Ake + others, 1992

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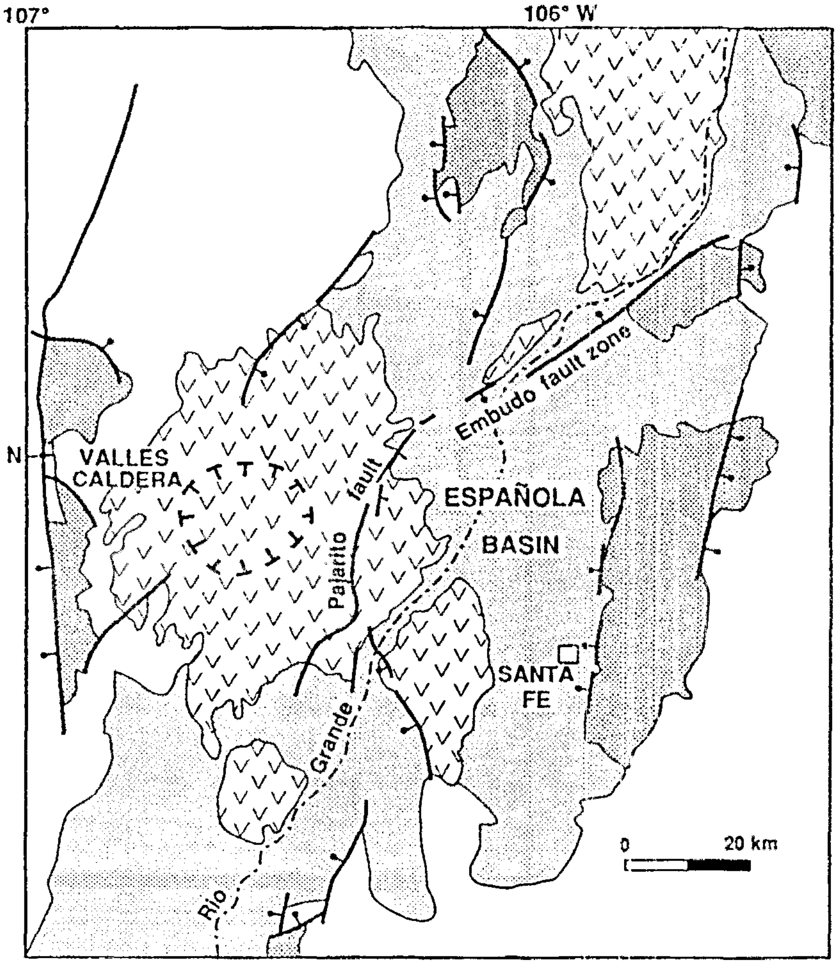

SSA MEMBERSHIP DIRECTORY

EASTERN SECTION
SEISMOLOGICAL SOCIETY OF AMERICA

Tuesday Morning, April 14, 1992 *Room I*

Induced Seismicity

Presiding: Jim Rutledge, Los Alamos National Laboratory
Marker Baker, Univ. of Texas at El Paso

8:30 A.M.

EARTHQUAKES ASSOCIATED WITH THE KEYSTONE OIL FIELD, WEST TEXAS

[illegible], BALLESTROS, L., DOSER, D. I., and BAKER, M. R., Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968

Between 1976 and 1979 a local seismic network operating in the Permian Basin region of west Texas recorded 15 earthquakes with duration magnitudes of 0.5 to 2.9 near the Keystone oil field located on the Central Basin Platform. Previous studies suggested that this seismicity was related to fluid injection associated with secondary recovery projects within the Keystone Field. We have relocated the earthquakes using a velocity model obtained from sonic logs and find that the earthquakes are actually located between the Keystone and Kermit oil fields at depths that place them within the Precambrian basement. The alignment of the epicenters suggest activation of ENE-WSW trending faults whose presence is confirmed by well log data. The earthquakes occur at the same depth level (3.4 to 5.4 km) as an overpressured zone located within the Delaware Basin 12 km to the west, suggesting possible migration of fluids from the Delaware Basin into the Central Basin Platform along basement faults. Composite focal mechanisms for the earthquakes are also consistent with strike-slip movement along ENE-WSW trending faults.

8:45 A.M.

A COMPARISON OF EARTHQUAKE LOCATIONS USING AN ANISOTROPIC 3-DIMENSIONAL MODEL WITH A LAYERED ISOTROPIC VELOCITY MODEL

BAKER, M. R., and DOSER, D. I., Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968

Between 1975 and 1979 over 200 earthquakes were well-recorded in association with the War-Wink oil field, Ward Co., Texas. Published studies of earthquake locations relative to the controlling anticline used HYPO71 and REL3D and relied on one-dimensional velocity models. Significant deviations from this simple layered model have been seen in well log interpretations. There is over 200m of structural relief on Paleozoic strata, strong lateral velocity variations within stratigraphic units due to anomalously high fluid pressures, and large velocity anisotropy in interbedded carbonates and overpressured shales and in thick evaporite deposits. Vidale's earthquake location technique for 3-dimensional structure has been modified to include orthorhombic elastic anisotropy. Earthquake locations using this approach are comparable with REL3D for an isotropic layered model. Inclusion of anisotropy and structure in the earthquake relocations reduces residuals and significantly modifies locations.

9:00 A.M.

MICROSEISMIC MONITORING IN OIL FIELDS OF THE SAN ANDRES DOLOMITE

RUTLEDGE, J.T., FAIRBANKS, T.D., and HOUSE, L.S., Los Alamos National Laboratory, MS D443, Los Alamos, NM 87545

Microseismicity was monitored in the Chaveroo and Tomahawk oil fields, located in southeastern New Mexico, to determine if microearthquakes induced during normal production activity would be of use in mapping reservoir fractures. Production in both fields is from the San Andres dolomite, a prolific oil bearing formation that extends throughout a large area of the Permian basin of west Texas and eastern New Mexico. The Chaveroo and Tomahawk fields have been under primary production for about 25 and 20 years, respectively, and are about to undergo secondary recovery by waterflooding. In the Chaveroo field, one 3-component, downhole geophone was placed at reservoir depth (1300 m) as a pilot waterflood operation began. Four injector wells were each taking about 200 to 250 barrels of water per day under hydrostatic pressure. Monitoring was intermittent over a 5-week period, nonetheless, microseismicity was detected during each monitoring period. During normal waterflood production, as many as several hundred events were detected during intervals as short as 12 hours. Events were detected up to distances of 1700 m, but most were within 900 m. Linear features indicative of fracture patterns were not apparent when the microearthquakes were located using a simple hodogram technique. The hodograms implied that events occurred within or near the production depth interval.

A follow-up experiment was conducted in the Tomahawk oil field using an array of 3 downhole geophones and continuous monitoring. Array geophones were deployed in a triangular pattern with each instrument placed within or near production depth (1300 m) in wells spaced approximately 800 m apart. Monitoring took place over a total of 5 months during which time the field was under normal production with no waterflooding. Average fluid production rates, per well, were about 10 barrels per day. No microearthquakes were detected in the immediate area of the array. Microearthquakes located near a salt water disposal well about 4.25 km southwest of the array were detected at a rate of about one per week. The injection rate in the disposal well was about 400 barrels per day. From the limited experience of these monitoring experiments, it appears that microseismicity may occur in these aged reservoirs only while fluid injection is taking place.

9:15 A.M.

INTERRELATION BETWEEN INDUCED SEISMIC INSTABILITIES AND COMPLEX GEOLOGICAL STRUCTURE.

GUYOTON, F., GRASSO, J.-R. AND P. VOLANT.
Laboratoire de Géophysique Interne et Tectonophysique, Observatoire de Grenoble, B.P. 53X, IRIGM, 38041 Grenoble Cedex, France.

From 1982 to 1989, more than 520 locally induced earthquakes were recorded by a permanent network of 9 telemetered stations over an active gas field (Lacq, France). Geological data of 46 deep boreholes coupled to several ten kilometers of seismic profiles, concentrated in a volume of 15x15x10 km^3, allow us the development a precise 3D velocity structure, exhibiting a dome geometry limited by faulted strips. The discretized velocity model includes almost 20000 blocks with 500 m x 500 m x 250 m minimum dimensions. The location technique, using this *a priori* detailed 3D velocity model, allows relocations of 350 induced earthquakes.
Relocated hypocenters show that the seismic activity is concentrated on geometrical discontinuities of the local dome structure. The location of seismic events are correlated with geomechanical layers of the structure in agreement with mechanical properties of geological beds. Though the location of each event is independant in the location process, hypocenters are concatrated in high velocity zones. Spatial and temporal migration of seismic rupture mimics the different permeability rings of the gas reservoir, which are progressively depleted due to gas extraction. Shallow events are at present confined close to major thrust planes that limit the dome structure laterally. Deep events are localised by pre-existing faults in the basement below the gas reservoir. The occurence of these deep clusters demonstrates that fluid manipulation in the sedimentary covers can activate pre-existing basement faults. This result changes previous assessments of local seismic risk and provides new insights into fault mechanisms in areas with complex geological structure.

9:30 A.M.

Microseismicity Induced by Fluid Injection in the Paradox Valley of Southwestern Colorado

Ake, J., P. S. Chang, and R. Martin, U. S. Bureau of Reclamation, MS-D3611, PO 25007, Denver, CO 80225.

As part of an ongoing effort at controlling salinity in the Colorado River Basin, the U. S. Bureau of Reclamation is attempting to reduce the influx of saline brine into the Dolores River by extracting brine at shallow depths and reinjecting beneath the extensive salt deposits of the Paradox Valley. Paradox Valley is an elongate salt anticline located within the Colorado Plateau near the Colorado-Utah border. This portion of the plateau is generally characterized by a low level of seismicity and generally northeast-southwest extensional stresses.

The Paradox Valley Seismic Network was installed in 1983/4 to determine the background level of naturally occurring seismicity in the area prior to initiation of deep, high-pressure injection. Results of the seven years of monitoring to date include: earthquakes occur within or near the network at a rate of only one or two per month ($M_L > 0.0$), focal depths are highly variable (5-32 km), and focal mechanisms for larger events suggest normal faulting on northwest-trending structures.

Two trial periods of injection occurred in late-1991. Both injection periods have been accompanied by a number of small earthquakes located very near the injection well. Both sequences of events began approximately 24-48 hours after injection commenced and ended shortly after cessation of injection. All focal depths were approximately 5 km (the maximum depth of the injection well). Duration-based magnitudes of the earthquakes ranged from 0.0 to 0.8. Preliminary focal mechanisms for these events are consistent with earlier results in the area. During the winter and spring of 1992, several additional trial injection periods will be conducted at sequentially increasing pressures.

9:45 A.M.

Possible Reservoir-Induced Seismicity (RIS) Associated with Ridgway Dam and Reservoir, Southwestern Colorado

Ake, J., R. Martin, and P. S. Chang, U.S. Bureau of Reclamation, PO 25007, MS-D3611, Denver, CO 80225

In terms of structural height and reservoir volume, Ridgway Dam and Reservoir would not be considered a highly probable candidate for reservoir-induced seismicity (height = 69 m, volume = $1x10^8$ m^3). However, due to the presence of active faults in and near the proposed reservoir, the future occurrence of RIS was considered possible at the Ridgway site. During 1983/4, prior to construction of Ridgway Dam, a seven station, high-gain seismic network was installed in the area. The objectives of the network were to: establish a baseline level of naturally occurring seismicity prior to reservoir filling; to further characterize the seismogenic capability of the Ridgway fault and associated branch faults; and to monitor the presence of possible RIS following reservoir impoundment.

Historic seismicity in the area is somewhat sparse but has included poorly located events as large as M_L 5.5 to the northeast of the study area. Monitoring during 1983-

87 established a general baseline level of naturally occurring seismicity. The results obtained during this time period suggest a fairly low level of activity with a few events occurring in the vicinity of the Ridgway fault and associated north-trending branch faults. No events larger than M_L 2.0 occurred during this time period. The general frequency of events in the area increased during late-1987 (coincident with first filling of the reservoir). The rate of seismicity since late-1987 has continued to be greater than that noted in the 1983-87 time period. A few focal mechanisms have been obtained for events near the north-trending branch faults, the solutions are consistent with normal faulting on north-trending fault planes. The rapid increase in the number of events after the onset of filling suggests loading may be the causative factor for these events. Ridgway Reservoir was finally filled to capacity in mid-1990, it is unclear at this time if any of the seismicity seen to date is associated with pore-pressure changes at depth.

10:00 A.M. BREAK

10:30 A.M.

NONLINEAR HYPOCENTRAL ERROR APPRAISAL: APPLICATION TO SEISMICITY NEAR O'NEILL DAM, CENTRAL CALIFORNIA

O'Connell, D.R.H. U.S. Bureau of Reclamation, Denver Federal Center, Denver CO 80225-007

The accuracy of linearized hypocentral error estimates is investigated by calculating spatial hypocenter probability density functions (PDF) using the method of Tarantola and Valette (1982). Marginal PDF's for epicenter and depth demonstrate the non-linear effects of Gaussian arrival-time picking uncertainties and theoretical travel-time uncertainties on hypocentral uncertainties, particularly for hypocenters located adjacent to seismic networks. Hypocentral depth uncertainties can be strongly asymmetric, with 2σ lower depth uncertainties > 2 times larger than upper depth 2σ uncertainties. Linear increases in timing uncertainties produce proportionally stronger non-linear increases in hypocentral uncertainties, particularly for hypocentral depth. The Kolmogorov-Smirnov test is used to determine if epicenter and depth differences between events are statistically significant.

Seismicity near O'Neill Dam, central California, increased dramatically in 1990. The California Department of Water Resources (CDWR) operates a 10 station network around O'Neill Dam. P and S arrival time data from the CDWR network for 95 earthquakes were used in a progressive inversion for P and S velocity structure, station corrections, and hypocenters. Most of the new earthquake epicenters where located beneath the surface trace of the O'Neill Fault, which is near the NE edge of the CDWR network. The seismicity below the O'Neill Fault appears to occur between 10-20 km depth. The nonlinear hypocentral error method is used to determine whether the epicentral position of the new seismicity is significantly different from historical background seismicity and to place bounds on its depth extent.

10:45 A.M.

HIGH RESOLUTION MICROEARTHQUAKE STUDIES AT THE GEYSERS

MAJER, E. L., Romero, A., and Peterson, J. E., Center for Computational Seismology, Lawrence Berkeley Laboratory, Berkeley, California 94720

In late 1987 a 16 station, 3-component, bore hole array with state-of-the-art digital telemetry (16 bit, 400 samples/sec per component) was installed by GEO Inc. (now Coldwater Creek Operating Company) in the Northwest Geysers geothermal steam field in northern California. The array was installed to coincide with the beginning of production in this part of The Geysers. Although production at The Geysers had been on-going in other parts of the field well before this array had been installed, the Northwest part of The Geysers was a new area of production. This provided a unique opportunity to trace seismicity from the beginning of producing an area in a detailed fashion. Data from over 2500 microearthquakes have been processed for precision location using a 3-D joint inversion procedure that solves for velocity as well as location. Correlation with reservoir properties and production activities indicates that fluid withdrawal and injection have different effects on the seismicity. In addition, the precision locations indicate planar features and boundaries that may be indicative of fluid pathways. The data were also processed for source mechanisms, and Poisson's ratio information

11:00 A.M.

SOURCE MODELLING OF SOUTH AFRICAN MINE TREMORS

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Previous work by McGarr *et al.* has shown that recordings of rockbursts from the Klerksdorp and Carletonville mining districts of the Witwatersrand Basin of South Africa have distinctly different spectral characteristics above the corner frequency. These differences have been interpreted as reflecting a strong influence on the mine tremor source mechanism of pre-existing deformations in the Klerksdorp region as compared to the relatively simple, undeformed structure of the Carletonville district. In particular, reactivation of existing faults has been implicated in several larger events in the Klerksdorp region. Using data recorded during a joint USGS/PL 1989 field experiment conducted in the Witwatersrand Basin, this problem is explored further through spectral analysis and moment tensor inversions of several events from each of the two mining districts. Analysis conducted to date shows that the f^{-3} S-wave roll-off in the Carletonville events can not be explained by attenuation and does appear to be source related. Moment tensor inversions of the Carletonville events indicates geologically reasonable double-couple type sources. Stress drops for these events have been found to range from 80 to 220 bars. Preliminary results on the Klerksdorp events confirms the lower S-wave roll-off above the corner frequencies as compared to the Carletonville events as found by McGarr *et al.*

Reference: McGarr, A., J. Bicknell, E. Sembera, and R.W.E. Green (1989) Analysis of Exceptionally Large Tremors in Two Gold Mining Districts of South Africa, *PAGEOPH*, 129, p. 295-307.