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Tracer Test Using Naphthalene Disulfonates in Southern Negros Geothermal Production Field, Philippines

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ABSTRACT

Tracer testing using naphthalene disulfonates (NDS) was conducted in the Palinpinon-II sector of Southern Negros Geothermal Production Field (SNGPF) with the following objectives: 1) to quantify the rate and extent of brine injection returns to the production wells, 2) to identify fluid flow paths/channels of the returning brine and 3) to predict possible cooling rates of production wells due to injection returns. Two types of NDS tracers (NDS-A and NDS-B) were pumped into two injection wells and monitored for recovery from 12 production wells. Three producing wells, namely NJ3D, NJ5D and OK5, showed tracer recovery 5-7 days after injection, with peak concentrations of 100-150 ppb between 15th and 36th day. The tracers were also recovered from 3 other wells with initial returns between 2 and 3 months. The tracer return curves were processed and interpreted using the one dimensional flow modeling utilizing the ICEBOX software package of the United Nations University, Iceland.

The results were used to assess the reservoir response to increased mass extraction and injection rates from a planned additional 20 MWe modular power plant. Cooling predictions are consistent with observed historical cooling trends. The current injection load in two of the injection wells appears to be close to the optimum injection rates. Additional brine production during operation of additional 20 MWe power plant necessitates drilling of a new injection well farther away from the existing injection area.

1. INTRODUCTION

Tracer test using naphthalene disulfonates (NDS) (Rose, et al., 2001a and 2001b). was conducted in the Palinpinon-II sector of Southern Negros Geothermal Production Field (SNGPF) to optimize injection well utilization develop a production/ injection strategy that will sustain steam availability for another 20 MWe modular power plant. The new power plant will utilize the excess steam supply from existing production wells **(Fig. 1)**.

With the current production-injection scheme in Palinpinon-II, injection returns have been continuously monitored in several production wells close to the Nasuji and Sogongon injection sectors. The injection returns have caused slight but distinct decline of temperatures and steam flows in the affected wells. Thus, in anticipation of an increase in injection rate as a result of increased mass extraction, the tracer test was proposed with the following specific objectives: 1) to quantify the rate and extent of injection returns from injection wells NJ2RD and SG2RD, 2) to identify fluid flow paths/channels of injection returns and 3) to predict possible thermal breakthrough or cooling of production wells due to unmitigated injection returns.

2. METHODOLOGY

Two types of naphthalene disulfonate tracers, NDS-A and NDS-B, were used for the tests The location of injection and monitoring wells are shown in **Figure 2**. NDS-A was dissolved in fresh water and was pumped into injection well NJ2RD through its wing valve over a period of 20 minutes. During tracer injection, the estimated brine injection load of 79 kg/sec from Nasuji was diverted into a thermal pond and was directed back into NJ2RD to push the tracer into the geothermal reservoir. Similarly, NDS-B was mixed with fresh water and was injected into SG2RD over a period of 20 minutes while the estimated brine flow of 53 kg/sec from Sogongon was diverted into a thermal pond. Twelve (12) production wells were subsequently monitored for tracer returns over a period of one year. The average injection rates in NJ2RD and SG2RD during the monitoring period were 60 kg/sec and 52 kg/sec, respectively.

Brine samples were collected from the monitoring wells into 500 ml polyethylene plastic bottles containing 5 ml of 10% hydrochloric (HCl) acid. The tracer samples were analyzed in the Geoservices Chemistry Laboratory of Leyte Geothermal Production Field (LGPF) using a portable High Performance Liquid Chromatography (HPLC) with fluorescence detection. For chromatographic separation of tracer types, paired-ion chromatography (PIC) was employed, with the mobile phase consisting of methanol phosphate-buffered solution of 5m molal tetrabutyl ammonium phosphate (TBAP).

3. TRACER RETURN CURVES

Three (3) producing wells, NJ3D, NJ5D and OK5, showed significant recovery of NDS tracers within a week after injection **(Figs. 3-5)**. First arrivals of tracers to these wells were only between 5 and 7 days, with peak concentrations of 100-150 ppb observed between 15th and 36th day. The NDS-B was recovered from NJ3D while the NDS-A was recovered in NJ5D and OK5. Another well, NJ6D also yield NDS-A but the first arrival and peak concentrations were not observed because monitoring in this well started only on the 54^{th} day of the test program. However, the recovered concentrations in NJ6D were almost the same as in OK5 during the same monitoring period. The tracer return curve of OK5 closely matches the data plot of NJ6D **(Fig. 6)** when superimposed. Thus, it is reasonable to assume that these wells would be equally affected by same magnitude of tracer injection returns, judging from the very close proximity of the two wells; water flow of 5-7 kg/sec in both wells and the presence of common flow path or channel (see Fig. 2).

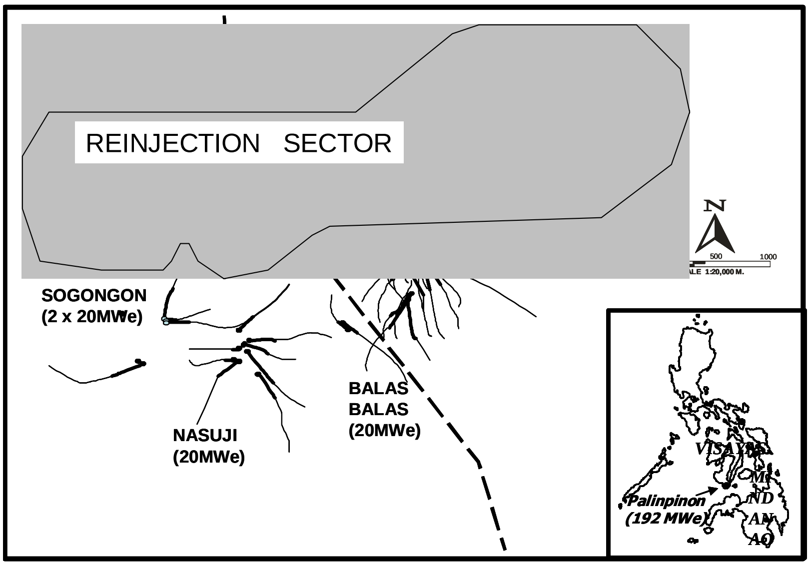

Figure 1: Well distribution map of Southern Negros Geothermal Field

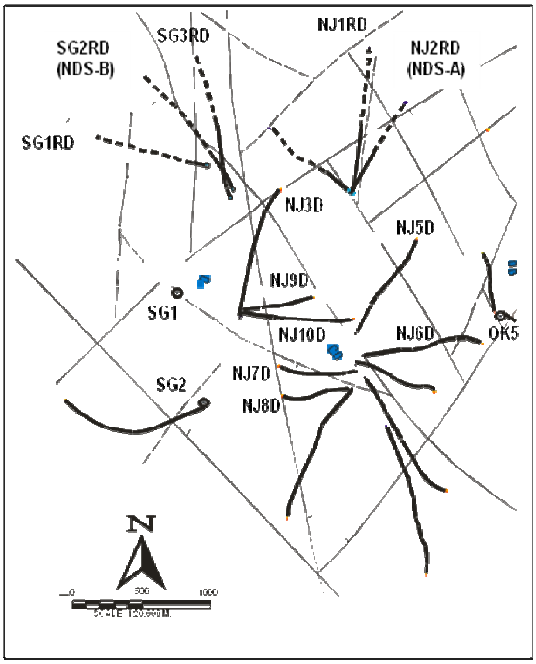

Figure 2: Location map of production wells (solid tracks) and injection wells (dashed tracks) in Palinpinon-II. Possible faults are shown as thinner lines.

Recovery of NDS-B was also monitored in N9D and NJ10D but the first arrivals were noted on the 86th and 107th day, respectively. The return concentrations were very low, ranging from 0.6 to 2.5 ppb **(Fig. 7)**. NDS-A return was observed in NJ3D starting on the 81st day after its injection into NJ2RD **(Fig. 8)**. with a peak concentration of 12 ppb. The tracer disappeared after the 110th day but was detected again on the 147th day at concentration of 1.55 ppb.

4. TRACER TEST ANALYSIS AND INTERPRETATION

The tracer return curves of NJ3D, NJ5D and OK5 represent ideal tracer recovery patterns that can be analyzed and interpreted using the one-dimensional flow model described by Axelsson (2002). The analysis and interpretation involved sequential application of 3 DOS-based interactive programs (TRMASS, TRINV and TRCOOL) in the software package called ICEBOX of the United Nations University (UNU), Iceland. The method and procedure was adopted from Axelsson (2002). The first step, which uses the program TRMASS calculates the mass of tracer recovered with time based on the tracer concentrations in the brine samples and the total mass flow from the production well. Then, the mass recovery data are used in the simulation by the tracer inversion program (TRINV) to generate a flow model based on the assumption that the flow between injection and production wells may be approximated by one-dimensional flow along a flow channel. The simulation yields information about the flow channel cross sectional area, distance traveled by the tracer and the flow velocity. The last step, which is actually the ultimate goal of the test, is the cooling prediction using the program TRCOOL. Based on the available data, interpretation will be focused on the wells with fast return and significant recovery based on detected tracer concentrations.

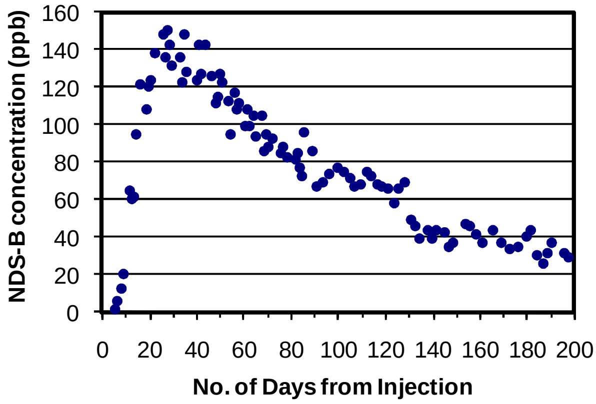

Figure 3: NDS-B tracer recovery in NJ3D from 52 kg/sec injection into SG2RD

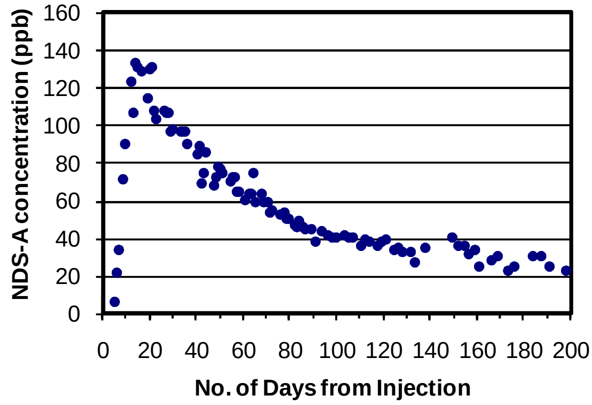

Figure 4: NDS-A tracer recovery in NJ5D from 60 kg/sec injection into NJ2RD

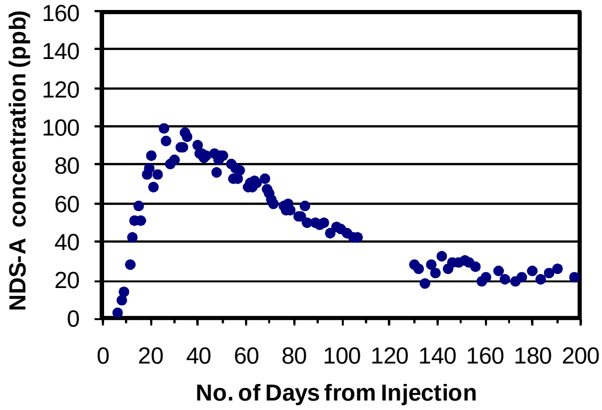

Figure 5: NDS-A tracer recovery in OK5 from 60 kg/sec injection into NJ2RD

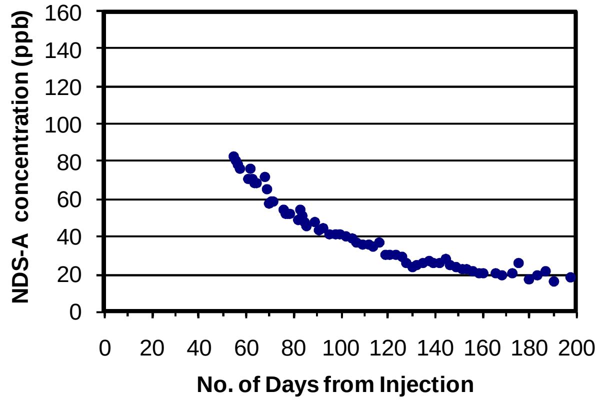

Figure 6: NDS-A tracer recovery in NJ6D from 60 kg/sec injection into NJ2RD.

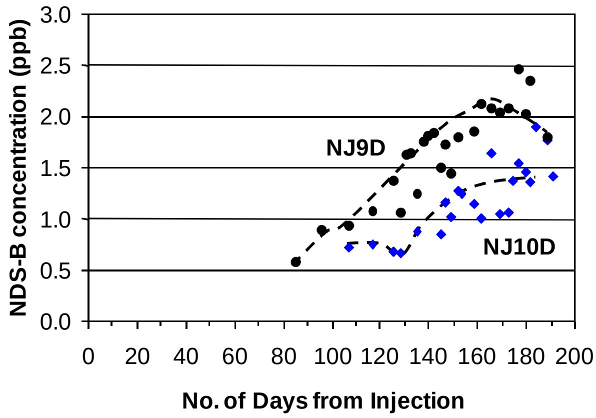

Figure 7: NDS-B tracer recovery in NJ9D and NJ10D from 52 kg/sec injection into SG2RD

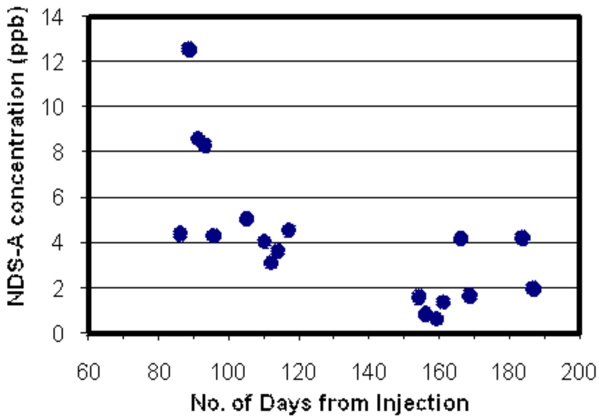

Figure 8: NDS-A tracer recovery in NJ3D from 60 kg/sec injection into NJ2RD. Dashed line indicates inferred tracer return curve. Filled circles are reservoir temperatures based on silica geothermometer.

4.1 Tracer Mass Recovery and Inversion Analysis

The calculated % tracer mass recoveries using the software TRMASS are shown in **Table 1**. The values range from 6.63% (OK5) to 23.84% (NJ3D). From tracer inversion analysis using TRINV, the flow model for each well is characterized in **Table 2**. For example, assuming a 1.5 kilometer length of flow channel from SG2RD, the NDS-B tracer recovered in NJ3D traveled with a velocity of 35.5 meters/day along a channel that has an average cross sectional area of 357.6 m^2. The calculated flow velocities in NJ5D and OK5 were 35.3 and 36 meters/day, respectively. The data describing the dimension of the flow channel, the assumed porosity value, the flow rates and temperatures (injection and reservoir) are used to predict the long term cooling effect of injection return through the application of TRCOOL. No simulation was done for NJ6D, NJ9D and NJ10D because of incomplete tracer return curves.

Table 1: Tracer recovery data

Tracer type	Injection Well	Prodn Well	First Arrival (days)	Mean Transit Time (days)	Mean Velocity (m/day)	Tracer Mass Recovery (%)
NDS-A	NJ2RD	NJ5D	5	15	35.31	23.78
		OK5	7	36	36.02	6.63
NDS-B	SG2RD	NJ3D	6	28	35.50	23.84

Table 2: Input data for cooling predictions

	NJ3D SG2RD	NJ5D NJ2RD	OK5 NJ2RD
Injection Temp (ºC)	**160**	**160**	**160**
Reservoir Temp (ºC)	**265**	**265**	**265**
Injection Rates (kg/sec)	**60, 105**	**80, 100, 160**	**80, 100, 160**
Production Rate (kg/sec)	**58.4**	**54.7**	**19.3**
Length of flow channel (m)	**1,500**	**1,500**	**2,000**
Width of flow channel (m)	**4.36**	**4.88**	**1.39**
Height of flow channel (m)	**91**	**104**	**100**
Rock porosity (%)	**10**	**10**	**10**

4.2 Cooling Predictions

Historical records show gradual decline of reservoir temperatures in NJ3D and NJ5D but stable temperature in OK5 based on the silica geothermometer. Accompanied by increasing chloride concentrations and decreasing CO_2, the decreasing temperatures are attributed to the effect of injection returns. Assuming that the Nasulo power plant in Nasuji sector will be commissioned on January 2011, brine production rate in Nasuji is projected to reach 160 kg/sec or an additional 100 kg/sec above the current injection rate in NJ2RD. Therefore, it is imperative that thermal breakthrough and the long term cooling effect of injection returns be evaluated so that a strategy can be developed for sustaining the steam supply requirement not only in Nasuji but in the entire Palinpinon-II sector.

NJ3D

At 60-70 kg/s injection rate in SG2RD between year 2000 and 2003, temperatures in NJ3D declined from 272 to 267ºC. During this period, the steam flow in NJ3D decreased gradually by 3 kg/sec for an output decline rate of 0.44 MWe per year. However, when injection rate was reduced and maintained at around 52 kg/sec, the temperature stabilized at 265-267ºC and the output deterioration was arrested. Using the NDS tracer data, the effect of 60 kg/sec injection rate was simulated and shown in **Figure 9**. The results indicate a thermal breakthrough after 1.5 years and a temperature decline rate of 2.5ºC per year for the succeeding years. The cooling rate is consistent with previous observation at the same injection load in SG2RD. Thus, steam flow is predicted to start decreasing gradually 18 months after power plant operation starts. Subsequently, the output of NJ3D may decline by 1.0 MWe after almost 3.5 years.

If SG2RD will be utilized to its maximum injection capacity of 105 kg/sec, thermal breakthrough will begin after 6 months. Then there will be a drastic cooling of about 15ºC during the next year. The cooling will slow down to around 6ºC per year for the next 2 years and further to 2.5ºC per year for another 2 years before stabilizing at around 230ºC. Nevertheless, this implies that utilizing SG2RD at its maximum capacity will have aserious adverse effect on the steam availability in the Sogongon sector.

NJ5D

Three (3) conditions were simulated for thermal breakthrough in NJ5D **(Fig 10)**. Using NJ2RD to its maximum injection capacity of 80 kg/sec, thermal breakthrough in NJ5D will occur after one year. The first stage of cooling will be rapid at 10ºC for the first 12 months. The rate will diminish to 4ºC per year for the next 2.5 years and will be relatively stable at around 1ºC per year thereafter.

Prior to NDS tracer test, it was believed that injection in both NJ1RD and NJ2RD affected NJ5D. Considering the combined capacity of these two injection wells, simulation was also conducted at 100 kg/sec injection rate. In this case, thermal breakthrough sets in after 8 months. It will be followed by more rapid cooling by 20ºC in 16 months for a rate of 15ºC per year. Then, cooling will slow down to 3ºC per year. If the total brine flow of 160 kg/sec is injected within the Nasuji sector, there will be a major detrimental effect on the productivity of NJ5D as its temperature will drop by 40ºC in the first year.

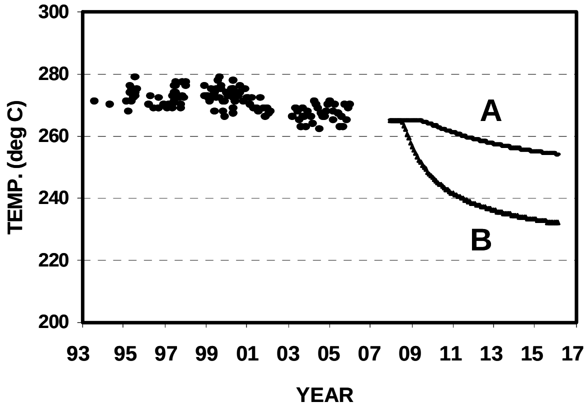

Figure 9: Cooling predictions in NJ3D based on injection temperature of 160oC and RI flows of 60 kg/sec (A) and 105 kg/sec (B) in SG2RD. Filled circles are reservoir temperatures based on silica geothermometer.

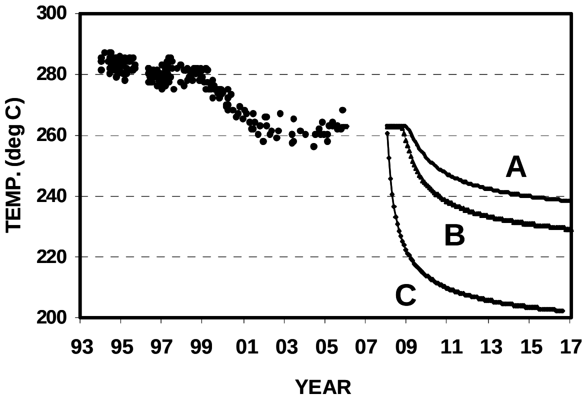

Figure 10: Cooling predictions in NJ5D based on injection temperature of 160oC and RI flows of 80 kg/sec (A) and 100 kg/sec (B) and 160 kg/sec (C) in NJ2RD. Filled circles are reservoir temperatures based on silica geothermometer.

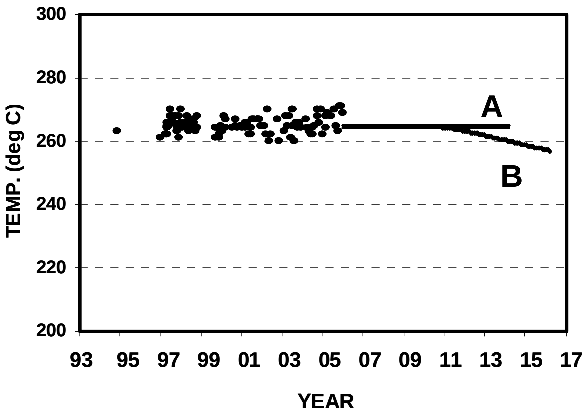

Figure 11: Cooling predictions in OK5 based on injection temperature of 160oC and RI flows of 80-100 kg/sec (A) and 160 kg/sec (B) in NJ2RD.

<u>**OK5**</u>

Based on tracer data, 6.63 % of injected brine in NJ2RD has reached OK5 in about 200 days. This rate of injection return has not caused observable thermal decline in OK5. Assuming that injection in NJ2RD increases to 80 kg/sec or 100 kg/sec, temperatures in OK 5 will remain stable **(Fig. 11)**. At 160 kg/sec, thermal breakthrough will manifest 3 years from the start of injection. However, the predicted cooling rate is less than 1ºC per year. Hence, additional injection load from the operation of the new power plant will have no adverse effect in OK5 and Balasbalas sector. Similar effects may be presumed in NJ6D based on comparable characteristics of the wells and tracer return curves.

5. CONCLUDING REMARKS

The NDS tracer test results have validated the control of fracture permeability on hydrological flows in the Palinpinon-II production sector. As much as 24% of the brine injected into NJ2RD and SG2RD returns to nearby production wells through NW-SE and NE-SW trending faults within one year. The fast returns and their cooling effects to the producing wells have also been quantified such that an appropriate injection scheme can be implemented to sustain the steam supply requirement of the existing power plants. The tracer test results also help formulate development strategy for future expansions such as for another 20 MWe Nasulo modular power plant in Nasuji.

These cooling predictions are consistent with observed cooling trends from actual injection rates. The current injection load in NJ2RD and SG2RD appears to be close to the optimum injection rates in Palinpinon-II based on stable quartz geothermometer values. However, additional brine production resulting from an additional 20-MWe power plant in Nasuji necessitates drilling of a new injection well farther away from the present injection area.

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REFERENCES

Axelsson, Gudni: Tracer Tests in Geothermal Resource Management: Analysis and Predictions (2002).

Rose, P. E., Benoit, W. R. and Kilbourn, P. M.: The application of the polyaromatic sulfonates as tracers in geothermal reservoirs, *Geothermics*, **30**, (2001), 617-640.

Rose, P. E., Johnson, S. D. and Kilbourn, P. M.: Tracer testing at Dixie Valley, Nevada using 2-naphthalene sulfonate and 2,7-naphthalene disulfonates, *Proceedings,* 26th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2001).