12.3	—
Hole 5, Mexicali, Mexico (h)[b]	340	1285	—	19	5820	1570	—	—	8	280	—	0.2	—	10,420	14.1	3
Wister mudpots, Salton Sea, Calif. (i)	21	0	7.1	9.6	6470	466	—	—	325	79	0.9	0.8	14	8480	—	—
Hole 1, IID, Salton Sea, Calif. (i)[b]	340	1600	4.7	215	50,400	17,500	135	14	54	28,000	1400	2290	15	155,000	120	[illegible]
Spring, Makhachkala, Dagestan, USSR	63	0	8.6	0.2	1137	5.4	—	—	2.4	16.4	—	—	0.4	335	1.6	[illegible]

[a] References: (a) Bodvarsson (1961). (b) Chemistry Division, DSIR, N.Z., and pers. comm. from Dr. G. Bodvarsson, and Dr. C. E. Sigvaldason. (c) Ivanov (1958). (d) Averyev et al. (1961). (e) Chemistry Division, DSIR. (f) Y.-C. Liu (personal communication). (g) Nakamura and Suumi (1967). (h) Mercado (1966). (i) Muffler and White (1969). (j) Ivanov and Nevraev (1964).

[b] Concentrations and pH in deep aquifer.

[c] Total CO_2, SiO_2, etc., is the total CO_2 + HCO_3^- + CO_3^{2-} expressed as CO_2, silica + silicate as SiO_2, etc.

Table 3.2

Source and reference[a]	Concentrations (mg/kg) for water collected at atmospheric pressure from discharge						
	SO_4	As	Total CO_2	Total SiO_2	Total B	Total NH_3	Total H_2S
Spring, Reykjavik, Iceland (a)	17	0.00	32	126	0.06	0.00	0.2
Drillhole, Reykjavik, Iceland (b)	16	—	58	155	0.03	0.1	—
Spring, Hveragerdi, Iceland (b)	65	—	—	386	—	—	—
Hole G-3, Hveragerdi, Iceland (b)	61	—	55	480	0.6	0.1	7.3
Spring, Pauzhetsk, Kamchatka, USSR (c)	83	1.0	32	160	39	—	—
Pauzhetsk drill holes, Kamchatka, USSR (d)	164	—	61	170	31.3	0.7	—
Jubilee Bath, Ngawha, N.Z. (e)	500	—	240	186	1020	80	6
Drillhole 1, Ngawha, N.Z. (e)	17	—	61	460	1200	46	<1
Ohaki Pool, Broadlands, N.Z. (e)	100	1.0	490	338	32	3.8	1
Drill hole 2, Broadlands, N.Z. (e)	8	8.1	128	805	48.2	2.1	<1
Champagne Pool, Wairakei, N.Z. (e)	26	2.5	55	—	21.9	0.7	1.8
Drill hole 24, Wairakei, N.Z. (e)	28	4.5	17	670	28.8	0.2	1
Spring 6, Rotokaua, N.Z. (e)	520	—	144	340	45.0	1.6	0.2
Drill hole 2, Rotokaua, N.Z. (e)	120	—	55	430	102	3.2	—
Spring, Tahuangtsui, Tatun, Taiwan (f)	456	—	71	167	13.0	9.5	369
Hole E103, Tahuangtsui, Tatun, Taiwan (f)	1462	—	—	170	—	—	1.7
Shofuso Hotel, Matsukawa, Japan (g)	315	—	—	68	3.3	2.4	5.0
Hole 1, Matsukawa, Japan (g)	1780	—	26	635	61.1	—	tr
Spring 22, Mexicali, Mexico (h)	20.0	—	23	121	—	—	12
Hole 5, Mexicali, Mexico (h)[a]	0	—	1653	740	12.4	—	700
Wister mudpots, Salton Sea, Calif. (i)	900	—	3130	59	54	32	—
Hole 1, IID, Salton Sea, Calif. (i)[a]	5	12	7100	400	390	386	16
Spring, Makhachkala, Dagestan, USSR	1299	—	560	—	5.2	—	—

water expands into a mixture of approximately 70.3% water and 29.7% steam at 1 atm pressure; hence, the solute concentrations in the water at the base of well 24, Wairakei, are approximately 0.7 times the concentrations given in Table 3.2. The Mexicali and the Salton Sea area water analyses are for the original deep water before steam formation.

(Continued)

Source and reference[a]	Molecular ratios							
	Cl/SO_4	Cl/B	Cl/F	Cl/Br	Cl/As	Na/Li	Na/K	Na/Ca
Spring, Reykjavik, Iceland (a)	4.8	150	16	75	—	>5000	190	145
Drillhole, Reykjavik, Iceland (b)	5.2	400	—	—	—	>300	110	330
Spring, Hveragerdi, Iceland (b)	7.7	—	90	—	—	—	—	—
Hole G-3, Hveragerdi, Iceland (b)	8.7	100	55	800	—	200	13	250
Spring, Pauzhetsk, Kamchatka, USSR (c)	55	13.2	1100	1200	3600	—	19.5	27
Pauzhetsk drill holes, Kamchatka, USSR (d)	24	14.3	—	—	—	—	—	~13
Jubilee Bath, Ngawha, N.Z. (e)	7.2	0.40	2400	—	—	23.9	18.7	190
Drillhole 1, Ngawha, N.Z. (e)	260	0.41	1100	—	—	23.5	20	59
Ohaki Pool, Broadlands, N.Z. (e)	29	10.1	109	800	2300	35	17.8	575
Drill hole 2, Broadlands, N.Z. (e)	590	11.0	128	690	450	27	8.5	830
Champagne Pool, Wairakei, N.Z. (e)	185	24.5	145	1000	1500	30	17.8	72
Drill hole 24, Wairakei, N.Z. (e)	210	23.5	140	910	1040	28.5	10.1	180
Spring 6, Rotokaua, N.Z. (e)	7.5	9.7	>800	—	—	39	16.5	155
Drill hole 2, Rotokaua, N.Z. (e)	60	8.0	2.7	—	—	45	14.7	53
Spring, Tahuangtsui, Tatun, Taiwan (f)	2.30	7.3	28	—	—	61	40	300
Hole E103, Tahuangtsui, Tatun, Taiwan (f)	2.26	—	—	—	—	—	8.9	>500
Shofuso Hotel, Matsukawa, Japan (g)	0.026	0.22	—	—	—	—	7.1	2.2
Hole 1, Matsukawa, Japan (g)	0.019	0.062	—	—	—	—	3.1	20
Spring 22, Mexicali, Mexico (h)	1150	—	—	1580	—	111	13.5	21.8
Hole 5, Mexicali, Mexico (h)[a]	—	256	—	1670	—	92	6.3	36
Wister mudpots, Salton Sea, Calif. (i)	2.55	39	325	—	—	203	23.5	14.2
Hole 1, IID, Salton Sea, Calif. (i)[a]	80,000	121	5500	2900	27,000	705	4.9	3.15
Spring, Makhachkala, Dagestan, USSR	0.70	19.6	450	470	—	1700	360	121

The loss of CO_2 and H_2S from the water with steam formation and the consequent readjustment of the acid–base equilibria in the water is discussed later in detail (Chapter 7). The waters collected at the surface are of a higher pH than the deep high-temperature water.

The situation is complex for spring waters. Although some concen-

TABLE 3.3

Some Minor Element Concentrations in Geothermal Waters[a]

Source and temperature	Cl (ppm)	Mg (ppm)	Mn (ppm)	Fe (ppm)	Ni	Cu	Pb	Zn	Sb	Ag	Ref.[b]
Mean, 1 and 2 IID wells, Salton Sea (300°–350°)	155,000	10–54	1400	2150	—	5500	91,000	520,000	400	1400	(a)
Well, Chelcken Pen., Caspian Sea (80°)	157,000	3080	46.5	14	330	1410	9200	3060	—	—	(b)
Aquifer, Cerro Prieto, Mexicali (340°)	7420–11,750	6–33	0.64	0.2	2.2	5	4.6	6	400	4	(c)
Well E205, Matsao, Taiwan (245°)	9000	88	28	148	—	35	500	3800	—	—	(d)
Average Wairakei wells (250°)	1500	<0.01	0.001	0.008	0.7	1.3	1	1.5	70	—	(d)
Well 2, Broadlands, N.Z. (260°)	1180	<0.01	0.001	0.01	0.1	0.6	0.8	0.6	130	0.5	(d)

[a] In parts per 10^9 in the underground water unless otherwise noted. Chloride concentrations give a measure of salinity.
[b] References: (a) White (1968), (b) Lebedev (1972), (c) Mercado (1967), (d) Chemistry Division.

3.2 STEAM

Although the term *fumarole* is often used for all natural st outlets, Ivanov (1958) noted a useful classification which w require a more restricted use of the term. *Fumarolic* steam can be as a term for high-temperature volcanic steam which arises dir from a magmatic origin and which has not passed through a hot w body. It contains gases such as HCl, HF, CO_2, H_2S, and SO_2. *Solfa* steam is a useful term for the steam boiling from an underground water phase, as in the area of Solfatara, near Pozzuoli in Italy. types of steam may condense in surface waters, when the steam or may be distinguished through the relative solution concentratio constituents such as Cl, F, B, SO_4, and CO_2. The Larderello and Geysers steam flows are considered to be special cases of solfa activity. Typical analyses for examples of each type—a fumarol White Island volcano, New Zealand, and Karapiti Blowhole, a st vent at Wairakei, New Zealand—are given in Table 3.4.

Steam and Gas Compositions

The concentration of gases in the steam is an important fact planning geothermal power generation plants and in assessing effect of exploitation on underground conditions in a system steam-producing systems, such as Larderello and The Geysers, th concentration in the steam samples does not vary with the colle pressure. However, in high-temperature water areas, boiling o either within the well or in natural flow channels as waters rise to the surface. After the formation of only a few percent of steam

TABLE 3.4

Comparison of Compositions of Steam from a Fumarole on an Active Volcano (White Island, Plenty, N.Z.) and from Underground Hot Water (Karapiti Blowhole, Wairakei, N.Z.)[a]

	H_2O	CO_2	SO_2	H_2S	HCl	HF	H_2	CH_4	N_2
White Island fumarole (650°)	79.6	13.9	4.8	1.5	0.17	0.2	0.16	0.0003	0.018
Karapiti Blowhole (115°)	99.8	0.16	0	0.004	0	10^{-6}	0.002	0.001	0.00

[a] Compositions in mole percent.

steam phase contains a large proportion of the gases originally dissolved in the water. The concentrations of such gases as CO_2, H_2S, CH_4, H_2, and N_2 in the steam are inversely related to the percentage of steam flashed from the water, and therefore to the separation pressure at which the steam is collected from the discharge.

In most areas where comparison was possible, natural steam from major fumaroles gave a good indication of the quality of steam produced later by wells. However, some hydrogen sulfide may be lost from steam rising in natural channels, and near-surface reaction of

steam with organic material may create additional methane, ammonia, and carbon dioxide in steam from minor steam vents.

Table 3.5 gives the composition of steam from geothermal wells and natural steam vents in several areas. For some hot water areas the analysis of steam from wells is given for atmospheric pressure separation, but for utilization studies the approximate gas concentrations at higher separation pressures can be calculated if the steam fraction of the well discharge is known.

Although gas concentrations and compositions cover a wide range,

TABLE 3.5

Composition of Steam from Fumaroles and Wells[a]

Source	Source depth (m)	Temp. (°C)	Pressure for composition (bars abs.)	Steam fraction in discharge at pressure	Total gas in steam (mole %)	Gas composition (mole %)								
						CO_2	H_2S	$\overline{HC}$	H_2	$N_2 + A$	O_2	NH_3	H_3BO_3	Ref.[b]
Fumaroles, Larderello	0	100	1[c]	1.00[c]	3	92.3	2.06	1.4	2.6	1.07	0.05	—	0.5	(a)
Average well, Larderello	500	200	1	1.00[c]	2.0	94.1	1.6	1.2	2.3	0.8	—	0.8	0.33	(b)
Average well, The Geysers	200–2000	230	1	1.00[c]	0.59	55	4.8	9.5	15	3	—	12.5	0.25	(c)
Well MR-2, Matsukawa	1080	230	1	High	0.22	81.8	14.1	——Remainder 4.1%——						(d)
Wells, Reykjavik	500	100	——Water only——			—	—	—	—	100	—	—	—	(e)
Well G-3, Hveragerdi	400	216	1	0.20	0.015	73.7	7.3	0.4	5.7	12.9	—	—	—	(e)
Karapiti fumarole, Wairakei, N.Z.	0	115	1	1.00	0.17	94.6	2.3	0.74	1.0	1.1	—	0.26	—	(f)
Average well, Wairakei, N.Z.	650	260	1	0.32	0.063	91.7	4.4	0.9	0.8	1.5	—	0.6	0.05	(f)
Well 11, Broadlands, N.Z.	760	260	1	0.355	0.61	94.8	2.1	1.2	0.2	1.5	—	0.2	—	(f)
Well 1, Ngawha, N.Z.	585	228	1	0.33	20	93.9	0.7	4.1	0.5	0.8	—	0.04	—	(f)
Fumarole, Matsao, Tatun	0	100	1	1.00	3.2	55.0	37.2	——Remainder 7.8%——						(g)
Well E205, Matsao, Tatun	1500	245	1	~0.3	0.15	92	5	0.7	0.8	1.5	—	—	—	(f)
Well 5, Mexicali	1285	340	1	0.44	0.54	81.4	3.6	7.0	0.5	7.0	0.4	—	—	(h)
Fumarole, El Tatio, Chile	0	86.6	0.6	1.00	0.10	75	0.6	0.1	0.0	19.4	4.9	—	—	(f)
Well 2, El Tatio, Chile	650	220	0.9	0.24	0.11	99	0.7	0.01	0.03	0.2	—	—	—	(f)
Wells, Salton Sea	1500–1800	300–350	16	0.18	0.1–1.0	90	Remainder mainly H_2S + minor $\overline{HC}$ and H_2							(i)
Well 1, Ahuachapan	1195	230	1	0.23	0.007	50–80	4	—	10–40	2–10	—	—	—	(e)
Well 7, Otake, Japan	350	230	3.0	0.215	0.10	96.7	0.65	——Remainder 2.7%——						(j)

[a] $\overline{HC}$ means total hydrocarbon gases.

[b] References:
(a) Nasini (1930).
(b) ENEL (1970).
(c) Kruger and Otte (1973).
(d) Nakamura and Sumi (1967).
(e) Dr. G. E. Sigvaldason (personal communication).
(f) Chemistry Div., DSIR.
(g) Y-C Liu (personal communication).
(h) Alonso (1966).
(i) Helgeson (1968).
(j) Noguchi (1966).

[c] Area of steam discharges only.

TABLE 3.11

Concentration of Metals in Some Precipitates Formed from Geothermal Waters[a]

	Concentration (ppm)							
	Sb	As	Hg	Au	Ag	Tl	Pb	Zn
Ohaki Pool, Broadlands, N.Z.	10%	400	2000	85	500	630	25	70
Well 2, Broadlands, N.Z.	5%	250	200	55	200	1000	50	200
Well 2, Rotokaua, N.Z.	30%	4000	15	70	30	5000	50	100
Champagne Pool, Waiotapu, N.Z.	2%	2%	170	80	175	320	15	50
Spring, El Tatio, Chile	1.5%	12%	50	3	1	10	100	100
Steamboat Springs, Nevada	2000	600	—	60	400	2000	400	200

[a] From the review of Weissberg *et al.* (1976).

natural channels but that most of the thallium precipitated (Weissb 1969). The study showed that lead, zinc, and copper precipi tended to form at depth within the Broadlands system, whe arsenic, antimony, thallium, mercury, and gold were transporte the surface before precipitation. There is good experimental evid that strong thio complexes of mercury, gold, antimony, and arsenic formed at high temperatures (e.g., Dickson, 1966; Seward, 1973) permit these metals to be transported up through deep zone changing pH, whereas metals such as lead, zinc, and copper with stable sulfur complexes are precipitated at depth as sulfides.

Metallic lead is known to deposit from some thermal wat Lebedev (1972) reported the deposition of metallic lead, sphale and pyrite from highly saline hot waters of the Cheleken Peninsul the eastern Caspian Sea. Waters from a high-temperature deep thermal well at Matsao, Taiwan, also produced on outflow pipe deposite rich in metallic lead and galena.

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Private Power and CFF Co-Financing of Geothermal Power Projects in the Philippines

1. ISSUE

Whether a private-sector geothermal power project in the Philippines may be eligible for funding from Concessional Financing Facilities ("CFF") in a manner consistent with US and Philippine government goals.

2. CONCLUSION

CFF funds are designed to provide the Philippine government with concessionary financing thereby allowing them to purchase US energy sector goods and services at rates competitive with those of other countries. Coupling CFF and private sector funds allows the leveraging of CFF funds. In the geothermal energy context, this approach is especially valid in the high risk phase of field exploration and development. A co-financed government/private sector exploration and development phase reduces the risk to both sides to an acceptable level. Especially under the Build-Own-Operate-Transfer (BOOT) approach, CFF financing of the high risk phase paves the way for private sector financing of a power production facility which, when debt and equity investment returns are satisfied, results in a transfer of the power generating facilities to Philippine government ownership.

3. BACKGROUND

The generation of electrical energy from geothermal resources is today cost competitive with other energy sources. Numerous economic analyses can be cited to support this, but it is also important to remember that these analyses do not include the environmental benefits of geothermal compared with fossil fuels and balance of payments benefits associated with independence from foreign sources of energy.

Geothermal exploration and development require relatively high up-front costs and risks not encountered in competing energy systems. In an economic analysis, geothermal will make up for these high initial costs through no on-going fuel costs, low operating and maintenance costs, and high power plant availability. However, because of the risks associated with the exploration and development drilling of a geothermal resource, there is a problem financing these initial costs using standard bank loans.

In the Philippines, geothermal resources continue to be perceived as national endowments and the generation of electricity and the ownership of the electrical power infrastructure is regarded as a government responsibility. However, recognizing a short-fall in their economic development capacity, the Government of the Philippines is looking for an innovative way to incorporate the private sector in adding to their electrical generating needs.

What is required is a partnership between the U. S. geothermal industry, U. S. government and the Philippines to increase electrical generating capacity while minimizing both the costs to the Philippines and the financial risk to the developer. The plan accomplishes this function while achieving the following objectives.

1. The Philippines maintains control over the geothermal resource.
2. The Philippines in time achieves ownership of the electrical generating facility.

3. The Philippines achieves power on-line in the least amount of time that is technically feasible.
4. The Philippines limits the amount of additional debt burden.
5. Foreign fuel imports are displaced.
6. Environmental degradation is minimized while increasing electrical power.

Geothermal resources can be developed incrementally using 5 to 10 MW modular power plants that typify the U. S. industry's technological lead. This staged development reduces risk by lowering initial capital costs, by starting payback after a small part of the resource has been developed, and by allowing reservoir engineering evaluations to be performed while geothermal power is being produced, prior to committing large amounts of additional capital.

4. GEOTHERMAL DEVELOPMENT SCENARIO

The following presents a scenario for geothermal development in the Philippines to illustrate the concept of industry and government partnering and incremental geothermal field development.

Phase 1: Exploration and Development

The Republic of the Philippines would contract with a U. S. developer for the exploration of one of their most prospective geothermal areas. It is essential that Phase 1 be pre-conditioned by a commitment from the Philippines to enter into a contract for Phase 2 if the resource is proven to be of commercial quality. The mechanism for this commitment would be a power purchase agreement.

The developer would perform geological and geophysical surveys designed to locate and drill exploration wells. Ordinarily, one discovery well and one confirmation well will be required to prove viability of the resource. These wells will be drilled so that they can be used in subsequent production. At this stage, the project is continually reevaluated, and a decision to abort is possible if the resource does not meet expectations. The successful completion of this phase would result in five production wells with an estimated cumulative capability of 5 MWe.

The estimated cost of Phase 1 is $7.5 million. This cost would be funded through CFF financing resulting in a loan obligation of $4.88 million (65%) by the Philippines. The timing of Phase 1 will depend on a number of factors including the level of knowledge of the exploration site, site access, and equipment availability. It is possible that this phase could be accomplished in 12 months.

Phase 2: Power Plant Development

The power purchase agreement is a bankable document and will be used to finance the power plant and associated surface facilities. It is estimated that another $7.5 million will be required for this part of the project. The emphasis here will be to get power on line as soon as possible.

This part of the project will utilize a BOOT approach where the developer is paid through the sale of electricity. When the Phase 2 investment has been amortized, the ownership of the plant will be transferred to the Philippines.

The stream of payments can be also used to fund additional exploration and development work on the project. Therefore, a portion of the payments for electrical power delivery can be applied to drilling additional wells and adding more modular power units.

GEOTHERMAL POWER DEVELOPMENT OF THE MALITBOG SECTOR, GREATER TONGONAN FIELD, LEYTE, PHILIPPINES

Executive Brief

PNOC
The Energy Company

PHILIPPINE NATIONAL OIL COMPANY
ENERGY DEVELOPMENT CORPORATION

AN INVITATION FOR JOINT VENTURE IN GEOTHERMAL DEVELOPMENT

In line with the Philippine Government's thrust towards encouraging private sector participation in energy development, the *Philippine National Oil Company - Energy Development Corporation (PNOC-EDC)* is inviting companies with demonstrated capability in the field of geothermal power plant installation and/or operation, to enter into a joint venture agreement for power plant construction in the Malitbog sector of the Greater Tongonan geothermal field in Leyte. The electricity that will be generated by the power plant shall be sold to the *National Power Corporation (NPC).*

The estimated power generating potential of the Malitbog sector over a 25-year power plant life is *at least 165 MWe* using conventional condensing turbines. This can be optimized to *as high as 240 MWe* with a second flash system using a combination of high pressure back pressure turbines and intermediate pressure condensing turbines. A total of about 117 MWe of power is presently available at the wellhead from 13 production wells.

In this joint venture invitation of PNOC-EDC, the extent of private sector participation shall apply as follows:

- o *Supply, construction and operation of at least 165 MWe power plant (up to 100 per cent)*

The following contracts/agreements will be negotiated for the joint venture project:

1) Joint venture for power plant project, if applicable

2) Steam sales agreement between steamfield developer and power plant company, and

3) Electricity sales agreement between power plant company and NPC.

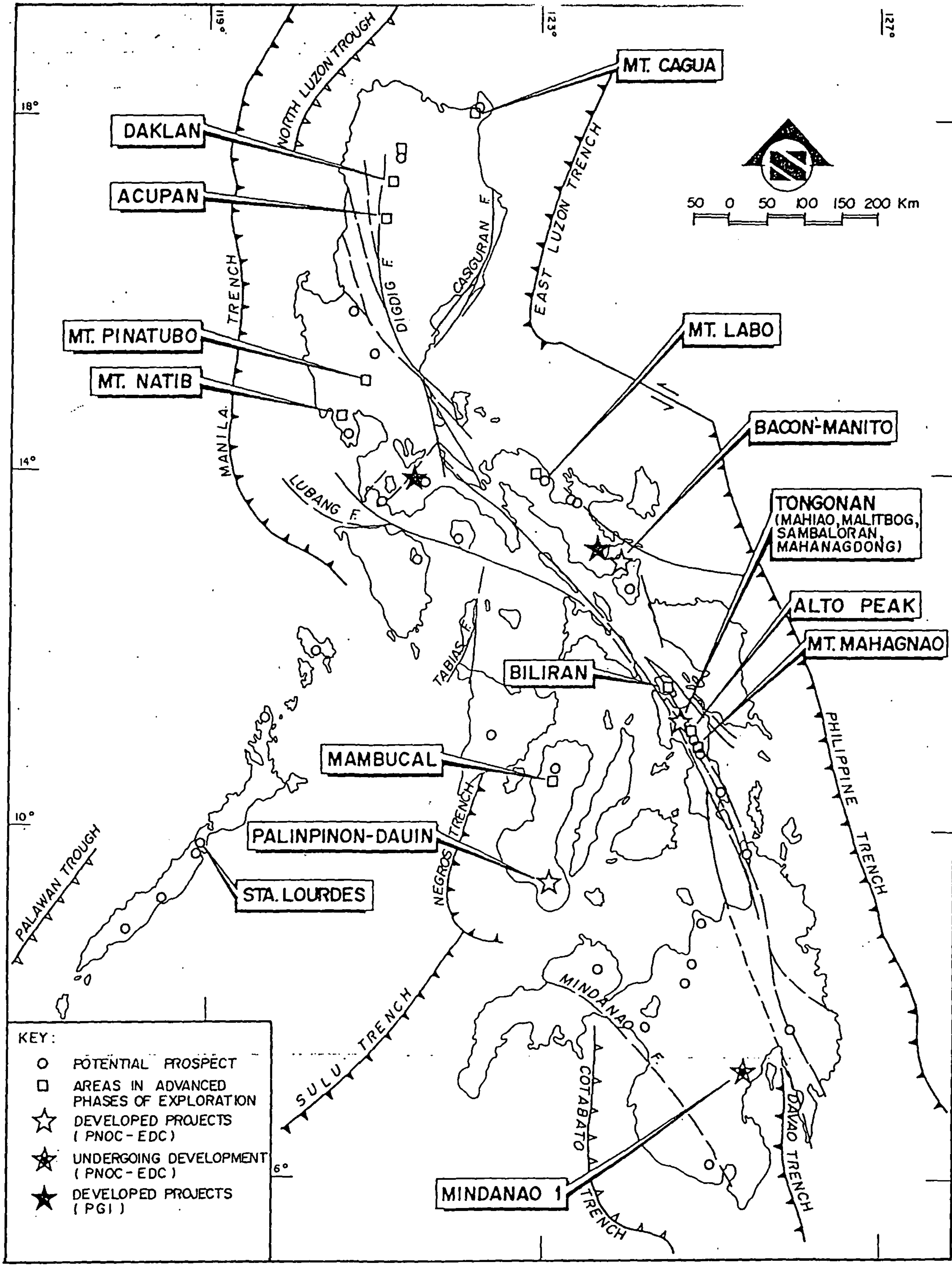


FIGURE 1
LOCATION MAP OF PHILIPPINE GEOTHERMAL AREAS

PNOC-EDC welcomes potential investors who would be interested in reviewing all technical data at its Manila office. Field inspection of the site development can be arranged. Interested companies should be willing to be party to the power plant project. Expression of interest to be submitted shall include company profile and testimonial attesting eligibility to undertake the work. All submissions should be forwarded to:

The Vice President - Energy
PNOC Energy Development Corporation
Merritt Road, Fort Bonifacio
Makati, Metro Manila
Philippines

Facsimile: (632) 815-27-47
Telex: 22666 EDC PH
Telephone: (632) 815-89-61

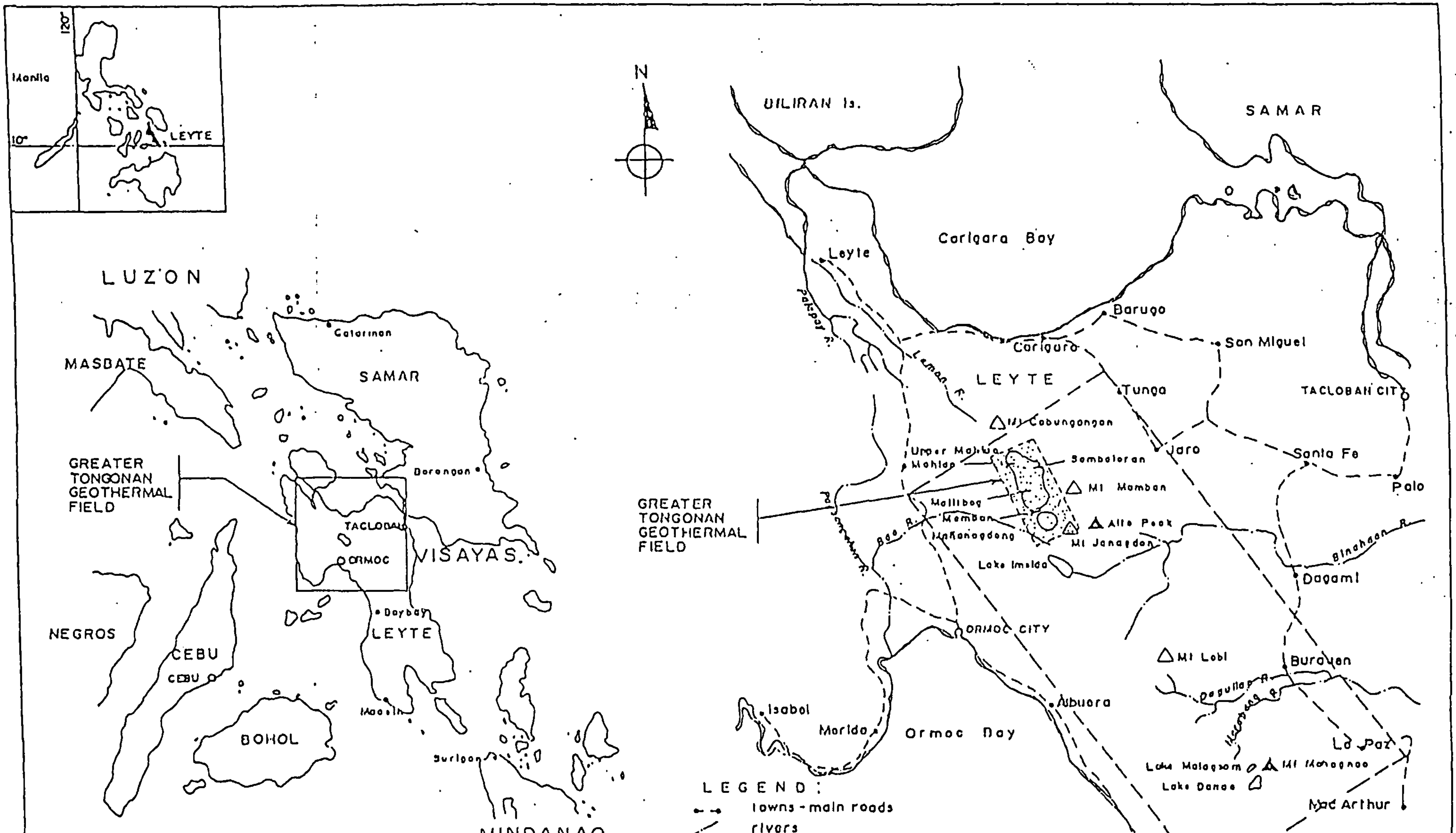


FIGURE 2
LOCATION MAP OF LEYTE-A GEOTHERMAL PROSPECT AREAS

GEOTHERMAL IN THE PHILIPPINES

The electricity generation mix in the Philippines consists of hydro, coal, oil, geothermal and other non-conventional energy sources. Geothermal energy accounts for twenty-two percent (22%) of the country's electric power generation.

As an energy source, geothermal is the most promising alternative in the Philippines. Geothermal energy occurs in abundance and is the least-cost alternative given other available indigenous energy sources. Geothermal power is also environment-friendly and a safe source of clean energy.

The power network of the country is divided into three major power grids: Luzon, Visayas and Mindanao. The National Power Corporation (NPC), the state-run power company, plans to ultimately interlink these island grids via submarine cables. The geothermal fields in Leyte serve as the centerpiece of NPC's interconnection plan of the various island grids.

SUMMARY OF ELECTRIC GENERATION ALTERNATIVES

DEVELOPMENT OPTION	INVESTMENT COST ($KW)	PLANT FACTOR (%)	GENERATION COST (P/KW)	LEAD TIME (MOS)
GEOTHERMAL	2103	85	1.18	48-84
IMPORTED COAL	1336	75	1.40	36-48
COMBINED CYCLE	825	80	1.43	36-48
HYDRO	3170	59	2.12	72-96
DIESEL	900	80	2.64	18-24
GAS TURBINE	546	15	3.89	12-24

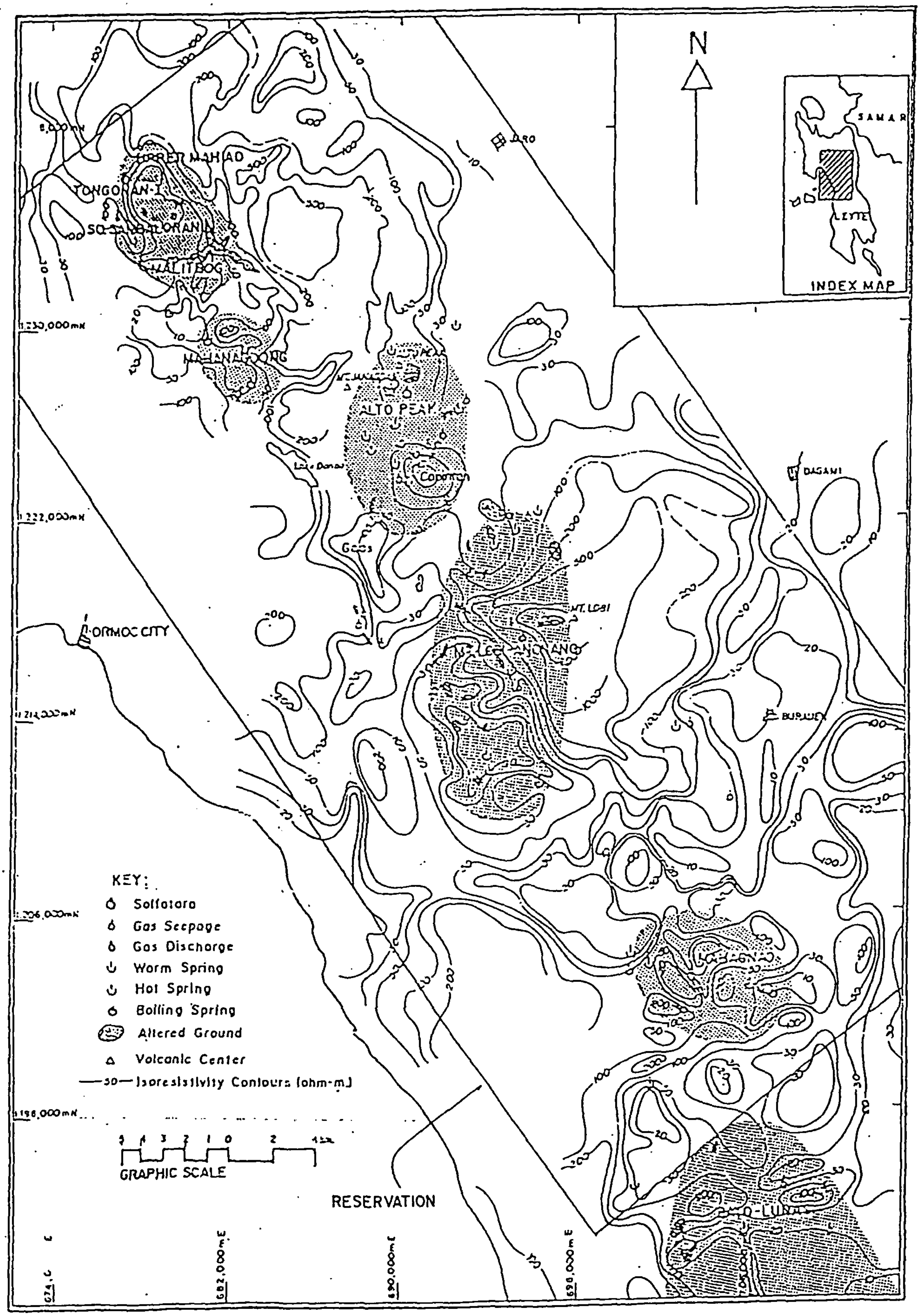


FIGURE 3
GEOTHERMAL PROSPECT AREAS IN LEYTE

THE GREATER TONGONAN GEOTHERMAL FIELD

The Greater Tongonan field is located in the northernmost part of the Leyte Geothermal Reservation. The field covers an area of about 40 km^2 and contains a number of prospect areas in various stages of exploration and development. The western boundary of the field follows the Central Philippine Fault while the eastern boundary is the main divide of the north-central Leyte mountain range. The Greater Tongonan field lies at an altitude of between 400 and 1000 m AMSL. Most of the surface runoff drains into the Bao river and into Ormoc Bay, 7 km west of Ormoc City.

Natural physiographic features divide the field into four sectors which can be considered separately for development: Upper Mahiao, Lower Mahiao-Sambaloran, Malitbog, and Mahanagdong. Geothermal manifestations consist of a number of boiling springs, mud pools, geysers and steaming grounds, the most impressive of which is found in the Bao River Valley.

Todate, fifty-nine (59) deep wells have been drilled in the Greater Tongonan field: 13 in Upper Mahiao, 22 in Lower Mahiao-Sambaloran, 18 in Malitbog and 6 in Mahanagdong. These exclude the 12 shallow thermal gradient wells drilled earlier in the Bao Valley.

At present, the Greater Tongonan field has an installed power generation capacity of 112.5 MWe which consists of 3x37.5 MWe Mitsubishi condensing turbines. The Tongonan I fluid collection and disposal system (FCDS) utilizes 12 production and 7 reinjection wells in the Lower Mahiao-Sambaloran sector.

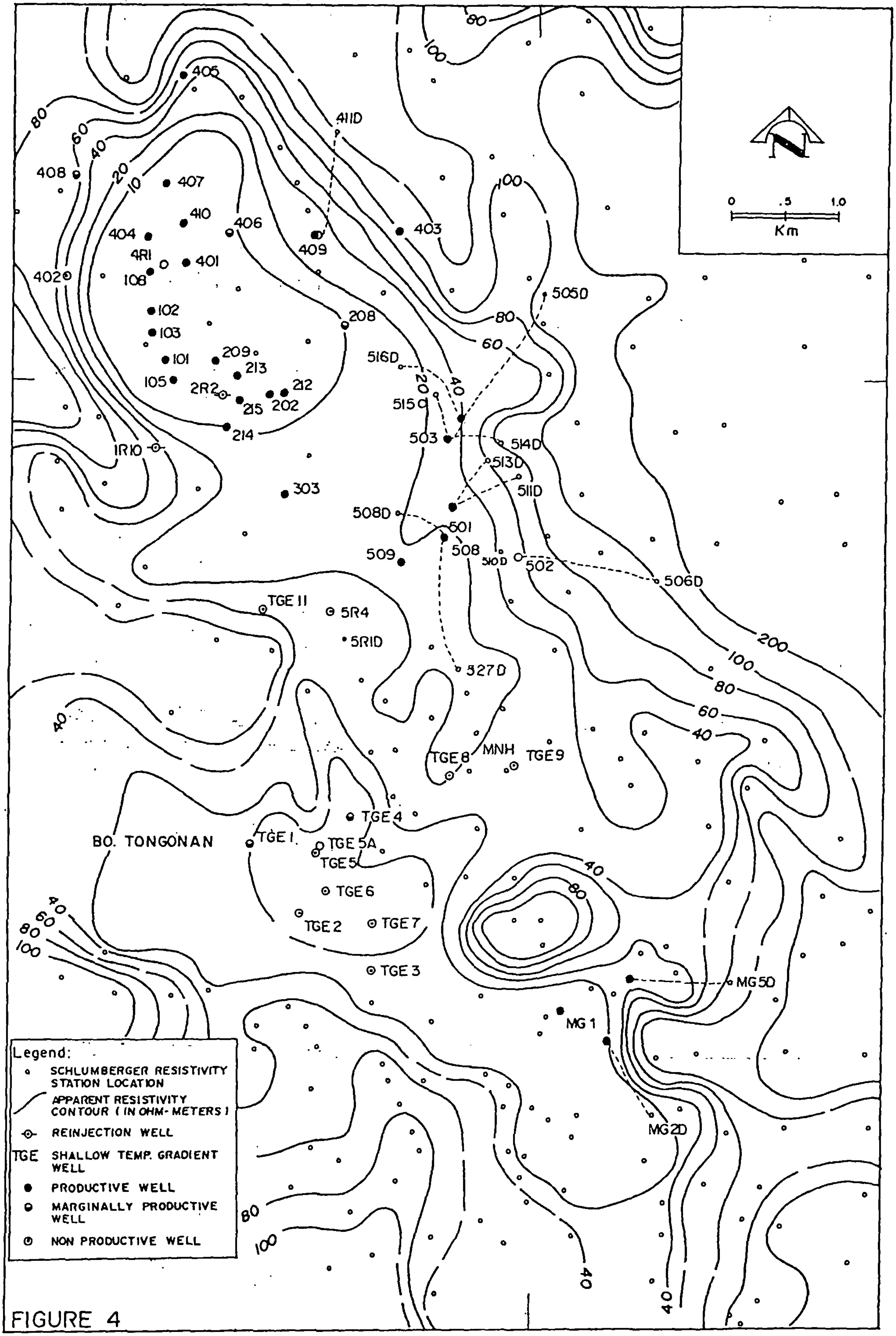


FIGURE 4
ISO-RESISTIVITY MAP AT AB/2 = 500m

HISTORY OF EXPLORATION AND DEVELOPMENT

The potential of the Tongonan geothermal field was first recognized in 1962 during the reconniassance geological survey of Leyte. In 1971, the Commission on Volcanology (COMVOL) with financial assistance from the National Science Development Board (NSDB), initiated an integrated geological, geochemical, and geophysical investigation of the area to assess its potential for electrical power generation.

In 1972, the governments of the Philippines and New Zealand concluded and signed an agreement to explore and develop the Tongonan geothermal field. Financial and technical assistance was provided by the latter under the Colombo Plan. The executing agency for the New Zealand government was Kingston, Reynolds, Thom and Allardice Limited (KRTA), in association with the Ministry of Works and Development (MWD) and the Department of Scientific and Industrial Research (DSIR). Their Philippine counterparts were the National Power Corporation (NPC) and the COMVOL.

Drilling of thermal gradient holes (TGE series) began in December 1973. By June 1976, a total of twelve (12) boreholes with an average depth of 610 m were drilled within an area of approximately 20 km^2. All these wells recorded higher than normal temperature gradients but TGE-10 (now 4R1) was the most promising with temperatures in excess of 250^oC at 540 m.

In 1976, the implementation of the exploration and development program was transferred by NPC to the newly created Geothermal Division of the Philippine National Oil Company-Energy Development Corporation (PNOC-EDC).

In October 1976, well 401, the first deep exploratory hole was drilled. It turned out to be the discovery well with a maximum temperature of 324^oC. Since that time drilling has extended to the Sambaloran, Malitbog, Mamban and Mahanagdong areas. Todate, 59 wells have been drilled as succesful producers and injectors for the existing and future power plants in the area.

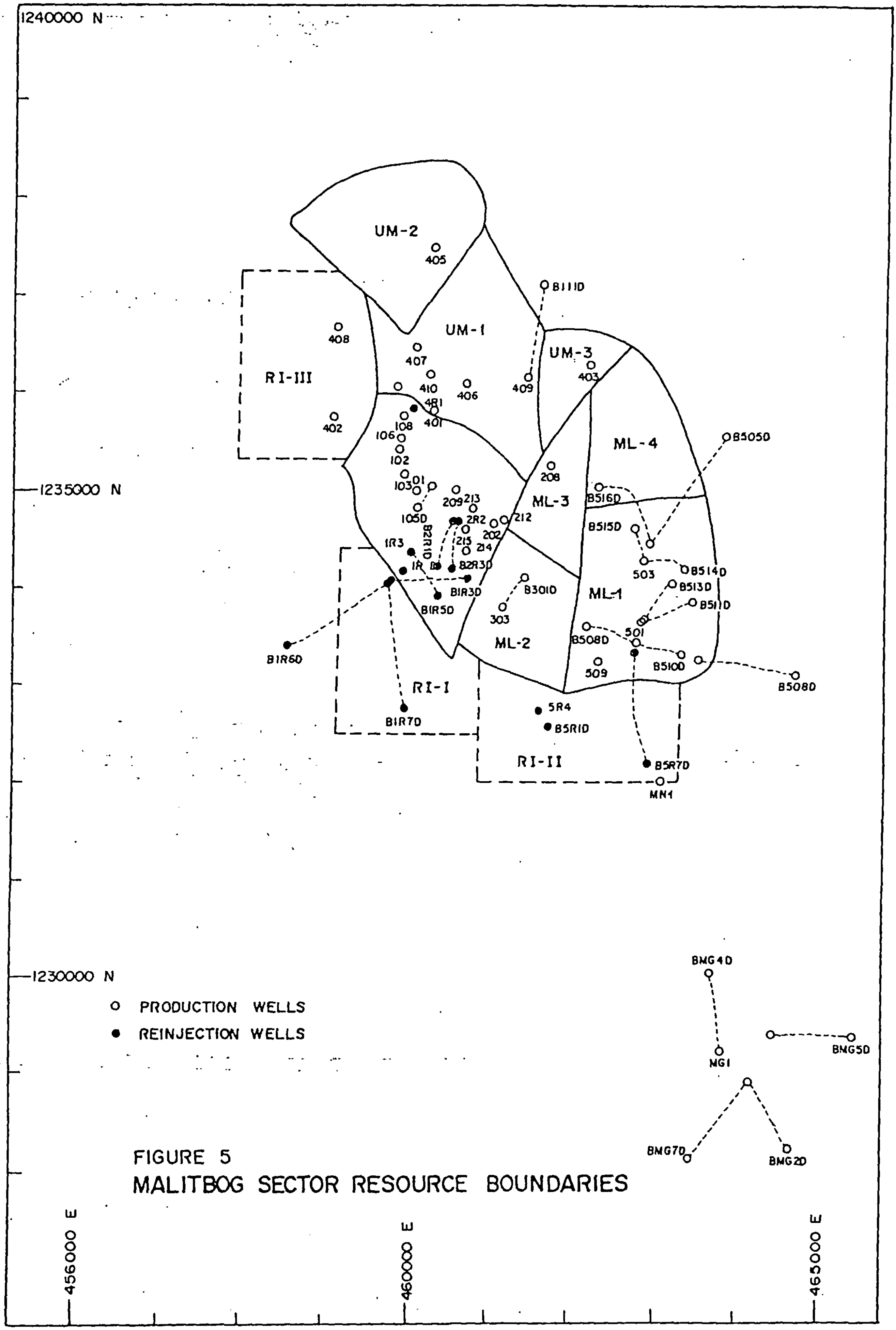


FIGURE 5
MALITBOG SECTOR RESOURCE BOUNDARIES

MALITBOG RESOURCE ASSESSMENT

In estimating the potential Tongonan reserves for development, PNOC-EDC divided the field into 11 resource blocks. The Mahanagdong sector was excluded as it is considered hydrologically separate. The subdivision into four production blocks and one injection block for Malitbog was based on grouping of wells with similar characteristics, structural boundaries and similarities in hydrothermal alteration patterns.

Economically recoverable resource was assumed to be defined by: (a) the 220°C isotherm (within the production block) and is considered the minimum acceptable initial resource temperature; (b) the -2700 m RSL level, which corresponds approximately to the deepest vertical production well depth plus 500 m; and (3) an abandonement temperature of 180°C, which is the separator rejection temperature.

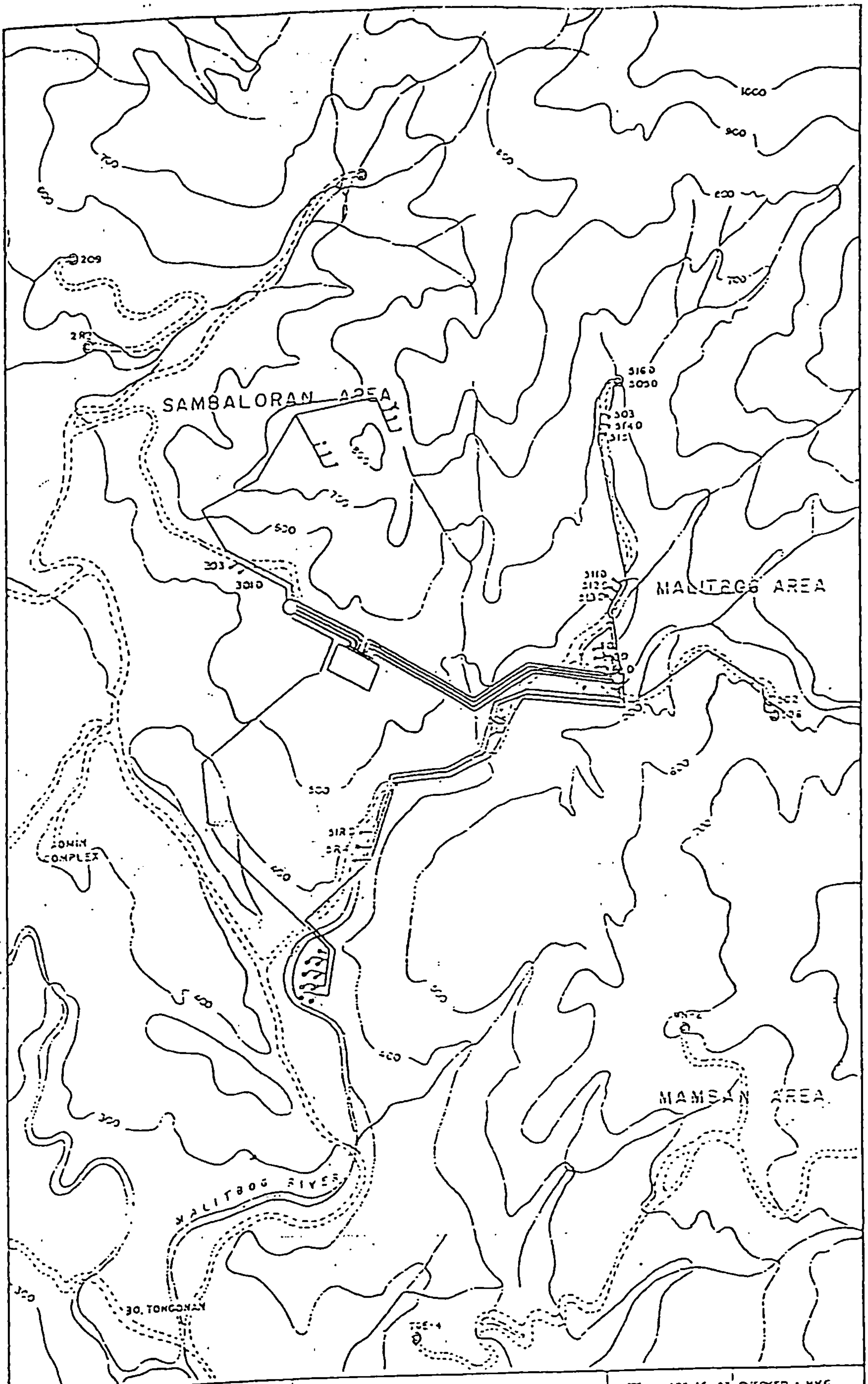
Volumetric or stored heat calculations were applied to the four Malitbog blocks. Two different porosity values were assumed for blocks ML1 and ML2. For a 25-year plant life and an 80% load factor, the indicated reserve is between <u>143 MWe and 196 MWe</u>. The range in this estimate derives from the use of both conservative and optimistic assumptions for recovery factors which vary as a function of rock porosity.

MALITBOG STORED HEAT/POWER CAPACITY ESTIMATE

Block	Area (Km^2)	Thickness (m)	T_r °C	S.H. (Kj/m^3)	ϕ %	R.F. %	C.E. %	Power (MW_e)	Power Density (MW_e/km^2)
ML 1	2.95	2,500	250	1.80×10^5	10	25	11.5	60.5	20.5
ML 2	1.70	2,800	240	1.54×10^5	10	25	11.0	31.9	18.7
ML 3	1.40	2,800	260	2.05×10^5	10	25	12.0	38.2	27.3
ML 4	1.50	2,200	260	1.50×10^5	5	15	11.0	12.9	8.6
								Total 143.5	
ML 1				1.90×10^5	15	38	11.5	95.0	32.2
ML 2				1.62×10^5	15	38	11.0	50.0	29.4
ML 3				2.05×10^5	10	25	12.0	38.2	27.3
ML 4				1.50×10^5	5	15	11.0	12.9	8.6
								Total 196.1	

ASSUMPTIONS:

Rock Density = 2670 Kg/m^3
ρC_r = 0.9 Kj/Kg - °C
Plant Life = 25 years
Plant Load Factor = 80%



PNOC

PNOC-ENERGY DEVELOPMENT CORP.
ENGINEERING DEPARTMENT
GEOTHERMAL DIVISION

PROJECT: LEYTE - A

TITLE: MALITBOG (3 X 55 MWe)

DATE : 03-16-92	CHECKED : NVG
DRAWN : JDS	APPRVD : ROB
DESIGNED : NVJ	SCALE : NTS
DRAWING NO	REV.

FIGURE 6
PREFERRED DEVELOPMENT AND FCDS LAYOUT

MALITBOG DEVELOPMENT STRATEGY

The development of the Greater Tongonan geothermal resource for power generation expansion will be funded largely out of the World Bank Leyte "A" Project Loan and an additional Energy Sector Loan signed in March 1990. The Leyte-A energy project calls for 600-640 MWe development from the different geothermal areas in Leyte for export of power via undersea cables to Cebu, designated as Phase I, providing 200 MWe of power to the grid. The second phase (Phase II) involves a sub-sea cable link from Leyte to Luzon (through the island of Samar) of 400-440 MWe.

PNOC-EDC is allocating the Malitbog development sector for the Cebu inter-connection. Both the steamfield development and power plant installation will be handled by PNOC-EDC. This arrangement has been recently agreed upon between NPC and PNOC-EDC through a Memorandum of Understanding (MOU). The Malitbog development will be the first project where PNOC-EDC will be involved in both steamfield development and power station construction as well. PNOC-EDC, therefore, plans to go on a joint-venture with local or foreign firms for the power plant component of the project.

The Malitbog steamfield will be developed initially for a 165 MWe (3x55 MWe) station capacity. For this power development, the preferred fluid collection and disposal system (FCDS) adopts a central power station to allow for greater flexibility in interconnecting existing and future wells. A central separator station will serve all the wells in the eastern sector of the field (300 series wells). The two-phase fluid from the western wells shall be separated in a cylcone separator located at well 501 pad. Well 509 will have a fully dedicated pad separator. Reinjection will be by gravity. The eastern wells will reinject at pad 5RB, the southermost major RI pad. The western wells will dispose their effluents using the existing wells at well 5R1D pad. The two reinjection pads will be interconnected to provide flexibility in the use of the RI wells especially at the 5RB pad.

LEYTE GEOTHERMAL FIELDS

TOTAL No. OF WELLS	....	82
Production Wells	....	45
Reinjection Wells	....	12
Non Commercial Wells	....	12
Exploratory Wells	....	12
Under Testing	....	1
Vertical Wells	....	47
Directional Wells	....	35
AVERAGE DEPTH	....	2260 m
Vertical Wells	....	2203 m
Directional Wells	....	2317 m
TOTAL MWe PROVEN		
Tongonan	....	411.2
Alto Peak, Burauen, Biliran	....	Under Testing/ Assessment

TONGONAN GEOTHERMAL PROJECT

Peak Load	....	82.0 MW
Daily Power Production	....	1464.4 MW-Hrs
Production since Day 1	....	3,967,897.2 MW-Hrs
Maximum Steam Flow Production	....	1020 Tons/Hr
Total Steam Flow Capability	....	1171.8 Tons/Hr
Max. Waste Water Flow Production	....	306 kg/sec
Separator Pressure	....	6.0 kg/sq.cm.
NPC Header Pressure	....	5.6 kg/sq.cm.
Steam Temperature	....	165 deg C
Area Proven with Geothermal Resource	....	27 sq.km.
Reservoir Temperature	....	250 - 330 deg C
Reservoir Estimate	....	485 - 610 MWe
Total Length of Pipe Network	....	9.0 km.
Two-Phase Line	....	4.9 km.
Steam Lines	....	2.3 km.
Re-injection Lines	....	1.8 km.
Total Length of Road Network	....	66 km.
No. of Personnel Working in PNOC-EDC	....	255
No. of Personnel Working in NPC	....	123
Plant Operations	....	66
Grid Office	....	52
Project Office	....	5

DOE/IE/10574--T2

DE90 008795

RADAR IMAGERY INTERPRETATION TO PROVIDE INFORMATION ABOUT SEVERAL GEOTHERMAL SITES IN THE PHILIPPINES

ARCI TR 8701-102

November 17, 1988

prepared by

ARKANSAS RESEARCH CONSULTANTS, INC

Department of Energy
Washington, DC 20585

JUL 24 1990

Dr. Phillip M. Wright
University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

Dear Mike:

I am enclosing a report from Arkansas Research Consultants, Inc., and would appreciate your comments with respect to:

1. Can radar imagery offer much to geothermal exploration?
2. Would this report be of any value to Unocal and other companies interested in the Philippines?

I appreciate your continuing help, Mike, and hope that all goes well for you this summer.

Sincerely,

Ted

John E. Mock, Director
Geothermal Division
Conservation and Renewable Energy

Enclosure

DOE/IE/10574--T2

DE90 008795

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1

PREFACE

INTRODUCTION

Arkansas Research Consultants, Inc. (ARCI), conducted an extensive imaging radar survey of selected petroleum and geothermal sites in the Republic of the Philippines. The effort was supported by the United States Department of Energy (DOE), Grant Number DE-FG01-86IE10574.A000.

OBJECTIVES

The primary objectives of this work were (1) to further the goals of international energy development by helping the Philippine's Government improve its understanding of its energy potential, (2) to advance the economic and energy development of the Philippines and, (3) to increase the world's oil supply base. Secondary objectives were (1) to teach scientists and engineers in the Republic of the Philippines the fundamentals of radar image interpretation, and (2) to provide them with a data base for their continued research and analysis.

SCOPE

The work conducted was limited to acquiring SAR (synthetic aperture radar) data which included four potential petroleum resource basins and three areas of geothermal resources in the Republic of the Philippines, to interpreting the data acquired for hydrocarbon or geothermal potential, and to ranking the potential of various prospects identified.

EXECUTIVE SUMMARY

This Executive Summary relates the essential aspects of the work conducted for geothermal site evaluation reported here. The petroleum basin investigation is reported in a separate document[1]. A separate report has also been prepared as a comprehensive Executive Summary for a more detailed summarization of the hydrocarbon analysis.[2]

As with most nations of the world, the Republic of the Philippines is intensely interested in the identification, development, and conservation of natural resources. In keeping with this, the Government of the Philippines has recently completed a nation-wide sedimentary basin evaluation program to assess hydrocarbon potential and assist in future exploration activities. This study was directed by the Philippine Bureau of Energy Development (BED) with a significant portion of the work performed by the Philippine National Oil Company Exploration Corporation (PNOC EC). Since this work was completed, the BED has been reorganized and is now known as the Office of Energy Affairs (OEA).

This program of collection and interpretation of the radar imagery was designed to augment and complement the existing data base prepared by BED and PNOC EC. Geothermal and hydrocarbon sites were selected through the cooperative efforts of BED and PNOC EC scientific personnel. The primary objective of the project was to further the goals of international energy development by aiding the Republic of the Philippines in the assessment of potential geothermal and petroleum prospects within the areas imaged. Secondary goals were to assist the Republic of the Philippines in utilizing state-of-the-art radar remote sensing technology for resource exploration, and to train key Philippines scientists in the use of imaging radar data.

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1 ARCI, 1988, ***Radar Imagery Interpretation to Assess the Hydrocarbon Potential of Four Sites in the Philippines***, ARCI TR 8701-101, Arkansas Research Consultants, Inc., November 17, 1988.

2 ARCI, 1988, ***Radar Imagery Interpretation to Assess the Hydrocarbon Potential of Four Sites in the Philippines: Executive Summary***, ARCI TR 8701-103, Arkansas Research Consultants, Inc., November 17, 1988.

RADAR'S UNIQUE CAPABILITIES

Because radar provides its own source of illumination, radar images can be produced that preferentially highlight geologic structure and surface detail. Radar images so constructed provide unique information about the local geology which may not be available from other sources. Such information is needed in the Republic of the Philippines because although the region has been extensively mapped via conventional techniques, large uncertainties in the petroleum resource potential of the area still exist.

Radar's unique capabilities include:

* All weather, day-night operation
* Control of look direction and look angle for improved geological interpretation
* Wide areal coverage-synoptic view
* High resolution comparable with most remote sensing systems
* Stereo capability allows rapid formulation of geologic models
* Sensitivity to vegetation at shorter wavelengths
* Terrain texture discrimination in non-vegetated regions
* Digital capability for image enhancement and multi-sensor integration
* Radar mosaic provides an accurate base map

DATA ACQUIRED

Radar imagery covering roughly 60,000 km^2 was acquired. These data were collected by Intera Technology, Inc., under subcontract from ARCI. ARCI provided mission planning and quality assurance for the program. Complete stereo coverage of five different regions was acquired. Within these five sites, the following seven different sets of data were collected, including three for geothermal evaluation and four for hydrocarbon interpretation.

Geothermal Sites

* Mt. Apo, Mindanao
* North Negros Island
* South Negros Island

Hydrocarbon Sites

* Bondoc Peninsula
* Cotabato Basin, Mindanao
* Mindoro Island
* Cebu Island

DATA PRODUCED

The final data products were (1) negative film and positive prints of each of 34 flight line strips, (2) computer compatible tapes (CCT) of each image strip, and (3) negative film and positive prints of radar mosaics of four petroleum sites at 1:250,000 scale. The Intera STAR-1 imaging radar system used to acquire these data operated at X-band, HH-polarization, with 12 m resolution. The final data set represents one of the best examples of radar imagery for resource exploration available anywhere.

Interpretive data products produced include (1) geologic maps, (2) lineament maps, and (3) prospect evaluations. Development of geologic maps and prospect evaluations included extensive use of surface and subsurface data furnished by BED and PNOC EC. Thus, the final evaluation is a synthesis of all data available rather than simply that obtainable from the radar imagery itself. This is perhaps the most significant aspect of the program in that it demonstrates the use of radar as a sensor in an integrated program for geothermal and hydrocarbon exploration. The imagery acquired is an excellent source of data that may be used to refine exploration strategy and define areas for more detailed investigation by ground survey and seismic data acquisition. The image analysis shows numerous areas of agreement with prospects developed from other data sources such as field and geophysical surveys. In addition, a considerable number of structures and prospects were discovered, particularly in areas where other data sources were unavailable.

SUMMARY

This synthesis of all available data shows radar imagery to be an excellent survey tool in an integrated multilevel exploration. The radar by itself may be used to guide acquisition of more detailed data and develop a general exploration strategy. Where other survey data such as photography or LANDSAT are available, the unique response and illumination enhancement of surface structure obtainable with radar is seen to provide additional data complementary to other survey imagery.

Important new prospects and prospect areas have been identified which will provide a focus for further follow-up field and geophysical studies.

Faults and fractures that transect a geothermal reservoir may be regarded as channelways or main trunklines of a geothermal plumbing system. Therefore, a clearer picture of the regional fault/fracture patterns provided by radar interpretation could prove useful in determining permeability controls.

Geothermal Prospects

* **Mt. Apo Geothermal Prospect** - Analysis of the radar data has led to identification of a previously unmapped east-trending fault system, and recognition of a dominant east and northwest fault system in the Mt. Talomo region where the faulting was previously believed to be radial.

* **North and South Negros Geothermal Prospects** - Recognition of regional fault patterns mapped from radar will be of significant value in the planning phase for future exploratory drilling.

HIGHLIGHTS

* The radar data and this project have significantly improved the knowledge of stratigraphy and structure, and in many cases have provided data for updating existing geologic maps.

* The radar geologic maps produced, while important by themselves, can be used to complement existing geoscience data and can provide new map products tailored to support exploration activities.

* An important aspect of radar investigations is that reconnaissance radar images facilitate field work in remote and impassable areas.

* The baseline survey and interpretation were conducted at a scale of 1:250,000, but the data support increasing the scale to 1:50,000.

* A training course on radar interpretation and SAR fundamentals has been provided to Philippines geoscientists, and they have become enthusiastic in the potential application of using radar images for this and other important investigations such as land cover mapping (forestry or other vegetation covers), land use mapping, hydrology, and ground-water exploration.

RECOMMENDATIONS

* Because the imaging radar program was designed for hydrocarbon exploration in moderate relief areas, excessive radar shadow occurred in some local areas. Therefore, the Negros and Mt. Apo geothermal sites should be reflown to obtain multiple-look direction radar imagery in order to obtain complete, shadow-free, stereo coverage.

* Additional radar imagery should be acquired over a much larger region of the Philippines, especially within those areas where radar can contribute significant data to the development of an integrated exploration strategy for geothermal resources.

* Radar also should be used to explore for other natural and non-renewable resources, in addition to geothermal potential.

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1 INTRODUCTION

In support of the hydrocarbon exploration program, radar imagery was acquired of four sites in the Philippines (ARCI TR 8701-101, Section 3.3). These sites were selected in coordination with Philippine Bureau of Energy Development (BED) and Philippine National Oil Company Exploration Corporation (PNOC EC) personnel. Site selection was determined from evaluation of the extensive data base of hydrocarbon potential in the Philippines previously assembled by BED and PNOC EC. Selection criteria were not only hydrocarbon potential but regions wherein it was felt the unique perspective of surface structure and features afforded by radar would best complement existing surface and subsurface data. Site selection was limited to a total area of approximately 45,000 km^2. Contract negotiations were then initiated with the firm selected to acquire the imagery, Intera Technologies, Inc. Subsequent to these initial negotiations a request was received from the Philippine representatives that coverage of a few small geothermal sites be included in the program even at the expense of dropping one of the hydrocarbon sites selected. During further contract negotiations Intera agreed to cover three small geothermal sites for the fixed maximum price even though this coverage increased the total area to well beyond 45,000 km^2. It was stipulated these data were also to have complete stereo coverage, however, no mosaics were to be delivered for the geothermal sites. This essentially no-cost addition of coverage was possible at this stage by selecting geothermal sites that could be imaged during the same flights that hydrocarbon site imagery was collected and in some cases by even sharing the same flight lines.

1.1 Background

Extensive geothermal exploration studies have been conducted in the Philippines over the past decade. More than 40 prospective geothermal resource areas have been identified (Figure 1.1). Thirty-one of these areas have been reconnoitered; 16 explored, 11 test drilled, and 4 have been developed with 894 MW(e) total of generating plants now installed and commissioned (Barnett et al., 1984). Geothermal energy constitutes approximately 20% of the country's currently installed power generating capacity.

As a result of the numerous comprehensive geothermal investigations conducted by Philippine geoscientists, a systematic procedure has evolved for the exploration and assessment of Philippine geothermal resources. According to Barnett et al. (1984), this procedure consists of the following stages of sequentially higher level investigation:

* Regional identification of prospective target areas
* Geoscientific surface prospecting methods
* Exploration and delineation well drilling
* Assessment of resource potential.

1.2 Scope

Geothermal areas are normally recognized using the multi-disciplinary integration of data from geological, geochemical, and geophysical investigations. The principal contributions to geothermal exploration provided by geological interpretation of radar imagery might include the recognition of:

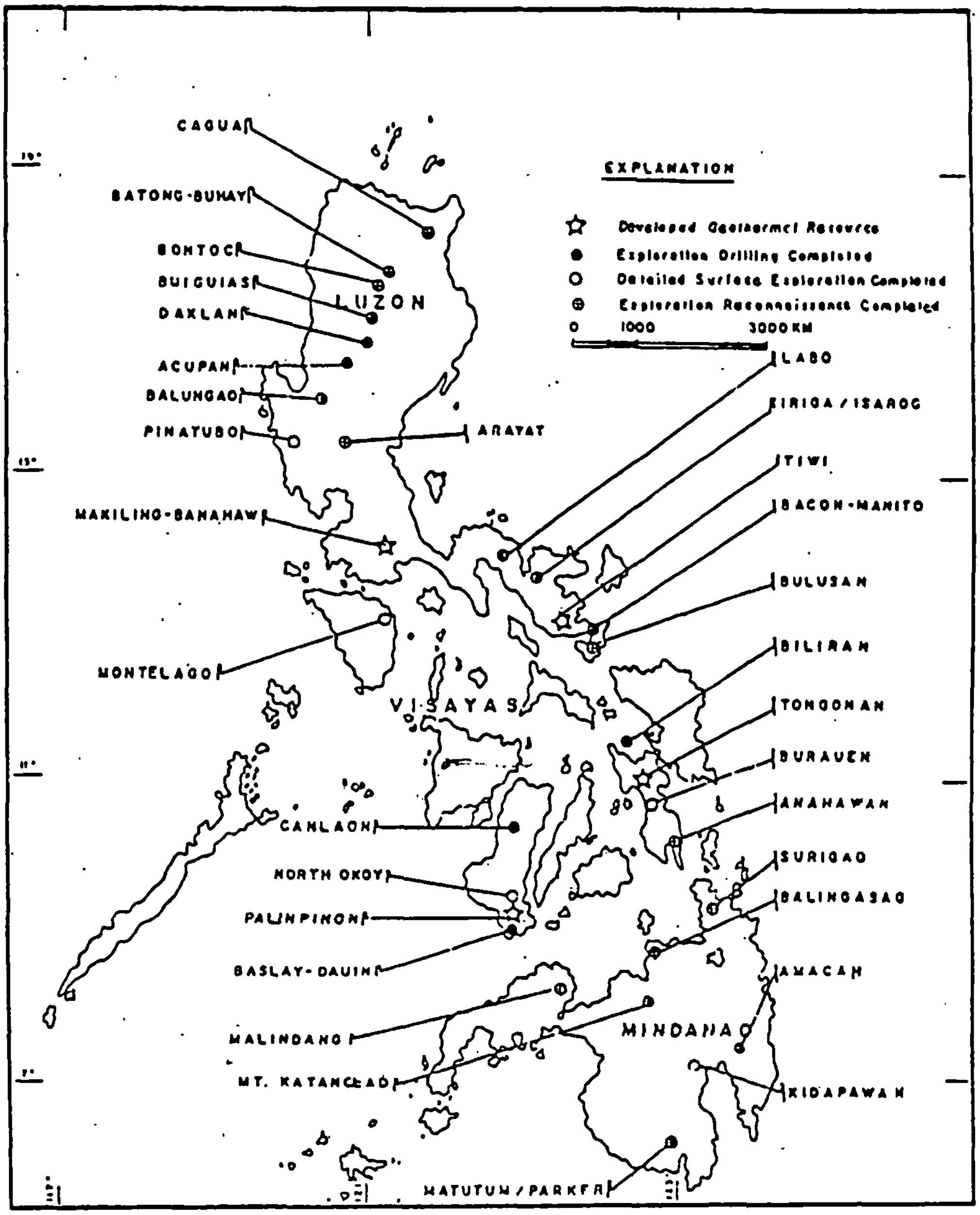

Figure 1.1: Philippine geothermal areas. Areas undergoing exploration and development. (After Barnett et al., 1984).

* Heat Sources: Potential heat sources can be clearly expressed on the radar imagery as recent volcanic piles or more subtly, as circular features suggesting the potential presence of an old caldera feature or incipient igneous intrusion.

* Plumbing Systems: An adequate plumbing system for convective circulation of geothermal energy is very important. Recognition of linear or curvilinear features which might indicate faulting or fracturing could provide potential hydrothermal conduits and reservoir controls.

* Reservoir Rocks: Normal faults and associated graben systems provide a mechanism for down-dropping high permeability and porous sediments. These sediments produce potentially excellent reservoirs for the collection and storage of geothermal waters.

Detailed surface exploration has been completed in the three areas selected for radar coverage. However, the synoptic radar imagery coverage provides geologic information beyond the areas where extensive geologic mapping has been completed, and provides the capability of integrating regional structural/tectonic features with known geologic data.

1.3 Objectives

Faults and fractures that transect a geothermal reservoir are believed to be major contributors to a geothermal's production capability. They may be regarded as channelways or the main trunklines of a geothermal plumbing system. For this reason, a clearer picture of the regional fault/fracture patterns provided by radar interpretation could prove useful in determining permeability controls on fluid upflow, outflow, and surface discharge. Therefore, the objectives of this radar interpretation investigation are to:

* Map the regional fault/fracture patterns

* Determine the significance of the regional fault/fracture pattern when compared with the detailed geologic maps available.

2 RADAR IMAGERY ACQUISITION

The final contract with Intera called for full stereo coverage (55% minimum side-lap) of four hydrocarbon and three geothermal sites at a cost based on 45,000 km^2, even though actual coverage exceeded this amount. The coordinates of the selected sites, both hydrocarbon and geothermal, are listed in Table 2.1. Sketch maps of the geothermal sites (which also include two hydrocarbon sites) are shown in Figures 2.1 and 2.2.

It should be pointed out that the total coverage actually obtained is well beyond simply the total of both the hydrocarbon and geothermal sites. This is due to extent of the flight lines beyond the boundaries of the contracted areas and extra coverage required to provide full stereo side-lap. While much of this additional coverage is monoscopic, it still represents a significant and valuable addition to the total data acquired. Table 2.2 shows the approximate area of each site along with the additional coverage obtained. Note again that the contracted areas represen. complete stereo coverage while much of the additional coverage is monoscopic.

Table 2.1: Site coordinates for Philippine radar survey project.

Hydrocarbon Site 1 - Bondoc Peninsula

Point	Coordinates	Point	Coordinates
1	13°55'N 121°41'E	4	13°13'N 122°45'E
2	13°31'N 122°15'E	5	13°52'N 122°31'E
3	13°08'N 122°35'E	6	14°17'N 121°57'E

Hydrocarbon Site 2 - Cotabatc Basin, Mindanao

Point	Coordinates	Point	Coordinates
1	7°07'N 123°55'E	3	6°22'N 125°42'E
2	5°50'N 125°00'E	4	7°30'N 124°40'E

Hydrocarbon Site 3 - Mindoro

Point	Coordinates	Point	Coordinates
1	13°15'N 120°32'E	4	12°41'N 121°35'E
2	12°11'N 121°00'E	5	13°02'N 121°30'E
3	12°11'N 121°26'E		

Hydrocarbon Site 4 - Cebu

Point	Coordinates	Point	Coordinates
1	11°17'N 123°56'E	5	9°23'N 123°24'E
2	10°30'N 123°41'E	6	10°00'N 123°41'E
3	10°00'N 123°21'E	7	10°26'N 124°04'E
4	9°23'N 123°16'E	8	11°17'N 124°06'E

Geothermal Site A - North Negros

Point	Coordinates	Point	Coordinates
1	10°41'N 123°00'E	3	10°18'N 123°20'E
2	10°18'N 123°00'E	4	10°41'N 123°20'E

Geothermal Site B - South Negros

Point	Coordinates	Point	Coordinates
1	9°30'N 123°00'E	4	9°19'N 123°19'E
2	9°03'N 123°00'E	5	9°30'N 123°11'E
3	9°03'N 123°09'E		

Geothermal Site C - Mt. Apo, Mindanao

Point	Coordinates	Point	Coordinates
1	7°05'41"N 125°04'16"E	3	6°49'26"N 125°21'36"E
2	6°49'26"N 125°04'16"E	4	7°05'41"N 125°21'36"E

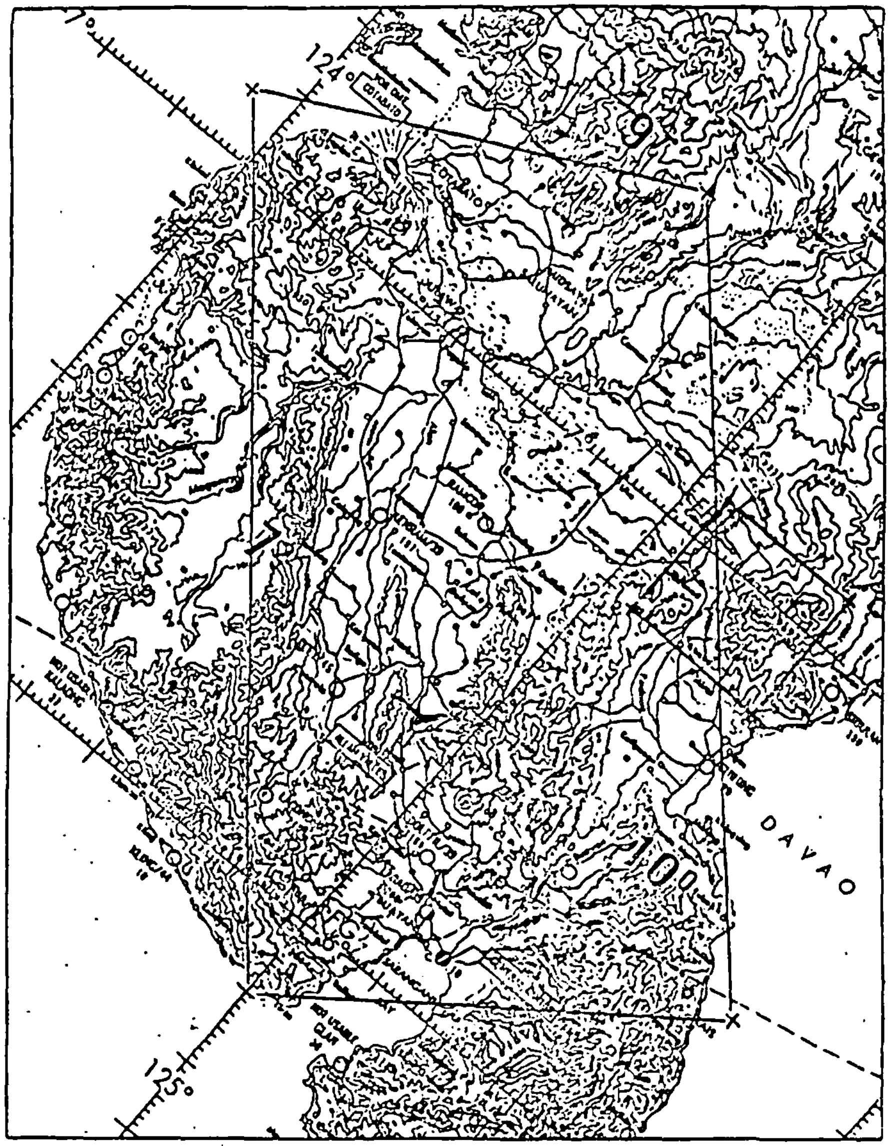

Figure 2.1: Cotabato Basin. Mindanao hydrocarbon site and Mt. Apo geothermal site.

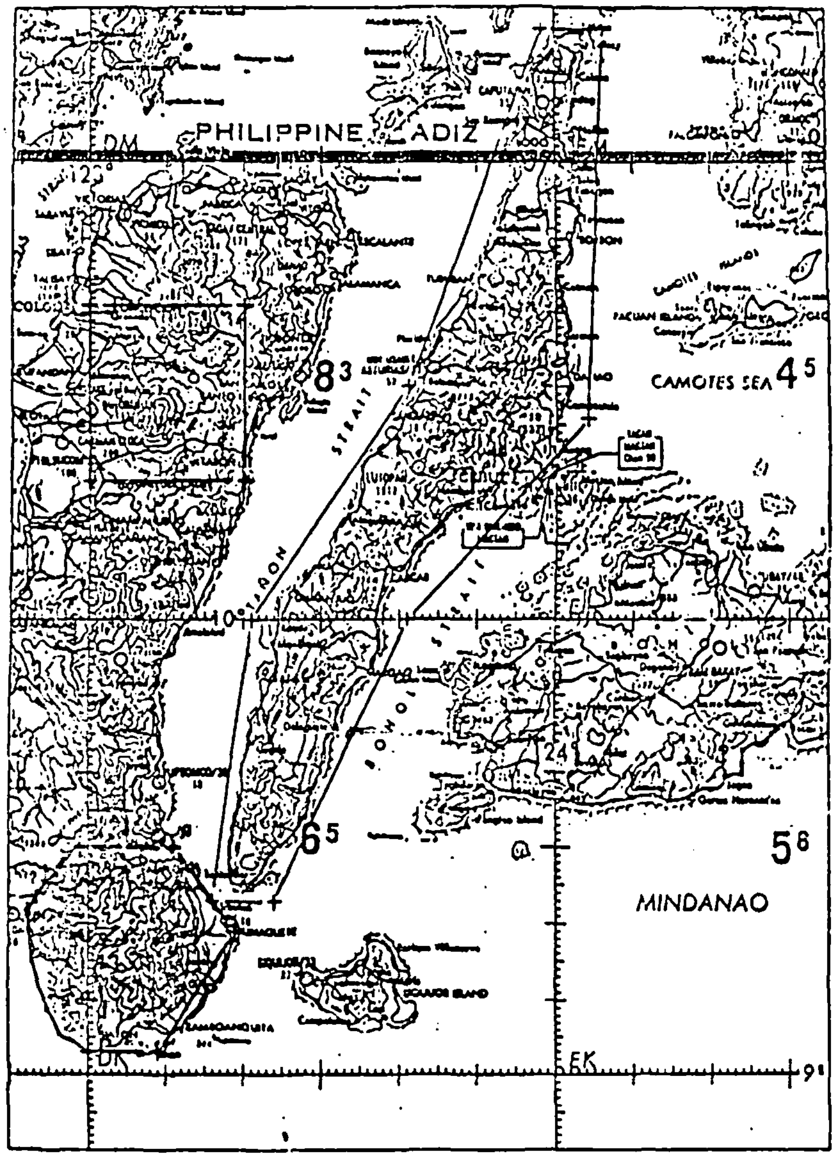

Figure 2.2: Cebu and Negros sites. Cebu hydrocarbon site, and North and South Negros geothermal sites.

Table 2.2: Coverage for Philippines radar survey project.

HYDROCARBON SITES

Site	Contract (km²)	Area Additional (km²)	Total (km²)
Bondoc Peninsula	6,250	2,010	8,260
Cotabato Basin, Mindanao	19,000	3,265	22,265
Mindoro	11,500	2,100	13,600
Cebu	7,525	400	7,925
Subtotal	44,275	7,775	52,050

GEOTHERMAL SITES

North Negros	1,325	2,600	3,925
South Negros	1,570	930	2,500
Mt. Apo	715	1,735	2,450
Subtotal	3,610	5,265	8,875
GRAND TOTAL	47,885	13,040	60,925

3 NORTH AND SOUTH NEGROS GEOTHERMAL SITES

The background geologic information in this section has been summarized from reports provided by the Philippine National Oil Company - Energy Development Corporation (PNOC-EDC) including; Alcaraz (1984), Alincastre (1983), Harper and Arevalo (1983), and Seatres (1982). Four geologic-related maps (scale 1:50,000) were also provided:

* North Negros - Structural/Geologic Map, Northern Geothermal Prospect, Mambucal Negros Occidental, PNOC-EDC, 1984
* Southern Negros - Geologic Map of North Okoy and Structural Alteration Map of Palinpinon and Baslay-Dauin, PNOC-EDC, 1984
* Lithologic Map - Southern Negros Geothermal Project, PNOC-EDC, 1984
* Fracture System(s) Map - Southern Negros Geothermal Project, PNOC-EDC, 1984.

Negros Island is situated in the western region of the Visayan group of islands and is bounded on the east by Tanon Strait, Guimaras Strait on the west; Visayan Sea on the north and Sulu Sea on the south (Figure 3.1). Generally, Negros Island is underlain by undifferentiated pre-Tertiary rocks consisting mainly of graywackes and meta-volcanics which are believed to be the basement rock (Alincastre, 1983). Extensive exposures of these rocks can be found on the southwestern part of the island. These pre-Tertiary rocks are overlain by a thick sequence of Tertiary to Quaternary sedimentary rocks intercalated by volcanics of andesitic, basaltic and dacitic composition. The sedimentary formations are composed of limestone and sedimentary clastics which comprise the eastern cordillera. Neogene intrusives, generally quartz diorite occur on the southwestern part of the island. These intrusives are probably responsible for the emplacement of copper porphyry deposits which are presently mined in the area. Alincastre (1983) provided a generalized geology map of Negros Island; reproduced as Figure 3.2.

The Island is further characterized by several dormant, and an active, volcanic centers; Mount Mandalagan, Mount Silay and Canlaon Volcano (active) on the north and the coalescing volcanos of Cuernos de Negros, Guinsayawan, and Guintabon in the south (Figure 3.2).

3.1 North Negros Prospect

The prospect area (approximately 1100 km^2) is characterized by moderately sloping topography which rises abruptly in the vicinity of Mt. Canlaon (2455 m), an active volcano. Towards the north-northeast the topography is dominated by two extinct, deeply dissected volcanic centers; Mt. Mandalagan and Mt. Silay (Figure 3.2). Geologic structures in the area such as volcanos and volcanic lineaments, collapse features, fractures and joints, and faults were mapped by Alincastre (1983) and are illustrated in Figure 3.3.

In 1982, a detailed geologic survey was conducted in a 278 km^2 area of the Northern Negros Geothermal Prospect (Alincastre, 1983). The investigation focused on three previously defined, low resistivity anomalies in the Saray, Mambucal, and Hagdan areas (Figure 3.3). Thermal features (manifestations) such as hot/warm springs, altered ground, and gas seepages were mapped (Figure 3.4). Alincastre (1983) conc'uded that the presence of the Saray volcanic plug, north of Mt. Canlaon suggests that a heat source at Mambucal, Saray and Hagdan areas is closely related to the Saray plug rather than the active Canlaon crater. He also reported that no fault of major extent was encountered in the area. However, the thermal manifestations in the Mambucal, Saray, and Hagoan areas are probably related to radial fractures or old structures buried by recent volcanism.

3.__.1 Image Analysis

The Northern Negros Geothermal Prospect, as outlined on the generalized geologic map (Figure 3.3), has been positioned on part of a radar imagery strip (Figure 3.5). For viewing purposes, and to avoid topographic inversion, the radar imagery has been rotated counter clockwise 90 degrees. Figure 3.6 shows the radar coverage of the Northern Negros Geothermal Prospect area (Figure 3.1), and has been used for illustration purposes even though considerable radar shadowing occurs in the Mt. Canlaon area.

Monoscopic and stereoscopic analysis of the imagery has allowed highlighting of numerous faults and fault patterns (Figure 3.7). In the vicinity of Mt. Canlaon and Mt. Mandalagan the dominant fault patterns are oriented in northeast-southwest and northwest-southeast directions. A highly conspicuous northwest-southeast trending fault separates the Mt. Canlaon and Mt. Mandalagan geothermal areas, and coincides with the channel of the Bago River. A similar fault separates the Mt. Mandalagan and Mt. Silay geothermal areas.

A high concentration of less regionally extensive faulting occurs on the northeastern slope of the Canlaon geothermal area. This intersecting network of closely spaced small scale fractures clearly suggests a zone of structural weakness. The sloping surface in this area appears extremely rough on radar imagery due to the presence of numerous highly dissected fault scarps. The absence of the characteristic volcanic flow features and high drainage density suggests the presence of a well consolidated lithologic unit.

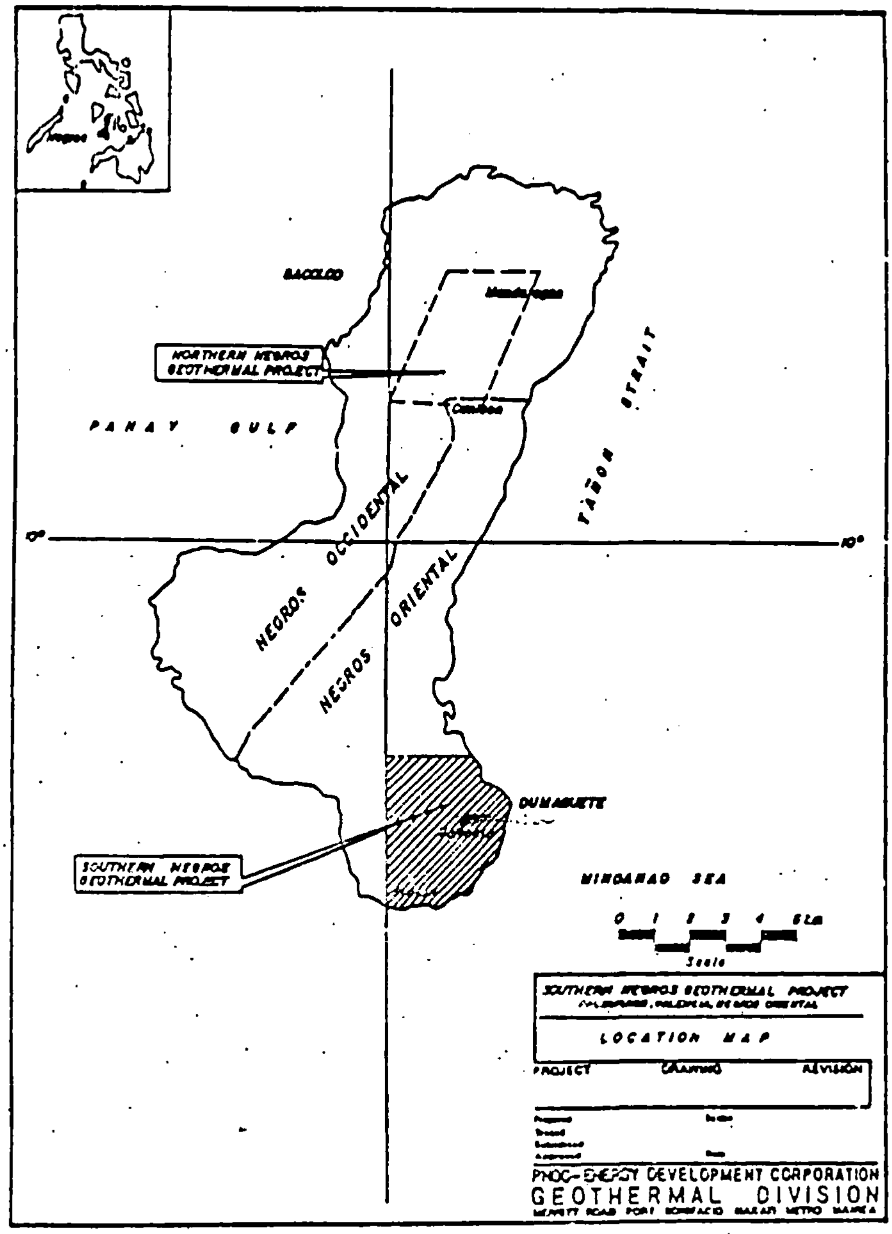

Figure 3.1: Location map. (After Alincastre, 1983).

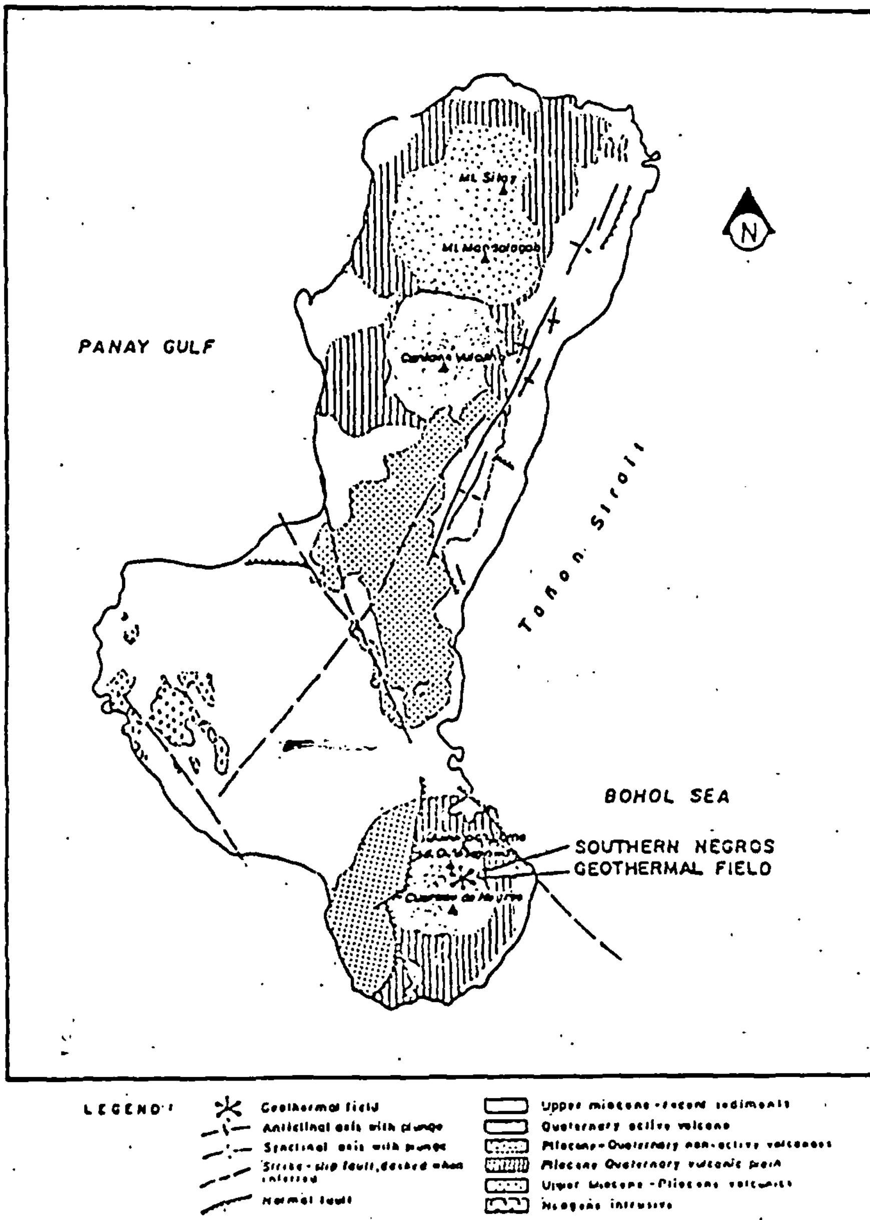

Figure 3.2: Map of Negros Island. Map shows generalized geology and structures. (After Alincastre, 1983).

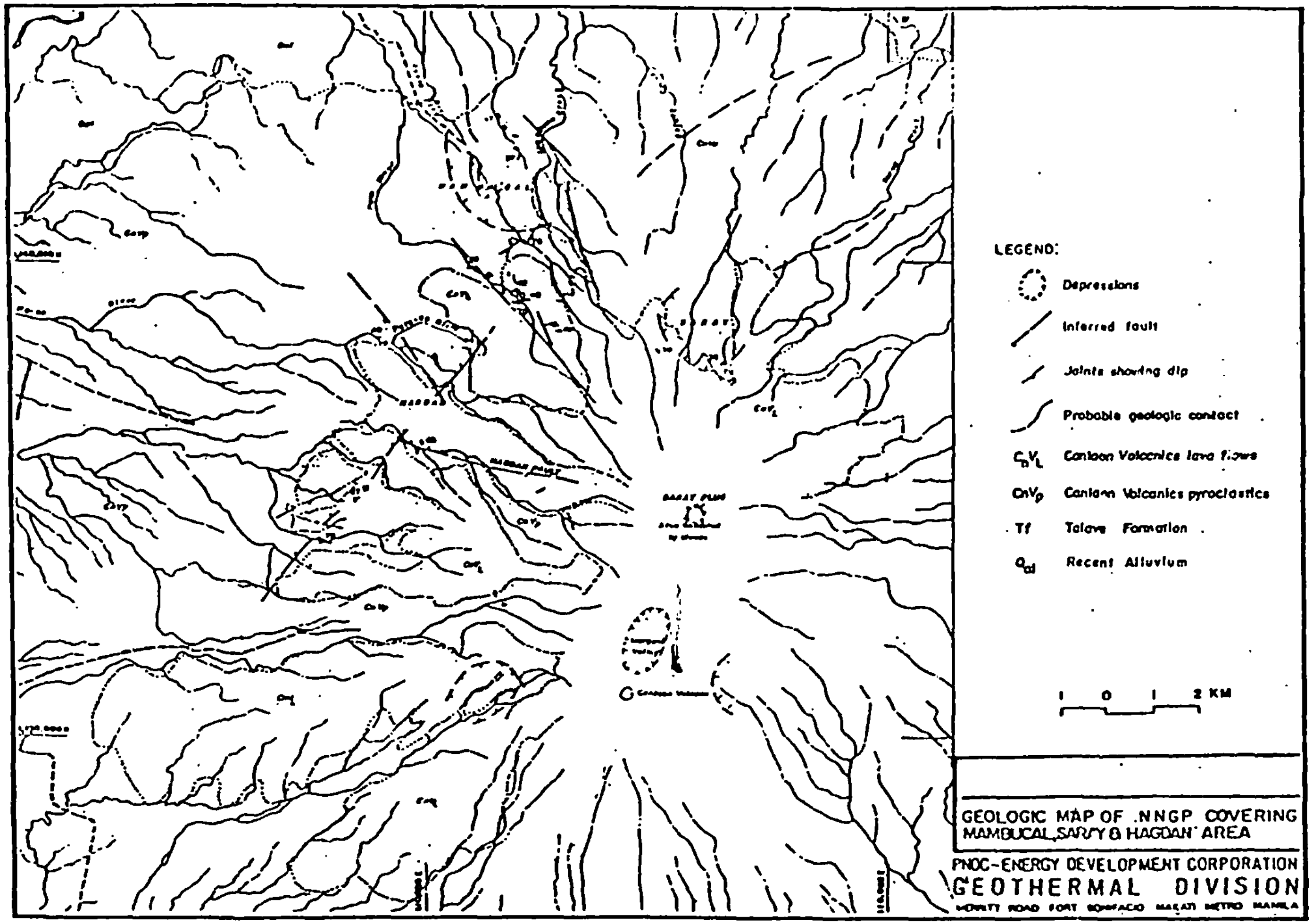

Figure 3.3: Geologic map of northern Negros prospect. (After Alincastre, 1983).

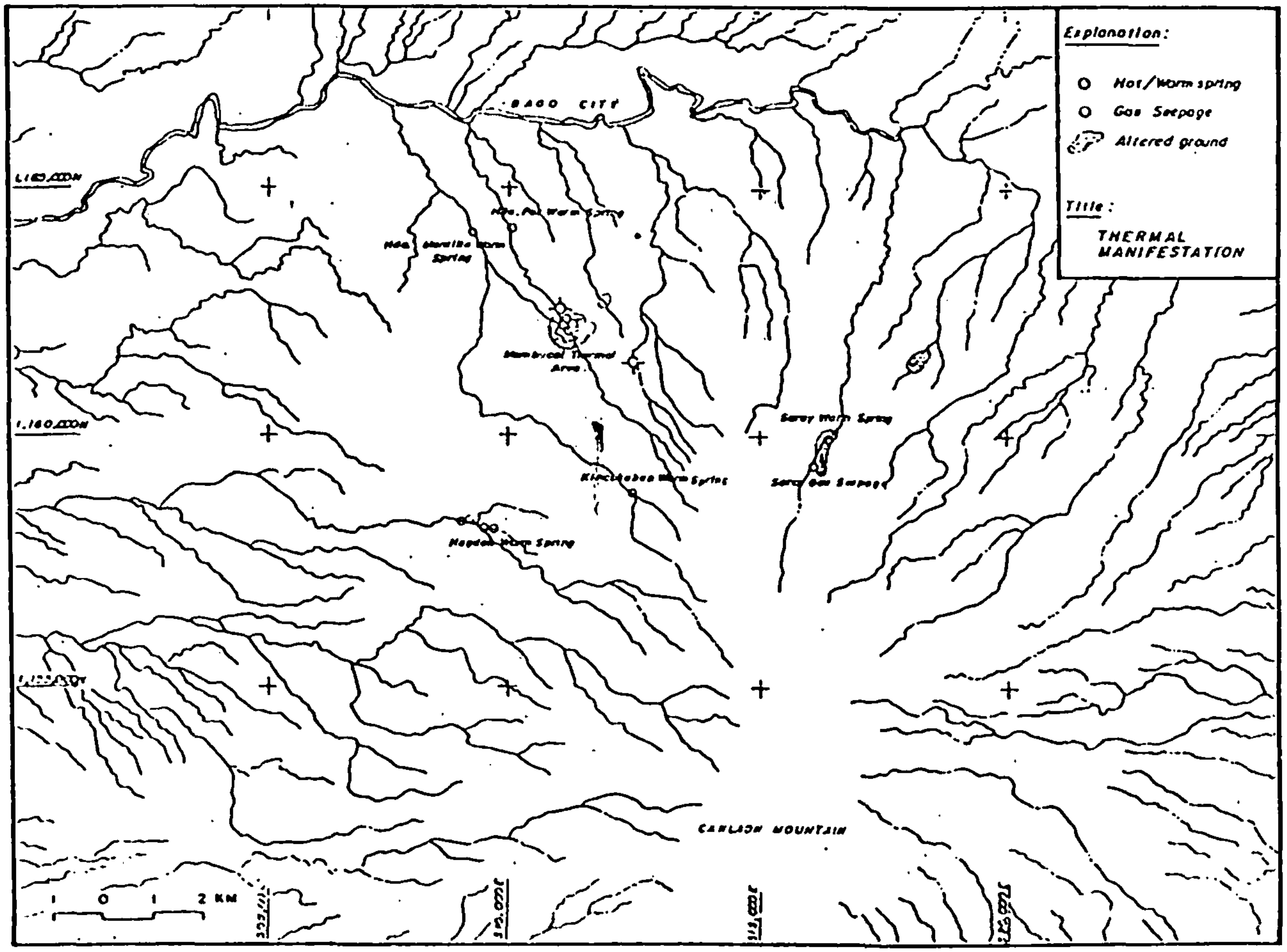

Figure 3.4: Thermal manifestations. (After Alincastre, 1983).

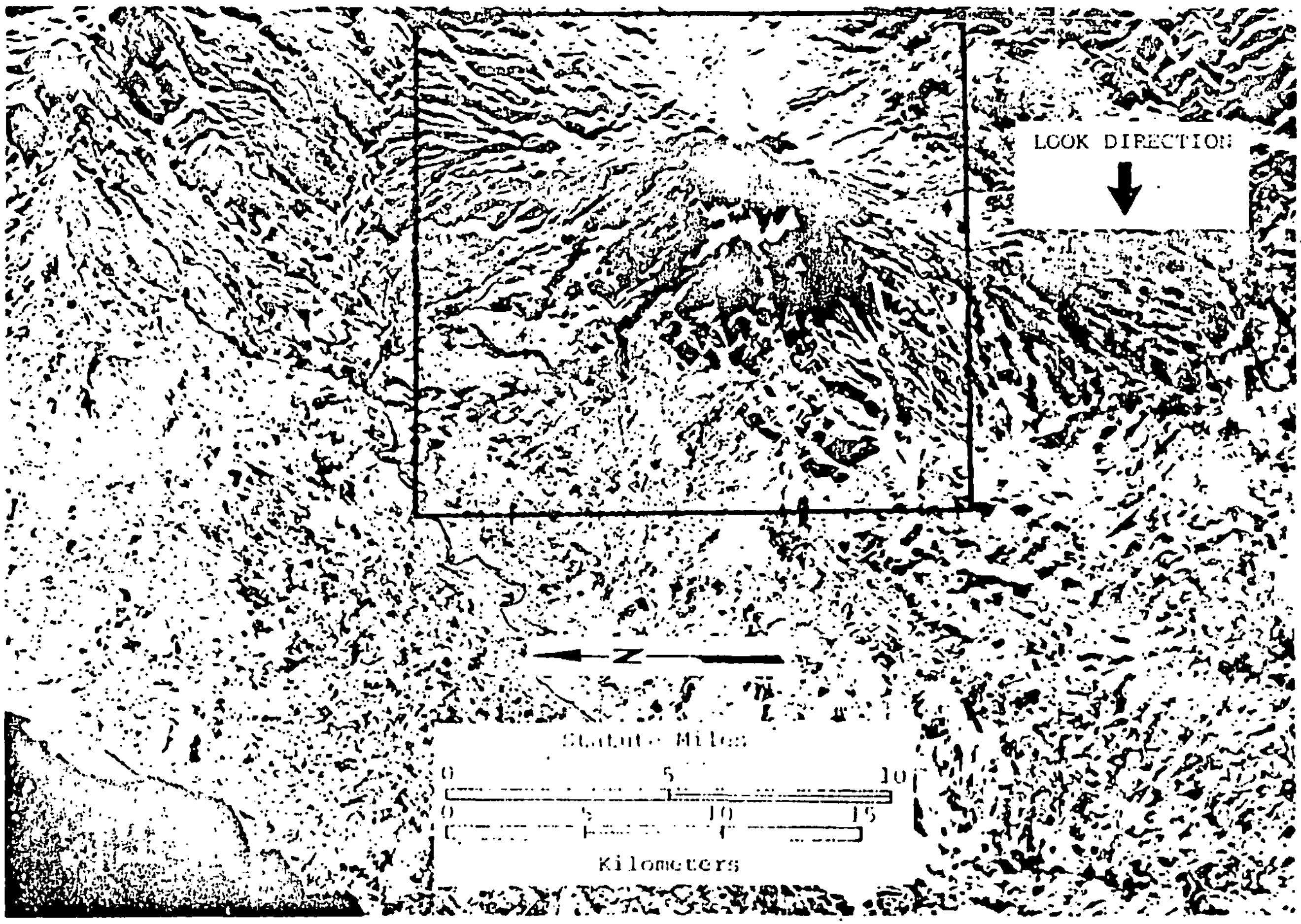

Figure 3.5: Radar imagery of Northern Negros. Radar strip of the Northern Negros Geothermal Prospect shows the outline of Figure 3.3.

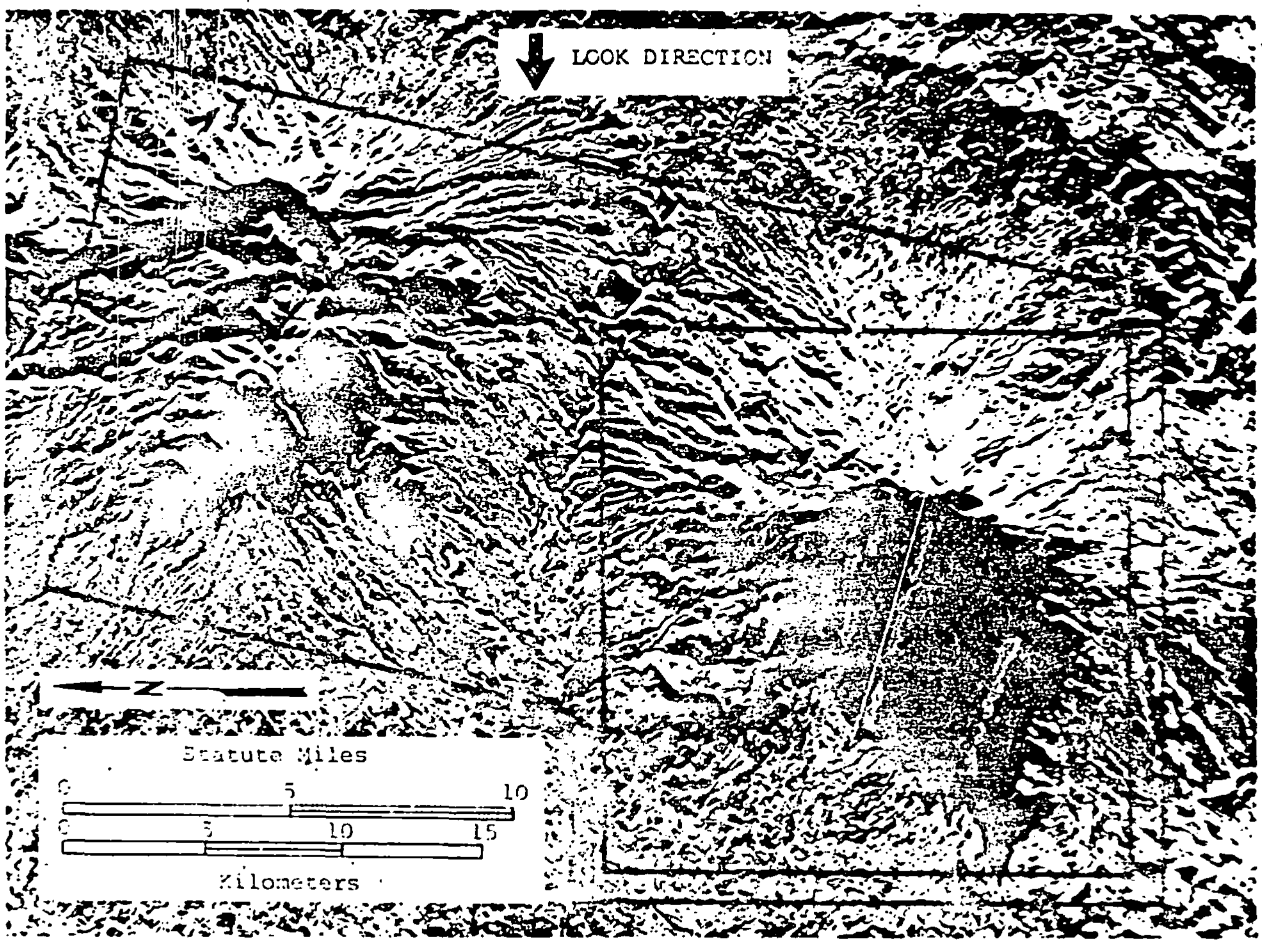

Figure 3.6: Radar coverage of Northern Negros. Geothermal prospect area is shown.

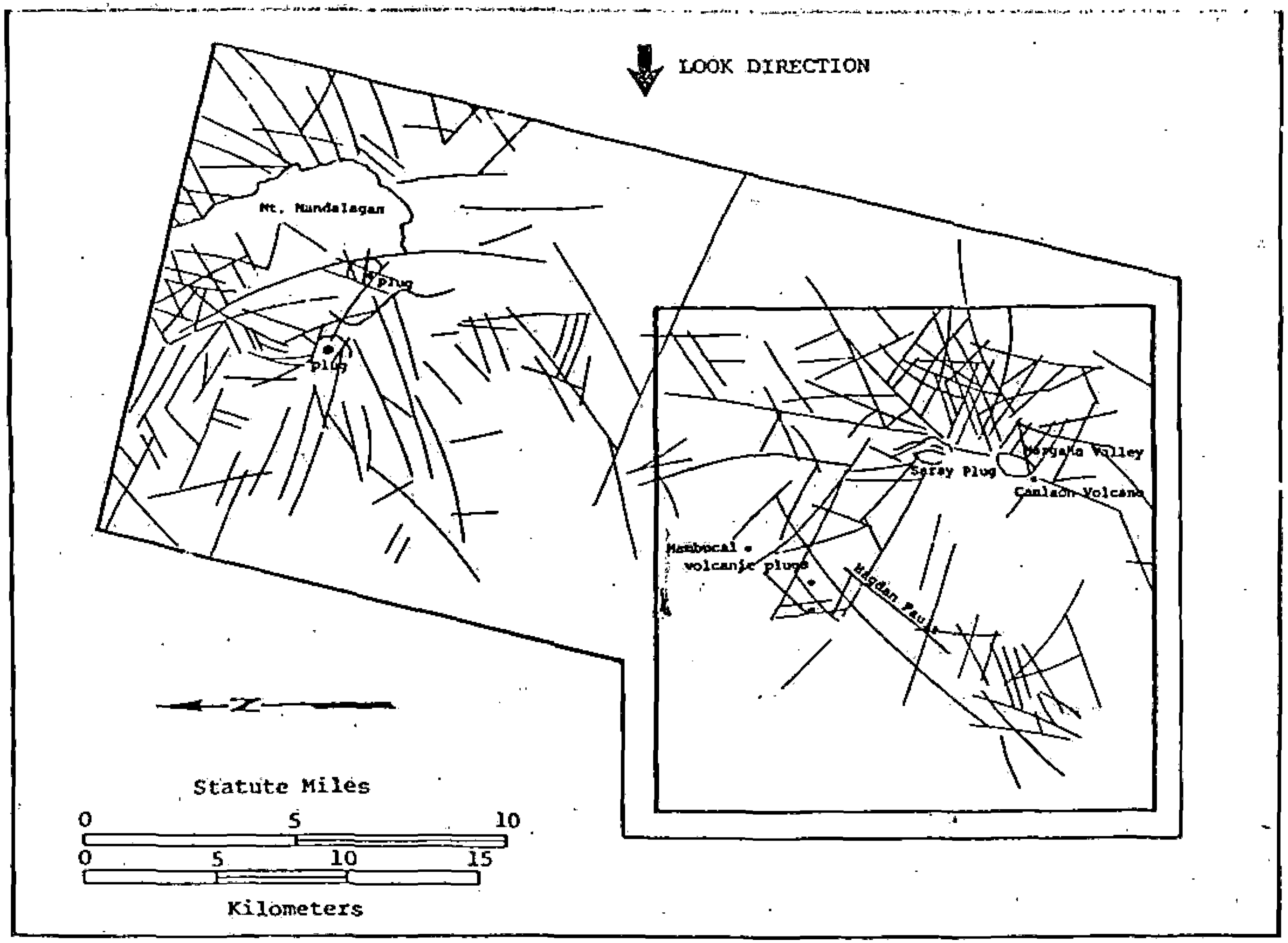

Figure 3.7: Fault interpretation of Northern Negros. Interpretation of the geothermal prospect is shown.

Volcanic features that can be identified on radar imagery of the Mt. Canlaon region include:

(1) The active Canlaon Volcano

(2) An older inactive crater located due north of the Canlaon Volcano which now forms the Mangaha Valley depression

(3) The Saray Plug and Saray depression

(4) Several small volcanic plugs and an associated field of recent lava flows in the Mambucal area

The Mt. Mandalagan structural style is dominated by a large highly dissected crater. The eastern rim of this feature is defined by a steeply dipping curvilinear escarpment which causes prominent radar shadow in the backslope region. Other volcanic structures identified in this area include:

(1) A small volcanic plug and associated area of recent lava located in the central to western region of the crater

(2) A larger elevated plug and peripheral rim structure located on the western slope of the Mt. Mandalagan geothermal area

As previously mentioned, the Mt. Mandalagan area is highly dissected by faults and drainage channels. Major faults transect crater walls and intersect in the central and west central region of the crater. Less regionally extensive faulting is prevalent throughout the area. The highest concentration of faults occurs a small distance west of the Napilas River in the northern region of the Mt. Mandalagan area.

The use of radar imagery has increased the amount of available geologic information in the Mt. Canlaon and Mt. Mandalagan areas. A number of faults have been inferred in the vicinity of the Saray Plug; however, detailed field work may be necessary to confirm these features.

Areas of radar shadow, caused by the steeply dipping, high relief volcanic features, can result in loss of interpretive data. This problem was partially resolved by using an image which provided an alternative viewing perspective, created by a change in the flight path of the aircraft (Figure 3.5).

3.2 South Negros Prospect

The Southern Negros Geothermal Reservation includes an area of approximately 1300 km^2. The South Negros geothermal field (Figure 3.8) encompasses the sectors of Puhagan and Nasuji - Sonongon (Seastres, 1982). Production of geothermal fluids in the Puhagan sector comes from four sources: (1) intraformational permeability, (2) lithologic contacts, (3) fractures induced by intrusive bodies, and (4) faults (Alcaraz, 1984). These fluids are now used to generate 112.5 MW(e) of electrical power from the area.

A structural map of the Southern Negros geothermal field was presented by Alcaraz (1984), and is shown in Figure 3.9. Detailed geologic information for the Southern Negros Geothermal Reservation area, compiled from field surveys, photo interpretation and a synthesis of previous reports is provided on the three PNOC-EDC (1984) maps listed in Section 3.

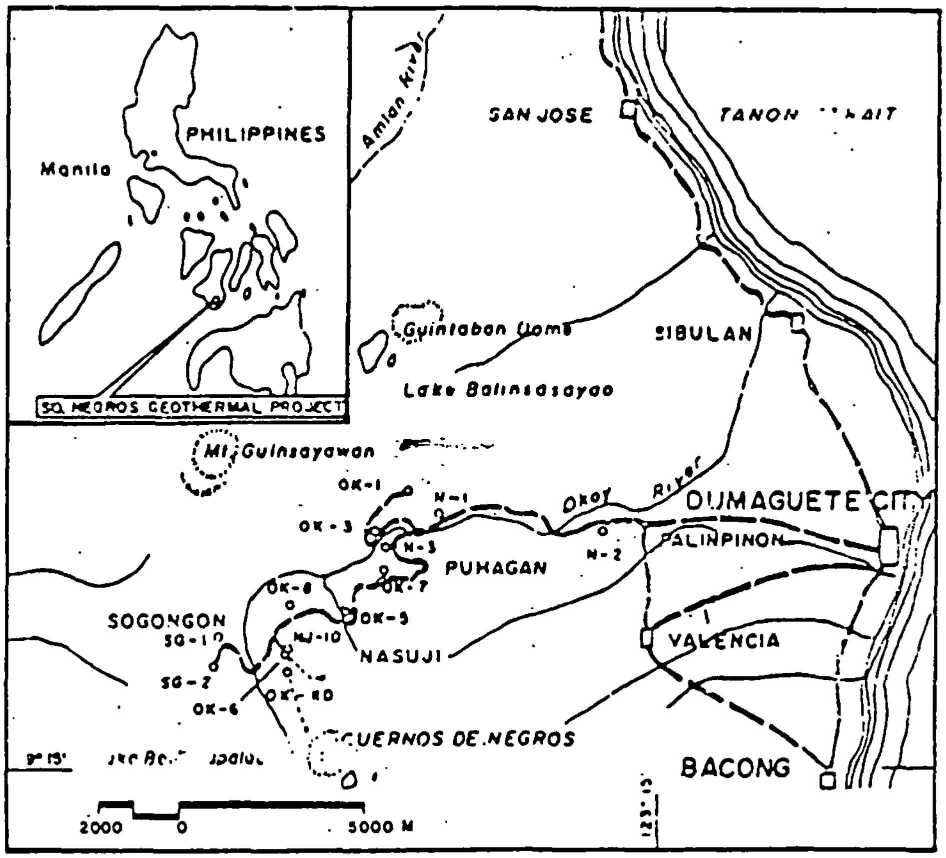

Figure 3.8: South Negros geothermal field. Location of drilled test wells is shown. (After Seastres, 1982).

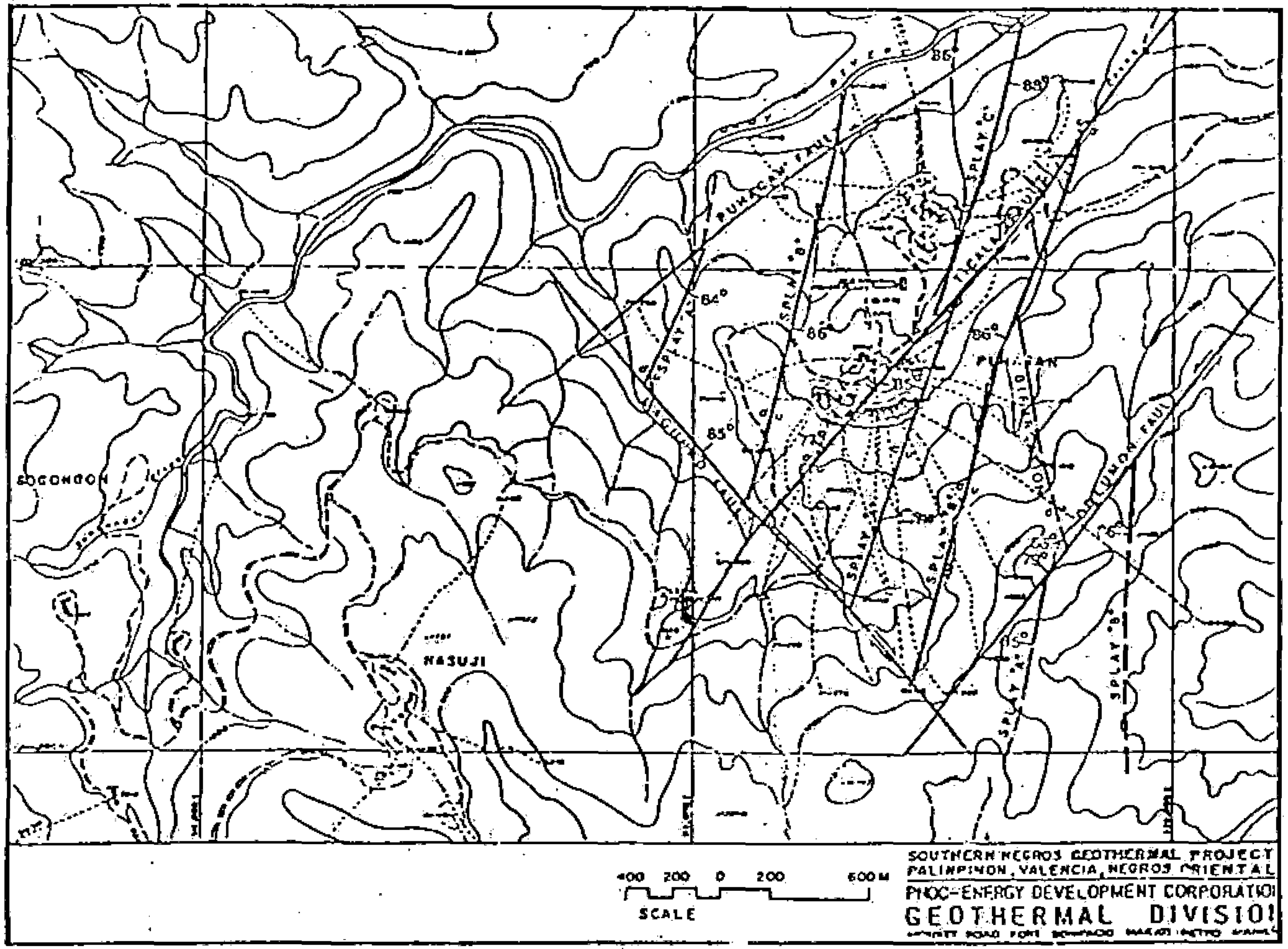

Figure 3.9: Fault systems of South Negros. Puhagan area, South Negros geothermal field, is shown. (After Alcaraz, 1984).

3.2.1 Image Analysis

The South Negros Geothermal Project area, as outlined on the generalized geologic map (Figure 3.10) has been located on a radar imagery strip (Figure 3.11). For viewing purposes, the imagery has been rotated counter clockwise approximately 135 degrees to avoid topographic inversion. Monoscopic and stereoscopic analysis of the imagery has allowed for the inference of many faults and fault patterns (Figure 3.12).

Faults in the South Negros Geothermal Project area appear to have two dominant orientations:

(1) A northwest-southeast trending group that includes the Okoy, Manguto, and Cainawan Faults and several radar-inferred faults

(2) A northeast-southwest trending group that includes the Nagambi, Ticala, Malaunay, and Siaton Faults and additional radar-inferred faults.

Other less dominant faults are oriented in a north-south direction parallel to the trend of the major volcanic features. These faults are in general only locally expressed and occur near collapse features. High concentrations of small scale fractures are located on the eastern slope of Mt. Guinsayawan and in the large depression to the southeast of Cuernos de Negros.

The regional structural style of the South Negros Geothermal Project area appears to be dominated by the northwest-southeast trending fault pattern. This fault pattern can be easily identified on radar imagery in locations outside the project area to the west and northwest. Several of the major faults extend outside the project area boundaries to the east, forming an area of rugged topographic relief.

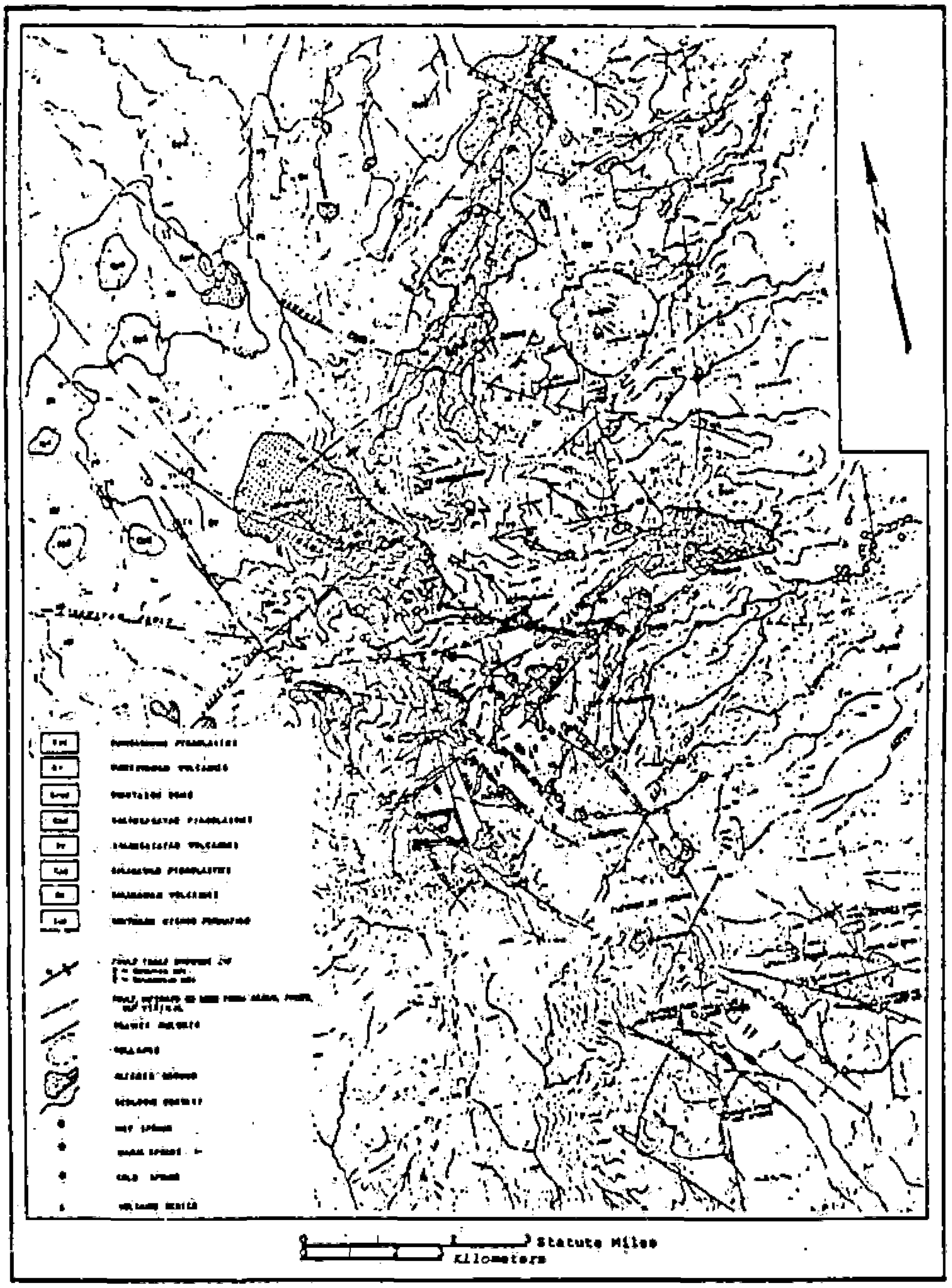

Figure 3.10: Generalized geologic map of South Negros. Geothermal Prospect area is shown. (After PNOC EC, 1984).

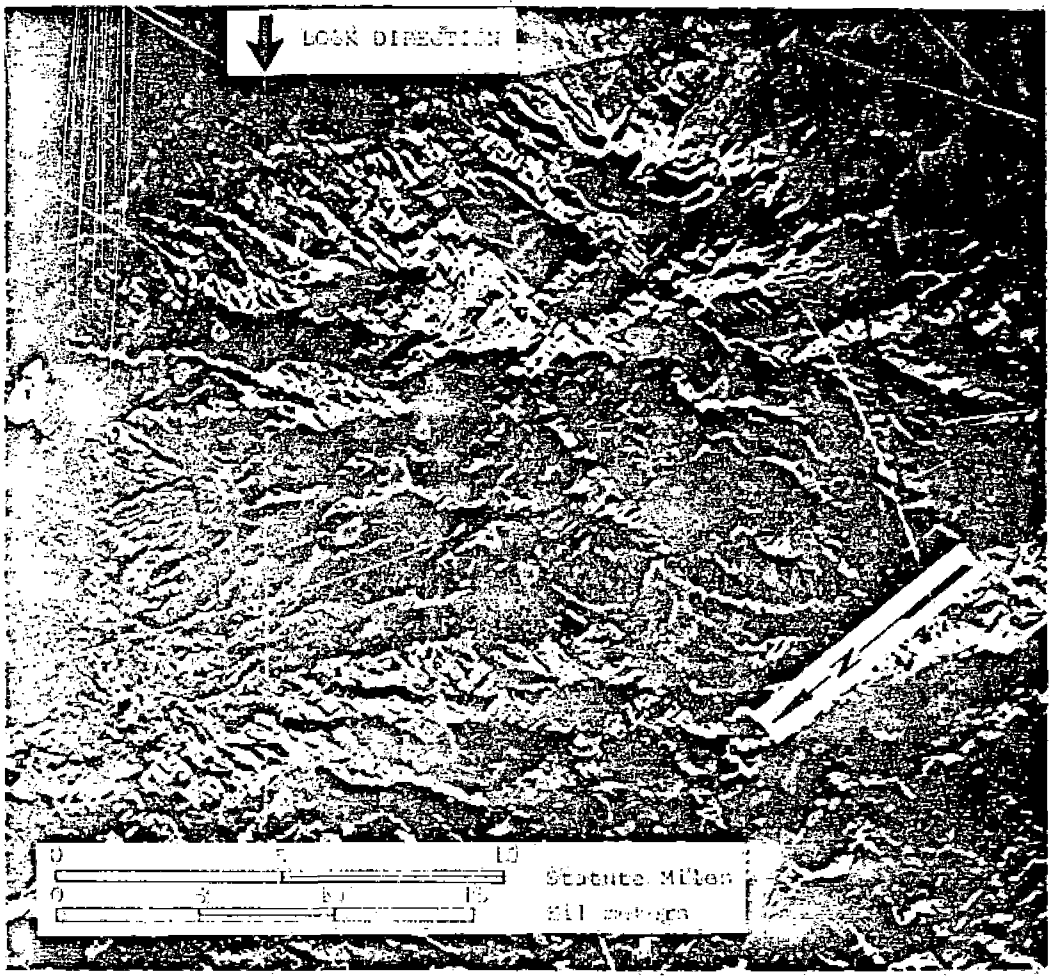

Figure 3.11: Radar coverage of South Negros. Geothermal Prospect area is shown.

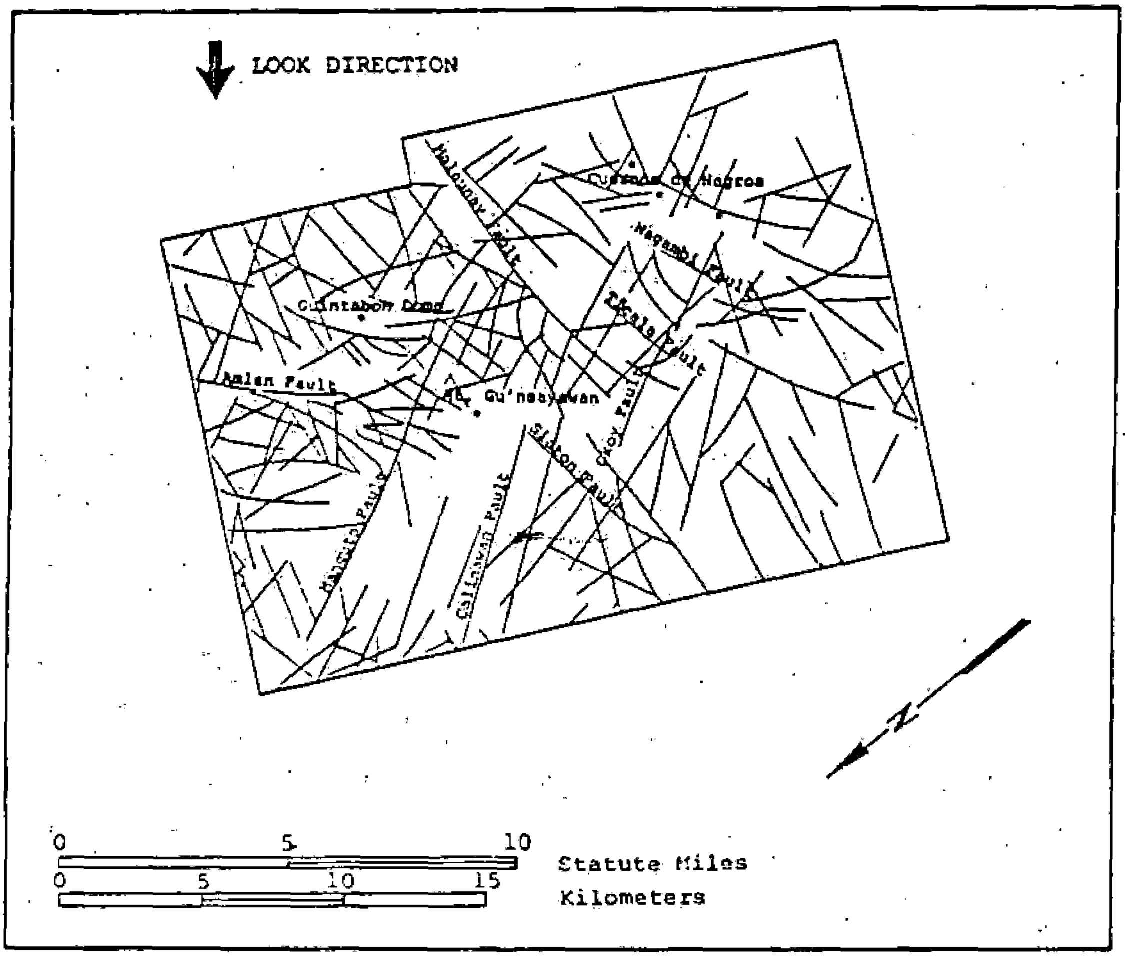

Figure 3.12: Fault interpretation of South Negros. Geothermal Prospect area is shown.

4 MT. APO GEOTHERMAL SITE

The background geologic information in this section has been summarized from a report provided by PNOC-EDC, and compiled by Deflin and Castro (1984). Two geologic-related maps were also provided: (1) Mt. Apo Geothermal Prospect - Kidapawan, North Cotabato Mindanao, PNOC-EDC 1987, Scale 1:50,000, and (2) Mt. Apo Geothermal Prospect - Province of Cotabato and Darao, PNOC-EDC 1984, Scale 1:20,000.

Mt. Apo, located in southcentral Mindanao approximately 40 km west of Darao City (Figure 4.1), is the Philippines' highest peak with an elevation of 2954 m. Since March 1983, PNOC-EDC has conducted an integrated geoscientific investigation in the area in order to assess Mt. Apo's geothermal potential and locate the most promising areas for deep drilling and development (Deflin and Castro, 1984).

4.1 Summary of Available Geological Information

The Mt. Apo volcanic field is part of a north-south trending chain of late Tertiary-Quaternary composite volcanos. This range separates the Agusan - Darao trough on the east from the Cotabato basin to the west. Mt. Apo and two other major composite volcanos (Mt. Sibulan and Mt. Talomo) within the geothermal prospect area have probable Pliocene to Quaternary age volcanics on their flanks. The Sibulan volcanics are believed to be oldest, the Talomo volcanics intermediate, and the Apo volcanics youngest in age.

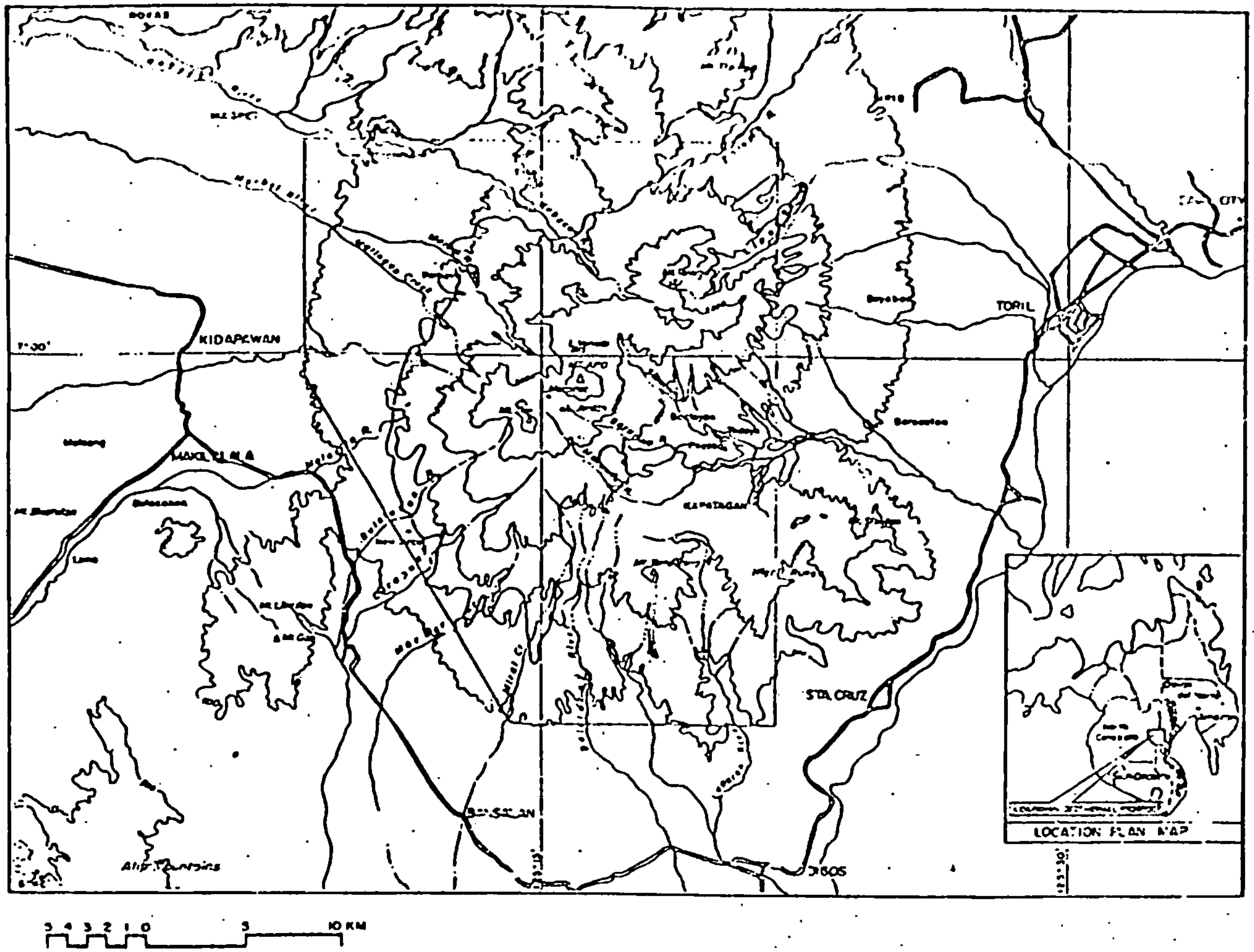

Figure 4.1: Mt. Apo Geothermal Prospect. (After Deflin and Castro, 1984).

According to Deflin and Castro (1984), faults in the area (Figure 4.2) can be grouped into three general orientations: (1) a broad and dominant northwest system containing one or more sets with strikes between 110°-160°, (2) a northeast system that trends between 20°-50°, and (3) a north-south system striking 170°-180°. In the vicinity of Mt. Apo, the dominant structural grain is WNW (300°-320°) whereas near Mt. Talamo the faults have a radial pattern. The Marbel Fault Zone, located northwest of Mt. Apo (Figure 4.2) has several thermal manifestations (steaming springs and grounds) along or near the trace of the fault zone indicating that this zone of weakness acts as an important conduit for hot fluids.

4.2 Image Analysis

The Mt. Apo Geothermal Prospect, as outlined on the generalized geologic map (Figure 4.2), has been located on the radar imagery (Figure 4.3). For viewing purposes, the imagery was rotated clockwise approximately 135 degrees to avoid topographic inversion. Monoscopic and stereoscopic analysis of the imagery has allowed for the inference of many faults and fault patterns (Figure 4.4).

Faults in the Mt. Apo area appear to have four general orientations:

(1) A northwest-southeast trending group that includes the Marbel and Kabacan Fault Zones and several radar-inferred faults of regional extent

(2) A north-south to northwest-southeast trending group that occurs predominantly in the central region of the geothermal area and intersects volcanic centers

(3) A group of east-west trending major faults which extend over 7 miles (11.2 km) in length

(4) A less dominant northeast-southwest trend

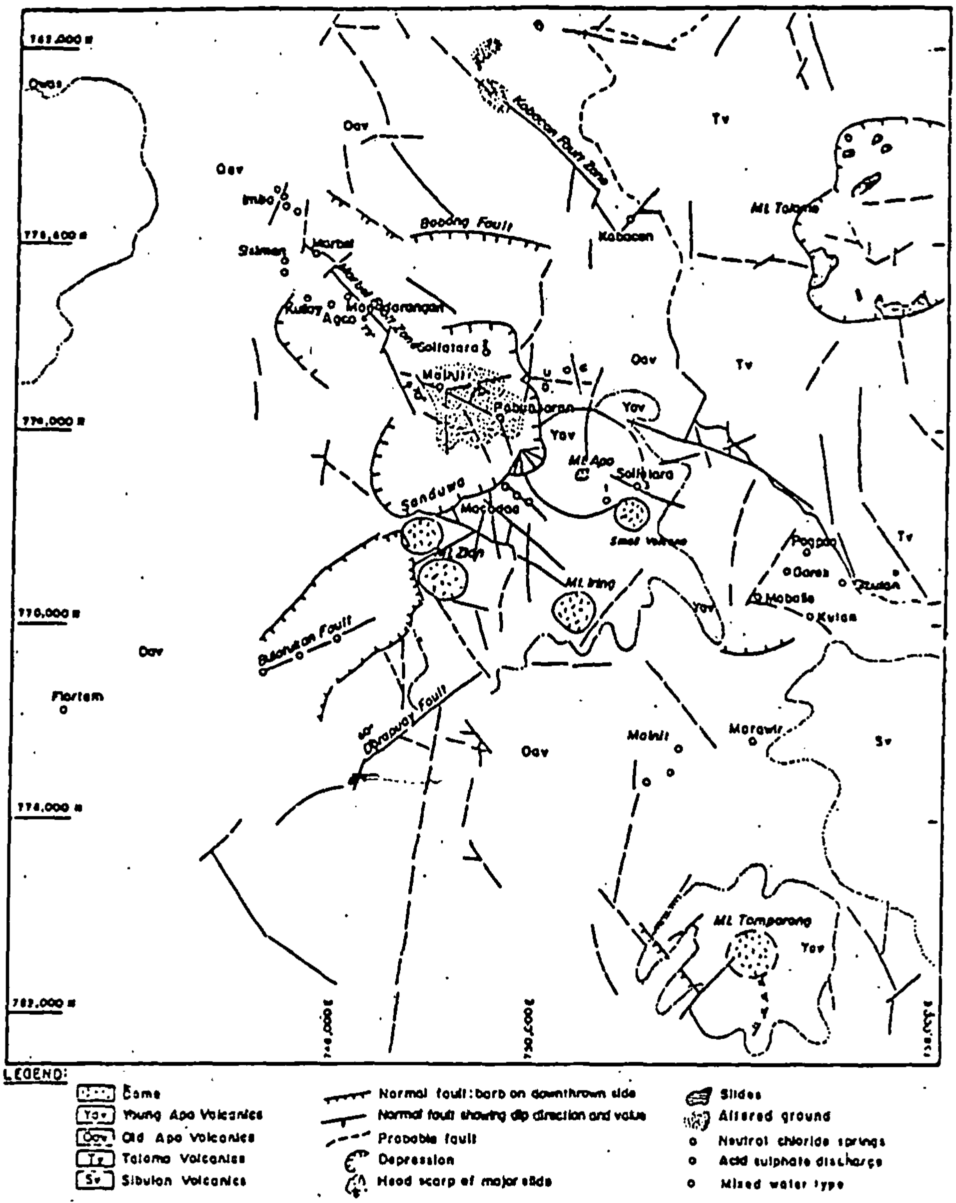

Figure 4.2: Generalized geologic map of the Mt. Apo area. Geothermal Prospect area is shown. (After Deflin and Castro, 1984).

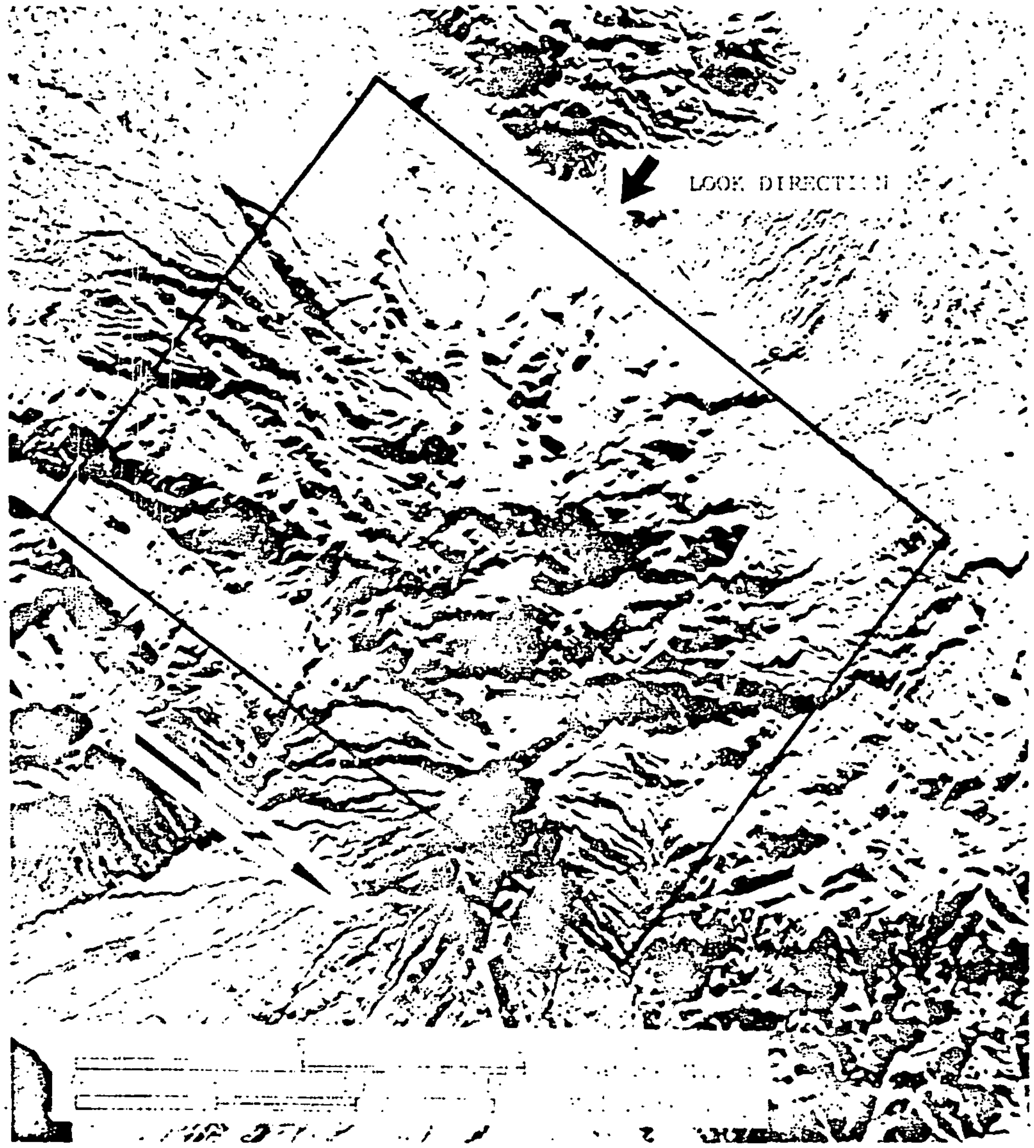

Figure 4.3: Radar coverage of the Mt. Apo Geothermal Prospect.

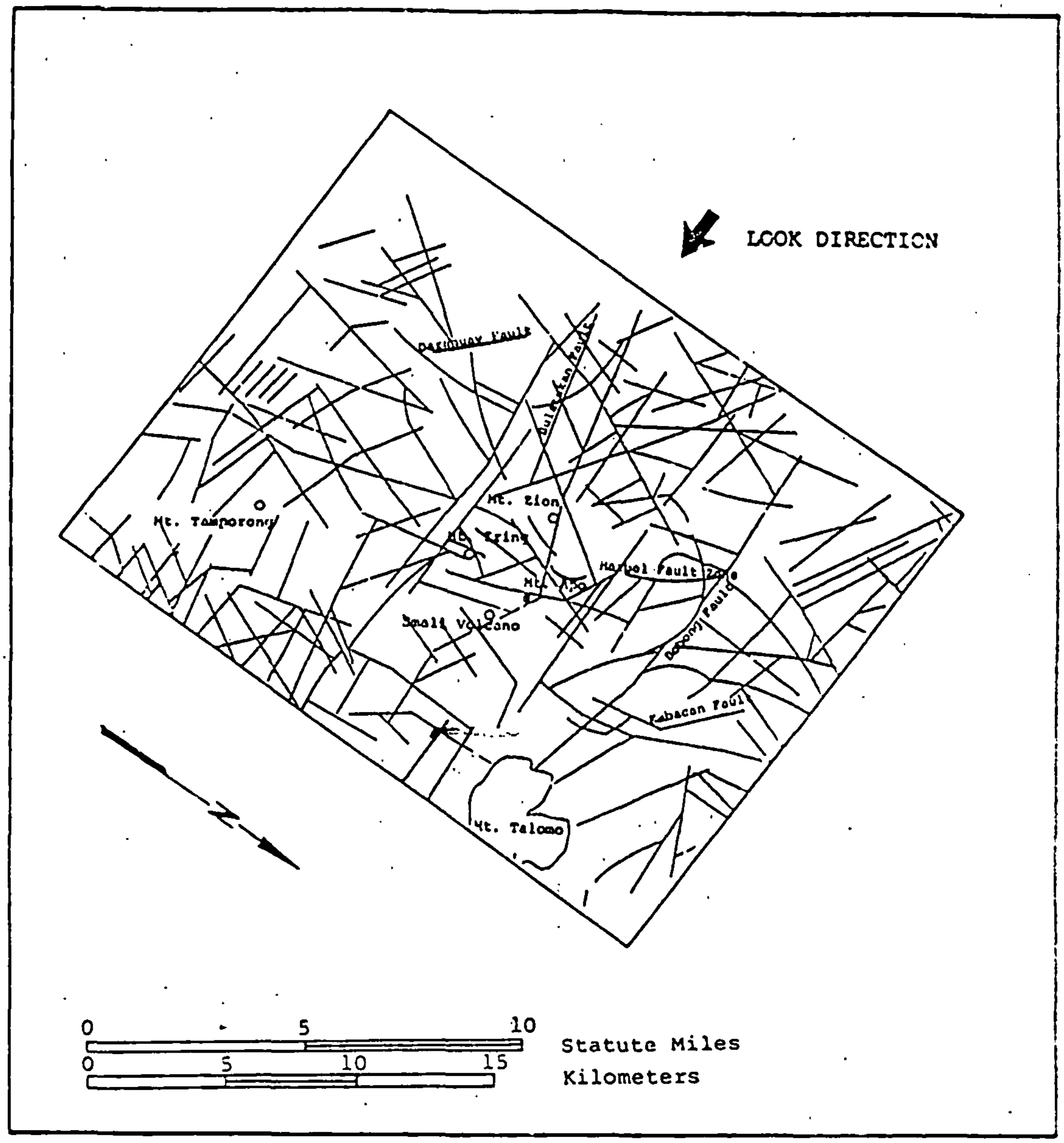

Figure 4.4: Fault interpretation of the Mt. Apo area. Geothermal Prospect area is shown.

Fault patterns in the Mt. Apo Geothermal Prospect area can be classified into two general categories. Linear to curvilinear faults that trend perpendicular to the local surface slope may represent normal faulting which forms as a result of uplift and/or subsidence during periods of magmatic intrusion and extrusion. These faults may have a limited subsurface expression and may be confined to surface or shallow subsurface volcanic material. On radar imagery, faults in this group are commonly identified by the displacement of drainage channels or volcanic flow features that radiate from volcanic centers.

A second category of fault patterns includes faults that are regionally extensive and may define areas of subsurface structural weakness. A group of radar-highlighted, east-west trending faults characterizes this category. These faults are located southeast of the Bulatukan Fault and southeast of the Marbel Fault Zone. Fractures located on the eastern slope of Mt. Talomo and in a large Middle Miocene exposure of clastic rocks to the north display this trend. These faults as a group tend to reinforce the possibility of regionally extensive zones of structural weakness in the east-west direction. In the Mt. Apo and Mt. Talomo areas, these faults may be the surface expression of deeper subsurface faulting in older stratigraphic units. Other such zones are identified by groups of north-south and northwest-southeast trending large scale faults. Regional faulting can be inferred from radar interpretation by recognizing abrupt textural and pattern changes that occur between rocks on adjacent sides of the fault trace. Local areas of radar shadow or high geological complexity may segment the continuous image expression of these faults.

A small group of conspicuous local faults occurs near the Sandawa Depression. A curvilinear fracture intersects the eastern end of the Bobong Fault to form a semi-circular feature around the Sandawa Depression. The rim of the Sandawa Depression, the Bobong Fault, and a curvilinear fault to the north of the Bobong Fault form a concentric fault pattern which partially surrounds the Sandawa Depression. The identification of this pattern suggests that the effects of the collapse event which formed the Sandawa Depression are more regionally extensive than previously mapped.

As previously discussed in Section 3.1.1, areas of radar shadow can result in the loss of interpretive information. Figure 4.5 provides an image of the Mt. Apo Geothermal Prospect area where shadowing has been reduced because of a different aircraft flight path.

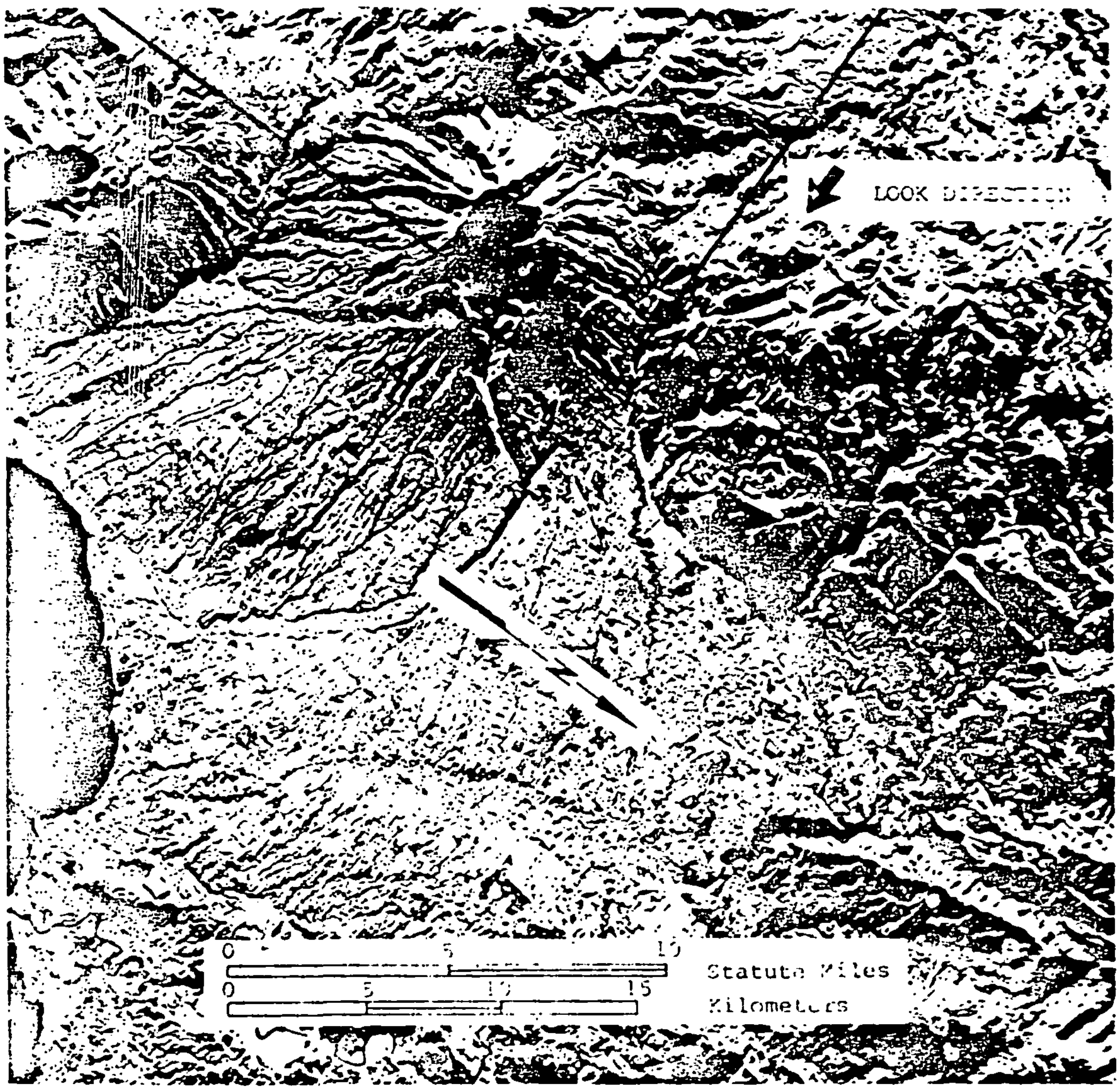

Figure 4.5: Radar imagery strip of the Mt. Apo area. Geothermal Prospect area is shown.

5 SUMMARY AND RECOMMENDATIONS

The Republic of the Philippines is not well endowed with hydrocarbon reserves, and the Government of the Philippines is anxious to spur more petroleum exploration. For both the Philippine National Oil Company Exploration Corporation (PNOC EC) and Bureau of Energy Development (BED), it has been an important goal to upgrade available geological information on various sedimentary basins in the interest of attracting foreign firms to invest or explore for hydrocarbons. The Government of the Republic of the Philippines has invited new bids from international companies to explore for oil and gas in onshore and offshore sedimentary basins. To assist the private oil industry in the evaluation of the petroleum potential of these basins, the Government, with the assistance of a loan from the World Bank, has completed a nation-wide basin evaluation program.[3]

The collection and interpretation of radar imagery was designed to augment and complement the existing data base prepared by PNOC EC and BED. The primary objective of the project was to further the goals of international energy development by aiding the Republic of the Philippines in the assessment of potential petroleum prospects within the areas imaged. Secondary goals were to assist the Republic of the Philippines in utilizing state-of-the-art radar remote sensing technology for resource exploration, and to train key scientists in the use of imaging radar data.

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3 BED et al., 1987, ***Sedimentary Basins of the Philippines - Their Geology and Hydrocarbon Potential***, Bureau of Energy Development, The Republic of the Philippines, Manila.

5.1 Radar's Value

Because a radar provides its own source of illumination, radar images can be produced that preferentially highlight geologic structure and surface detail. Radar images so constructed provide unique information about the local geology which may not be available from other sources. Such information is needed in the Republic of the Philippines because although the region has been extensively mapped via conventional techniques, large uncertainties in the petroleum resource potential of the area still exist.

Radar's unique capabilities include:

* All weather, day-night operation
* Control of look direction and look angle for improved geological interpretation
* Wide areal coverage--synoptic view
* High resolution comparable with most remote sensing systems
* Stereo capability allows rapid formulation of geologic models
* Sensitivity to vegetation at shorter wavelengths
* Terrain texture discrimination in non-vegetated regions
* Digital capability for image enhancement and multi-sensor integration
* Radar mosaic provides an accurate base map

5.2 Data Acquired

Radar imagery covering roughly 60,000 km^2 was acquired. These data were collected by Intera Technology, Inc., under subcontract from ARCI. ARCI provided mission planning and quality assurance for the program.

Complete stereo coverage of five different regions was acquired. Within these five sites, the following four different sets of data were collected for hydrocarbon interpretation.

Geothermal Sites

* Mt. Apo, Mindanao
* North Negros Island
* South Negros Island

5.3 Data Produced

The final data products were (1) negative film and positive prints of each of 34 flight line strips, (2) computer compatible tapes (CCT) of each image strip, and (3) negative film and positive prints of radar mosaics of four petroleum sites at 1:250,000 scale. The Intera STAR-1 imaging radar system used to acquire these data operated at X-band with the linear HH-polarization, and produced data representing 12 m resolution. The final data set represents one of the best examples of radar imagery for resource exploration available anywhere.

Interpretive data products produced include (1) geologic maps, (2) lineament maps, and (3) prospect evaluations. Development of geologic maps and prospect evaluations included extensive use of surface and subsurface data furnished by BED and PNOC EC. Thus, the final evaluation is a synthesis of all data available rather than simply that obtainable from the radar imagery itself. This is perhaps the most significant aspect of the program in that it demonstrates the use of radar as a sensor in an integrated program for hydrocarbon and geothermal exploration. The imagery acquired is an excellent source of data that may be used to refine exploration strategy and define areas for more detailed investigation by ground survey and seismic data acquisition. The image analysis shows numerous areas of agreement with prospects developed from other data sources such as field and geophysical surveys. In addition, a considerable number of structures and prospects were discovered, particularly in areas where other data sources were unavailable.

5.4 Summary

This synthesis of all available data shows radar imagery to be an excellent survey tool in an integrated multilevel exploration. The radar by itself may be used to guide acquisition of more detailed data and develop a general exploration strategy. Where other survey data such as photography or LANDSAT are available, the unique response and illumination enhancement of surface structure obtainable with radar is seen to provide additional data complementary ~~to other~~ survey imagery.

Important new fault and fault patterns have been identified which will provide a focus for further follow-up field and geophysical studies.

Faults and fractures that transect a geothermal reservoir may be regarded as channelways or main trunklines of a geothermal plumbing system. Therefore, a clearer picture of the regional fault/fracture patterns provided by radar interpretation could prove useful in determining permeability controls.

Geothermal Prospects

* **Mt. Apo Geothermal Prospect** - Analysis of the radar data has led to identification of a previously unmapped east-trending fault system, and recognition of a dominant east and northwest fault system in the Mt. Talomo region where the faulting was previously believed to be radial.

* **North and South Negros Geothermal Prospects** - Recognition of regional fault patterns mapped from radar will be of significant value in the planning phase for future exploratory drilling.

5.5 Highlights

* The radar data and this project have improved the knowledge of stratigraphy and structure, and may provide data for updating existing geologic maps.

* The radar geologic maps produced, while important by themselves, can be used to complement existing geoscience data and can provide new map products tailored to support exploration activities.

* An important aspect of radar investigations is that reconnaissance radar images facilitate field work in remote and impassable areas.

* The baseline survey and interpretation were conducted at a scale of 1:250,000, but the data support increasing the scale to 1:50,000.

* A training course on radar interpretation and SAR fundamentals has been provided to Philippines geoscientists, and they have become enthusiastic in the potential application of using radar images for this and other important investigations such as land cover mapping (forestry or other vegetation covers), land use mapping, hydrology, and ground-water exploration.

5.6 Recommendations

* Because the imaging radar program was designed for hydrocarbon exploration in moderate relief areas, excessive radar shadow occurred in some local areas. Therefore, the Negros and Mt. Apo geothermal sites should be reflown to obtain multiple-look direction radar imagery in order to obtain complete, shadow-free, stereo coverage.

* Additional radar imagery should be acquired over a much larger region of the Philippines, especially within those areas where radar can contribute significant data to the development of an integrated exploration strategy for geothermal resources.

* Radar also should be used to explore for other natural and non-renewable resources, in addition to geothermal potential.

6 References

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