techniques. This compares favorably with the Sachs dilatometer, especially considering the substantial cost savings involved. Hydrogeologic conditions favorable to strain response will be discussed, and recommendations for locating and completing wells will be given. The data collection and filtering methods used in this study will be presented.

S22R-02

Recent Movement on the Garlock Fault As Suggested By Water-Level Fluctuations in a Well--Fremont Valley, California

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Water levels have been continuously recorded since March 1978 in a well in Fremont Valley, where several strands of the adjacent Garlock fault zone have exhibited both left-lateral and components of normal displacement. Differences in water levels indicate that a fault segment lies between the observation well and a nearby irrigation well. The recorded water levels, with a maximum fluctuation of approximately 3 cm, respond to earth tides and hence indicate a high sensitivity to strain in the surrounding rock mass.

During the 4-year recording period, six sharp fluctuations, or "spikes," were noted. These fluctuations, occurring over 2- to 4-day periods, have amplitudes of 15 to 30 cm. They appear to be the result of creep events on a nearby fault. Two types of creep events are plausible: (1) normal slip on an en echelon trace of the Garlock fault less than 300 m south of the well, with the north side up relative to Fremont Valley; or (2) left-lateral slip on the same fault. Because of the nature of the fluctuations, we favor the latter interpretation.

Dislocation models utilizing exponential, arctangent, and skewed cosine functions were applied to the analysis of the water-level fluctuations, associated pressure distribution, and fault displacements. The results suggest that creep on the fault ranges from several millimeters to a centimeter for individual events. Estimates of cumulative creep for the period 1978-82 range from 2 to 5 cm, depending on the particular model employed.

S22R-03

GROUND WATER ANOMALIES ALONG THE SAN ANDREAS AND SAN JACINTO FAULT ZONES, SOUTHERN CALIFORNIA

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Abandoned water wells along the San Andreas and San Jacinto fault zones have been monitored for earthquake prediction research since 1976. Anomalous spikes occurred over a four-day period on the continuous water-level record of a well near Ocotillo Wells. The spikes, consisting of single lines extending above and below the normal water-level record, are believed to be caused by gas emissions; they were recorded three weeks before a M4.5 event on 22 March 1982 13 km southwest of the well. High radon concentrations were observed in three wells in Borrego Valley for the month of June 1982. The anomalies may be related to the M4.8 event in Anza on 15 June 1982.

Anomalous downward spikes (drop and return to normal) in water level occurred over a six-hour period in four wells being monitored in Borrego Valley on 8 September 1982, and three upward spikes (rise and return to normal) in water level occurred on 6 February, 1 March and 2 March 1983 in a well near Palmdale. Neither these nor the anomalies in Borrego Valley were associated with seismicity and may represent creep events.

S22R-04

Deepwell Water-Level Studies Along the Southern San Andreas Fault

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A group of 12 deep, abandoned wildcat wells, located in the locked portion of the San Andreas Fault between Gorman and San Bernardino, have been instrumented with continuously recording high-resolution water-level transducers to monitor changes in groundwater parameters which may be sensitive to regional strain. Relatively complete data sets from several of these wells exist for the last 2-3 years.

Variability in the raw data is due primarily to solid-Earth tides, barometric pressure changes, and rainfall. Rainfall effects occur regionally with time-scales of weeks to years, and often occur locally as 'spikes' with rise times of hours to days and decay times of several weeks to months. The relationship between measured rainfall and well response is complex and non-linear, and the precise mechanism by which rainfall is communicated to the air/water interface in the borehole is not well understood. The timescales of variability have all been confirmed by spectral analysis and cross-covariance studies. Without further data processing, these effects would all tend to mask any long or short term strain-induced groundwater variations, unless such phenomena were extremely large in amplitude or short in duration (t < 1 hour).

Strain-induced water-level variations can be perhaps observed through the use of 1) statistical techniques that search for 'anomalous' trends or intervals in the water-level data, or 2) transfer functions that separate out the known, forced water-level responses. Time dependent variations in the transfer functions may also indicate strain-induced changes in bulk aquifer characteristics. Time and frequency dependent phase lags have already been observed in several wells.

Earthquake Prediction
HI, Redwood Tues PM
Presider, S. P. Nishenko, USGS

S22R-05

Long Term Probability Estimates and an Earthquake Prediction Experiment Along the San Andreas Fault System

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A simple statistical approach is used to translate long term recurrence and historic seismicity data into probabilities of earthquake occurrence along the San Andreas fault system. The resulting probability distribution is consistent with more subjective, qualitative estimates of risk. Annual probabilities in the 1-4% range of characteristic events (M 6-8) on various fault segments are for most of southern California. A much lower probability is obtained along most of the 1906 break in northern California. At Parkfield, the probability of a repeat of the M 6 1966 event is estimated to be about 70% in the next decade.

Given the high probability of a moderate event at Parkfield in the next 10 years, the U. S. Geological Survey, in cooperation with workers at several other institutions has initiated an earthquake prediction experiment in the Parkfield region. A detailed study of available seismic data and historical accounts indicates that the last five Parkfield events were probably identical; since their interevent times varied by a factor of three, they do not appear to conform to the time predictable model. However simple extension of the time predictable model to include a finite probablity of an earthquake occurring before the failure stress is reached satisfies the data and is consistent with other observations at Parkfield.

From a detailed study of the microseismicity in the hypocentral region of the 1966 earthquake we infer that failure initiated within a small area on the fault (a few km on a side) centered at about 9 km depth. This area has been seismically quiet for the past decade although clusters of M 3 events have occurred near its perpherey. Some of these M 2-3 events have static stress drops about 3 times those of events in adjacent regions. One objective of the experiment underway at Parkfield is to monitor the seismicity of this small fault as precisely as possible, in hopes of identifying any precursors, and understanding the precesses leading up to, and including the next moderate earthquake.

S22R-06

Conditional Probabilities for the Occurrence of Large Plate Rupturing Earthquakes along the San Andreas, San Jacinto and Imperial Faults, California, 1983-2003

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The San Andreas, San Jacinto and Imperial faults in California are divided into 19 segments; conditional probabilities are calculated that a particular segment will be the site of a large plate rupturing earthquake during the next 20 years. We forecast the likelihood of large future earthquakes for each segment using a simple probabilistic approach with input being the date of the last large shock, the average or expected recurrence time, and the standard deviation of time intervals between events. Dates of the last large shock are available for most of the segments investigated. Average or expected repeat times are estimated with varying degrees of precision from the times of historic and prehistoric events, tectonic similarity, intervals inferred from either rates of fault motion or strain build-up, and displacements that are either observed at the surface or estimated from seismic moments. A normalized standard deviation of 1/3 of the expected recurrence time is adopted for all calculations of conditional probability. Several segments have well-constrained probabilities for rupture during the next 20 years, whereas several have large uncertainties. Nine of the segments, constituting about 40% of the total lengths of the three faults, have moderate to high probability. The segment of the San Andreas that broke less than 1.5 m in 1906, from west of San Jose to San Juan Bautista, is calculated to have a moderate to high probability for an earthquake of magnitude 6 3/4 to 7 1/4 during the next 20 years. A 325 km-long segment of the southern San Andreas, between Tejon Pass and the Salton Sea, is the only segment along the three faults that appears to have more than a small chance of rupturing in a shock of magnitude near 8 during the next 20 years.

S22P-07

Temporal Attenuation Changes in the Koae Fault System, Southern Hawaii

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Attenuation of the seismic coda of magnitude 1.6 to 2.4 earthquakes recorded at station AHU in Southern Hawaii changes as a function of time. Coda envelopes of smoked paper seismograms were digitized for more than 200 events located within a 2.5 km radius source volume, centered 8 km southeast of the station AHU. A 14% decrease in coda decay rate in mid 1971 is interpreted to result from an increase in Q by approximately a factor of 1.5. This roughly coincides with an observed travel time decrease of 0.13 sec at station AHU, inferred to be caused by a 10% velocity increase within the Koae fault system. The station AHU is located at the northern edge of the Koae fault system, which is a several kilometer wide band of normal faults with open cracks visible at the surface. During the time of the attenuation and velocity increase magmatic intrusion in the nearby rift zone of Kilauea volcano (5 km northeast of AHU) caused a compression of the crust around AHU which was measured geodetically as $4\cdot10^{-5}$ strain. The most probable cause for the attenuation and velocity changes was the closure of cracks in the Koae fault system. No magma was present in the volume through which the analyzed seismic waves passed to reach AHU.

S22R-08

Regional study on the anomalous change in apparent resistivity before the Tangshan earthquake ($M = 7.8$, 1976) in China

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Electrical resistivity measurements have been conducted as a possible means for obtaining precursory earthquake information. Before five great shallow earthquakes ($M > 7$, $h < 25$ km) in China, the apparent resistivity showed systematic variations within a region 200 km from the epicenters. I particular, 9 stations in the Tangshan-Tianjin-Beijing region prior to the Tangshan earthquake ($M = 7.8$, $h = 11$ km, 7.28, 1976) showed consistent decreasing apparent resistivity around the epicenter, with a maximum resistivity change of 6% and a period of variation of 2-3 years. Simultaneous watertable observations in this region showed a declining watertable and ground surface observation indicated a slight (2-3 cm) uplift in the epicenter region relative to its surroundings.

In order to develop an explanation for the observed change of resistivity associated with these great earthquakes, we have explored the electrical effects of changes in rock porosity, water content and water salinity based on the Archie's law. We further utilize layer media calculations to explore apparent resistivity sensitivity to variation on subsurface parameters such as layer thickness and local resistivity.

Tentative conclusions of this study are as follows: (1) the apparent resistivity is opposite to the effect of the simultaneous watertable trend. (2) The dilatancy needed to give such resistivity variaions (assuming Archie's law holds) is much larger than that needed to explain the observed uplift (by 2-3 orders of magnitude). (3) Salinity changes in the pore water is left as the only possible explanation for the variation of resistivity; an increase in the salinity would cause a proportional decrease in resistivity. Further investigations of pore water salinity changes before earthquakes are needed. Data needed to test this hypothesis are lacking.

S22R-09

Precursory Seismicity Patterns: Triggering and Tectonic Control

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Seismicity patterns prior to the 1976 Kermadec earthquake (January 14, M_S=8.0) include seismic quiescence

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