

ABSTRACT
SEISMOTECTONICS
TECTONICS OF THE CERRO PRIETO GEOTHERMAL AREA
OF THE
DOUGLAS B. BAUSCH
CERRO PRIETO GEOTHERMAL AREA

Cerro Prieto geothermal area lies within Mexico,
only 25 km south of the California border, and
is an echelon offset by the Cerro Prieto and
Faults. Data from a six-week eight-
station seismic survey, conducted in southwesternmost
the Arizona Earthquake Information Center (AEIC),
includes phase arrival times and first motion data
from 12 station sites.

by Douglas B. Bausch

A Thesis

Submitted in Partial Fulfillment

of the Requirements for the Degree of Superior

Master of Science in Geology

Northern Arizona University

December 1991

Approved:

David S. Baumgardner

Nathan Best

Paul Morgan

ABSTRACT

SEISMOTECTONICS OF THE CERRO PRIETO GEOTHERMAL AREA

DOUGLAS B. BAUSCH

The Cerro Prieto geothermal area lies within Mexico, approximately 25 km south of the California border, and between the en echelon offset of the Cerro Prieto and Imperial faults. Data obtained from a six-week eight-station microseismic survey, conducted in southwesternmost Arizona by the Arizona Earthquake Information Center (AEIC), were combined with phase arrival times and first motion data from permanent stations within the joint USGS-California Institute of Technology southern California Network and the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) network. The resulting data allowed good locations for epicenters and some focal solutions for events occurring within the Cerro Prieto geothermal area.

During a one-month period beginning January 15 and ending February 15, 1988, 42 events with coda magnitudes between 0.9 and 2.95, and location errors of less than two kilometers occurred within the Cerro Prieto geothermal area. These epicenters follow a trend northward ($N3^{\circ}W \pm 4^{\circ}$), connecting the Cerro Prieto and Imperial faults. Well-constrained single-event focal solutions were produced from

the first motions of fourteen events. Five of these solutions, obtained from events occurring within the production zone of the Cerro Prieto geothermal area, exhibited a combination of strike-slip motion on northwest and northeast-trending focal planes with normal motion on steeply dipping northward-trending focal planes. Solutions illustrating events which took place outside of the production zone were obtained from the first motions of nine events. These solutions demonstrate predominantly strike-slip motion on northwest and northeast trending focal planes with a small component of normal motion.

The seismicity of the Cerro Prieto area has previously been compared to the Brawley seismic zone, which connects the Imperial and San Andreas faults. Both seismic areas are defined by a pod-shaped distribution of epicenters elongated in a north-south orientation. This distribution of epicenters, as well as the focal solution data, suggests a model of "leaky" transform faulting. The leaky transform model, first proposed by Hill (1977), suggests northward-trending dike emplacement at lower crustal levels, and that these dikes are interconnected by strike-slip faulting.

TABLE OF CONTENTS

List of Tables vi

List of Figures vii

Chapter 1: Introduction 1

 Purpose of Study 1

 Regional Tectonic Setting 4

 The San Andreas-Gulf of California System 4

 The Salton Trough 9

Chapter 2: Methods 21

 Data Collection 21

 CIT Catalog 21

 Incorporation of Permanent Station Data 21

 AEIC Microearthquake Survey Network 24

 Data Analysis 27

 HYPO71PC 27

 HYPO71PC Input 27

 HYPO71PC Output 28

 Magnitude Determination 31

Chapter 3: Seismicity of the Cerro Prieto Geothermal Area 32

 Crustal Velocities 32

 Crustal Velocity Models 32

 Station Corrections 34

 Previous Surveys 41

 Majer and Others, 1978 Survey 43

 Majer and McEvelly, 1980 Survey 43

 Wong and Frez, 1980 Victoria Aftershock Survey 44

 Permanent Station Data 46

 Joint USGS/CIT Southern California Seismic Network 46

 CICESE Northern Baja California Network 46

 Hypocenter Distribution 51

 Temporary Microearthquake Survey 51

 Statistical Significance 54

Chapter 4: Relationship of Seismicity to Tectonic Setting 57

 Crustal Spreading 57

 Focal Mechanisms 59

Cerro Prieto	59
Regional Comparison	68
Plate Tectonic Model	70
Leaky Transform Concept	70
Spreading Center Migration	70
Chapter 5: The Potential for Passive Seismic Methods in the Exploration and Study of the Cerro Prieto Geothermal Area	75
1. Hypocenter Data	77
Previous Studies	77
Cerro Prieto Study	81
2. b-Values	83
Previous Studies	83
Cerro Prieto Study	84
3. Estimates of Poisson's Ratio	86
Previous Studies	86
Cerro Prieto Study	90
4. Seismic Attenuation	92
Previous Studies	92
Cerro Prieto Study	95
6. Mapping Passive Seismic Parameters	95
Chapter 6: Discussion and Findings	99
Discussion	99
Salton Trough	99
Cerro Prieto Geothermal Area	99
8. Findings	101
Hypocenter Distribution	101
Focal Solutions	101
9. Exploratory Passive Seismic Methods	103
Seismic Stations Within and Outside	
References	104
Appendix A: HYP071PC Output	112
Appendix B: Single-Event Focal Mechanisms	146
Biographical Statement	161

LIST OF TABLES

1. Field Equipment and Settings for the 1988 of the Microseismic Survey	25
2. HYP071PC Grading Scale (Lee and Lahr, 1975)	29
3. Quality of First Motions-Grading Scale	29
4. Velocity Models-Cerro Prieto, Imperial Valley and Mojave Desert	33
5. RMS Values for Five Velocity Models	35
6. Station Locations and Corrections	37
7. RMS Values for the Two Best Fitting Velocity Models After Applying Station Corrections	39
8. Vp/Vs and Poisson's Ratios Measured at Seismic Stations Within and Outside of the Geothermal Source Area	91
9. Direct P-Wave Velocities Measured at Seismic Stations Within and Outside of the Geothermal Source Area	96

LIST OF FIGURES

1.	Relative Plate Motions Along the Boundary of the Pacific and North American Plates	2
2.	Sketch of Plate Cross Sections During the Ridge and Trench Collision	6
3.	Reconstruction of Plate Evolution and Deformation Related to Late Cenozoic Interactions of the North American and Pacific Plates	8
4.	Structure and Tectonics of the Imperial Valley Region	12
5.	Idealized Relationship Between Strike-Slip Faulting and Spreading Centers	14
6.	Plate-Tectonic Model and Map of Northern Gulf of California and Salton Trough	15
7.	Idealized Model Adapted for Extension of the Salton Trough	18
8.	Locations of Seismic Stations Used in This Study	23
9.	Two Best Fitting Crustal Velocity Models	36
10.	A Comparison of RMS Values Calculated by HYPO71PC for the Final Two Best Fitting Velocity Models	40
11.	Copies of Field Seismograms Representing an Imperial Valley Event Recorded on AEIC Station MEX, and a Cerro Prieto Event Recorded on AEIC Station BOM	42
12.	Epicenters of Production Area Earthquakes from a Seventeen Day, 1980 Survey, Conducted by Majer and McEvelly	45
13.	Distance-Depth Relationship for Aftershocks of the 1980 Magnitude 6.7 Victoria Earthquake	47

14.	A and B Quality Epicenters of Earthquakes Occurring from 1969 to 1988 in the Cerro Prieto Region Between the Offsets of the Imperial and Cerro Prieto faults	48
15.	Network of Seismic Stations and Epicenters from June, 1977 through May, 1978	50
16.	Epicenters of Earthquakes Located by a Temporary Southwesternmost Arizona Network Combined with Data from Permanent Networks in Northern Baja California and Southern California	52
17.	Close-up of Earthquake Epicenters Recorded During Temporary Survey	53
18.	Cross-Section of Activity Recorded by the Temporary Network	55
19.	Survey Locations from January 15 through February 15, 1988, and Major Transform Faults	61
20.	A Close-up of Production Zone Epicenters and Focal Solutions	62
21.	P and T Axes of Single-Event Focal Solutions Obtained During This Survey	64
22.	Locations of Earthquake Swarms Which Produced the Composite Focal Solutions of Albores and others (1978)	66
23.	Composite Solutions Representing Strike-Slip Motion Associated with the Transform Faults, and Normal Solutions Between the Transforms	67
24.	Map of the Central Part of Imperial Valley, California, Showing Focal Solutions and the State-of-Stress Orientation	71
25.	Schematic Representation of Dikes and Conjugate Faulting in the "Leaky" Transform Model of Hill (1977)	72
26.	Isopleth Map from Gastil and Bertine (1986) Showing Concentrations of Earthquake Epicenters 1900-1974	78
27.	Concentrations of Thermal Springs and Wells from Gastil and Bertine (1986)	79

28.	Epicenters of Earthquakes Occurring within the Cerro Prieto Production Area During Temporary Survey	159 82
29.	The b-Values Calculated from Events During the Survey within the Production Zone as Compared to Those Occurring Outside of the Production Zone	85
30.	Wadati Diagram Produced from a Single Shallow Event Occurring within the Production Zone	88
31.	Wadati Diagram for Events Recorded from June, 1977 through June, 1978	89
32.	Wadati Diagram Produced from Events Occurring within the Production Zone During the 1988 Survey	93
33.	Wadati Diagram Produced from Events Occurring outside the Production Zone During the 1988 Survey	94
34.	Map Comparing Area of Present Production Zone with Region of Earthquakes Producing Greater Vp/Vs and Poisson's Ratios than Regional Values, as well as Velocities Which are Slower than Regional Values	97
35.	Focal mechanism for event number 2	147
36.	Focal mechanism for event number 6	148
37.	Focal mechanism for event number 8	149
38.	Focal mechanism for event number 11	150
39.	Focal mechanism for event number 13	151
40.	Focal mechanism for event number 14	152
41.	Focal mechanism for event number 18	153
42.	Focal mechanism for event number 20	154
43.	Focal mechanism for event number 21	155
44.	Focal mechanism for event number 30	156
45.	Focal mechanism for event number 34	157
46.	Focal mechanism for event number 36	158

47.	Focal mechanism for event number 40	159
48.	Focal mechanism for event number 43	160

A complete text version is located at [NAU's Cline Library](#)