UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Review of the Denver Water Department Induced Seismicity Program at Strontia Springs, Colorado

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Open-File Report 82-64

U.S. Geological Survey

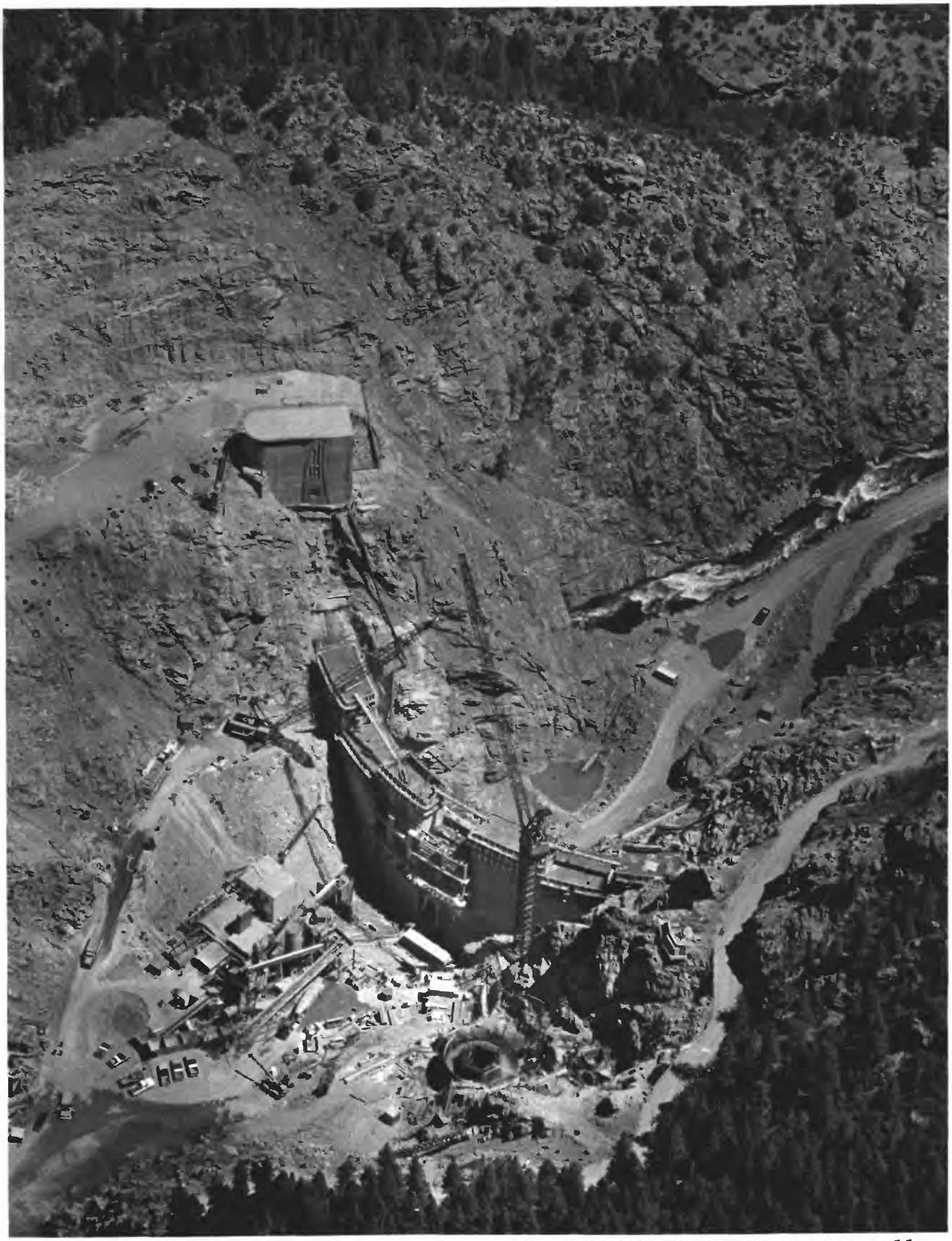

Photo by David L. Cornwell

Frontispiece. Aerial view of the partially completed Strontia Springs Dam, published on page 1 of the June 13, 1981, issue of the Rocky Mountain News (reproduced by permission of the Rocky Mountain News). Dam is in the South Platte River Canyon of the Front Range and is located about 37 km (22 mi) southwest of downtown Denver. At completion, the dam will have a height of 74.1 m (243 ft).

Summary

The six-month baseline seismicity study (January-July 1978) found two groupings of low-level seismicity, clustered in space and time, in the vicinity of the Strontia Springs, Colo., dam site. This significant finding implies that the tectonic stress level in the immediate region of Strontia Springs is sufficient to produce natural concentrations of seismicity. If the increase of hydrostatic head because of reservoir impoundment results in increased pore pressure at depth, levels of seismic activity could be expected that are significantly higher than that observed during the monitoring period. Suggestions are made concerning a comprehensive induced seismicity program at Strontia Springs.

Introduction

The review covers 1) the materials furnished the U.S. Geological Survey (USGS) by the U.S. Bureau of Land Management (BLM) relating to treatment of historical seismicity, and the establishment of a low-magnitude, natural seismicity baseline in the immediate vicinity of the proposed reservoir (the documents reviewed by the USGS are listed in the Appendix) and 2) the overall program of the Denver Water Department (DWD) for evaluation of possible induced seismicity near its planned Strontia Springs reservoir.

The degree of natural seismicity in Colorado is low to moderate, as shown in studies by Presgrave (1979), Kirkham and Rogers (1978), Scott (1970), Hadsell (1968), and Algermissen and Perkins (1976). However, the state of stress in the crust near the Front Range of Colorado is high enough to result in concentrations of seismicity, particularly when works of man modify the conditions under which natural earthquakes occur.

On June 11, 1979 the Bureau of Land Management gave written authorization to the U.S. Geological Survey to review the Strontia Springs induced seismicity program and to publish the results of such reviews. This review is in accord with work proposed and costs estimated by the USGS and approved by BLM; a slightly abbreviated form of this review was sent to the Bureau of Land Management via the Assistant Secretary of Energy and Minerals on October 30, 1980. The BLM interest in the induced seismicity program at Strontia Springs arises from the planned inundation of Federal land administered by the BLM and by the U.S. Forest Service, although the dam site is on land which is owned by the Denver Water Department, Denver, Colo.

The Strontia Springs Dam, Colo., is now under construction on the South Platte River, and is located 9.4 km upstream from Kassler, Colo., about 5 km west of the eastern boundary of the Front Range, and about 37 km southwest of downtown Denver. Figure 1 is a location map for the study area; Figures 1-4 are adapted from figures contained in the reviewed material. According to the Final Environmental Impact Statement issued by BLM prior to July 1978, the dam is to be of concrete construction using a thin-arch configuration 74.1 m high with a crest length of 183.2 m. At a planned normal water elevation of 1829 m, the reservoir will be 2.7 km long, have a maximum pool depth of 73.2 m, and have a capacity of 0.0026 km^3. First concrete was poured near the end of May 1980 and scheduled completion date is May 1982. The frontispiece is an aerial photo of the finished base of the Strontia Springs dam as it appeared on the front page of the June 13, 1981 edition of the Rocky Mountain News.

The example of induced earthquakes resulting from disposal of fluids in a 3671 m-deep well at the Rocky Mountain Arsenal (RMA), northeast of Denver is

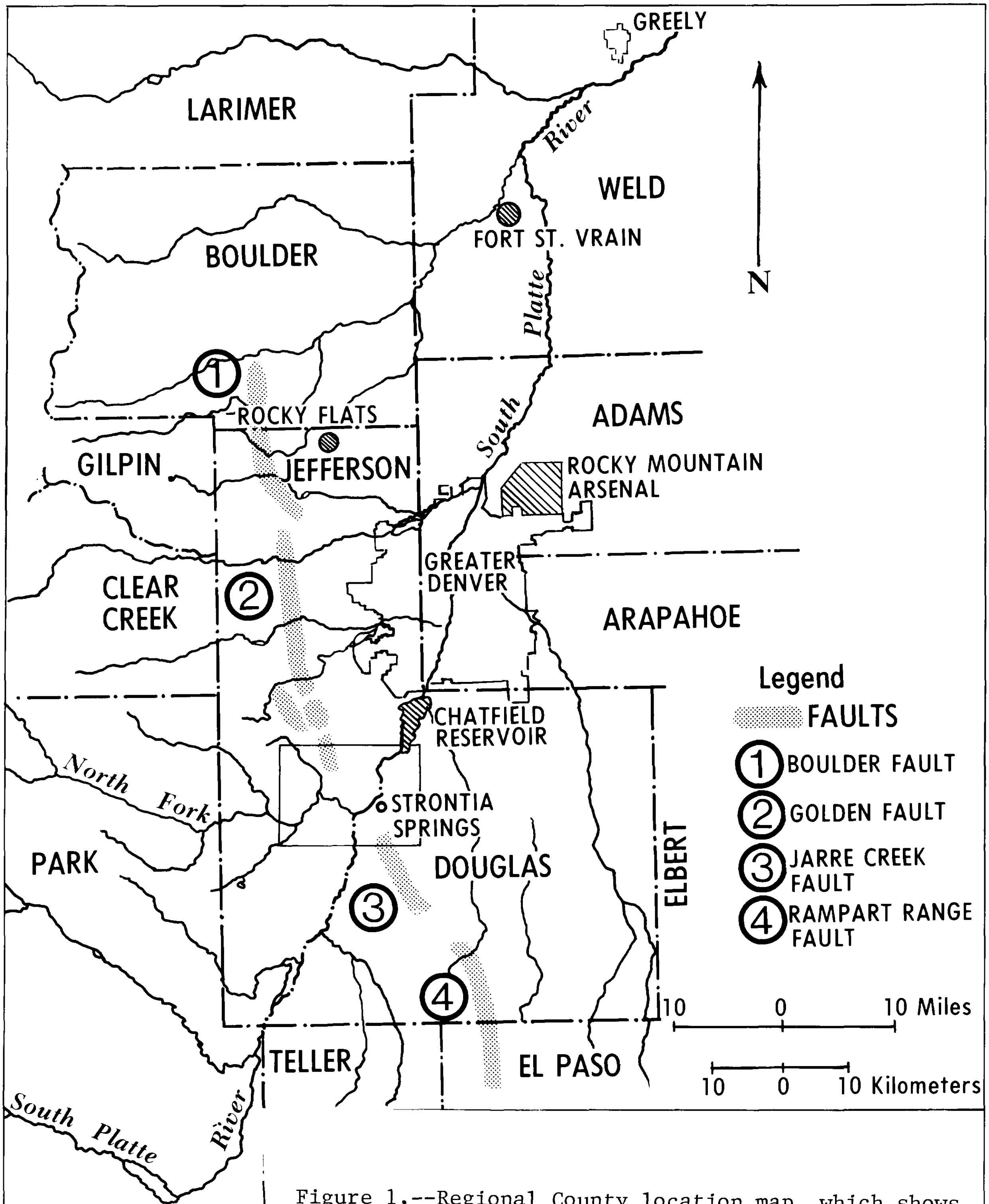

Figure 1.--Regional County location map, which shows the study area of figure 2 by a solid rectangle. Regional drainage and fault zones of the Front Range are indicated.

classic. In this case fluid injection began on 8 March 1962 and injection was stopped on 20 February 1966, because of a suggested correlation between the conditions at the disposal well and a sudden increase of seismicity in the Denver area near the disposal well (Evans, 1966). Beginning more than 1 year after cessation of fluid injection three earthquakes occurred in the magnitude-five range: 10 April 1967 (5.0), 9 August 1967 (5.3), and 26 November 1967 (5.1). Healy and others (1968) noted an absence of earthquakes in the magnitude range 4.5-4.9. Focal mechanisms for the three largest earthquakes, determined using P-wave first motion data together with long-period surface wave data (Herrmann, Park, and Wang, 1981), are each characterized by normal faulting along a northwest-striking fault plane. Thus the direction of least horizontal compression in the area is northeasterly. The rate of seismicity has since decreased, but "Denver" earthquakes associated with the source zone beneath the Rocky Mountain Arsenal are still occasionally felt. These earthquakes generally occur at depths of about 3-10 km (Major and Simon, 1968; Herrmann, Park, and Wang, 1981), align on a N 50° W trend, and have first-motion data that are consistent with normal faulting on northeast- or southwest-dipping fault planes. A reservoir analysis of the Denver earthquakes shows that these earthquakes are confined to that part of the reservoir where the pressure buildup exceeds only 32 bars, thus suggesting that the basement rock at the RMA was under significant tectonic stress and very close to failure prior to injection (Hsieh and Bredehoeft, 1981). The Denver earthquake series was a factor in the selection by the U.S. Geological Survey of the Rangely Oil Field, western Colorado, to conduct an experiment in earthquake control (Raleigh, Healy, and Bredehoeft, 1976) by controlling the pore pressure at a buried fault zone.

The cases of induced seismicity at Rangely and at the Rocky Mountain Arsenal are interpreted as resulting from increased pore pressure that lessened the normal stresses acting across a preexisting fault, such that existing tectonic stresses could lead to earthquake activity along that fault. The accepted mechanism for reservoir-induced seismicity is the same as inferred for these cases of induced seismicity in Colorado, provided certain conditions are met. The newly added weight of reservoir water will load stresses on nonvertical faults, which tends to offset the effects due to pore pressure increases (Bell and Nur, 1978). Thus it has been observed in compressional environments with old thrust faults, that seismicity actually may decrease following reservoir impoundment (e.g., Jacob and others, 1979). However, the faults in the Strontia Springs section of the Platte Canyon are vertical, striking northwest. This orientation is similar to that found for the Denver earthquake series and there are several indications that the local tectonic stress field is oriented such that movement could be induced on the northwest-trending faults in the South Platte Canyon.

In addition to stress considerations, water acts to reduce the coefficient of initial friction (Byerlee, 1978; Stesky, 1978), and it has some long-term chemical rock-weakening effects (Orowan, 1944; Griggs, 1967). However despite such effects, reservoir-induced stresses (order of bars at depth) are probably not of sufficient magnitude to initiate fracturing in the absence of a tectonic or a residual stress (Bell and Nur, 1978).

The local structural arrangement of permeable and impermeable strata likely will exert a strong control on the mechanism by which changes in reservoir level will communicate pore pressure changes through the subsurface rocks. Thus even if vertical faults exist in the immediate zone of the Strontia Springs reservoir, which should act as hydraulic conduits for such pore pressure changes, it is possible that steeply-dipping impermeable strata will act as barriers to pore pressure equilibration at a given depth horizon. Such conditions could lead to existence of zones that are subhydrostatic and offer the potential for a greater pore pressure changes than would simply arise from the change in hydraulic head due to the reservoir itself. An observational example of the influence of local variations in permeability in a complex geologic zone on reservoir induced seismicity is given in the paper on induced seismicity at the Nurek, Tadjikistan, USSR reservoir by Leith, Simpson, and Alvarez (1981).

An important parallel may exist between the tectonic situations at Strontia Springs and the Rocky Mountain Arsenal. At the RMA, the ambient level of shear stress was high and a moderate change in pore pressure triggered the earthquakes. The initial pore pressure at the RMA was subhydrostatic, and merely raising the pore pressure to hydrostatic triggered the events. At Strontia Springs the background seismicity indicates that the ambient shear stress level is high. If the pore pressure at depth is subhydrostatic, the subsurface change in pore pressure resulting from impoundment can be much greater than that resulting from the 73 m reservoir head. In this case, provided that permeability barriers are overcome by the increased pore pressure, the chance for induced seismicity to occur would be high.

Simon (1969) noted that seismicity has been observed at some Colorado reservoir sites, namely Cabin Creek (Georgetown, Colo.), Lake Hattie, Harvey Gap, and Mount Gunnison (Blue Mesa reservoir) but does not identify this seismicity as particularly associated with the presence of these reservoirs. It is clear that the regional state of stress, particularly at the Front Range and to about 150 km west of this boundary (Presgrave, 1979), is sufficient to result in a low-to-moderate level of natural seismicity, and that there exists a tangible risk of inducing earthquake activity when activities of man alter the local stress conditions in the shallow crust.

Review of Baseline Seismicity Study

MicroGeophysics Corp., Golden, Colo., operated five seismometers in the immediate zone of the Strontia Springs Dam site, from January 1, 1978 through July 12, 1978, in an attempt to establish a baseline of natural seismicity for the immediate zone of the Strontia Springs reservoir. The five stations were operated at high magnification and were supplemented by the WWSSN seismographic station operated by the Colorado School of Mines at Bergen Park (GOL). The station network was reconfigured several times because of severe weather or because of changing seismic noise conditions; all station sites are shown in Figure R2. From a technical standpoint, the seismicity baseline study was well executed, recording high quality data for a high percentage of possible station days. However, considering the low seismicity rate in the Front Range of Colorado, the six months duration of this experiment is almost certainly too short to establish a local seismicity baseline for the Strontia Springs region. The documents summarizing the baseline seismicity study are listed in the Appendix to this review. Figures in this review are based on figures in documents 1 and 9, dated September 17, 1977 and December 14, 1978.

The Front Range has numerous mining operations that engage in blasting. A portion of the MicroGeophysics Corp. effort involved development of criteria to discriminate between blasts and natural seismic events; numerous illustrations of actual blast and natural microearthquake seismic signatures are given. This effort intitially adopted the approach of Presgrave (1979) to retain only natural seismic events occurring during the normal hours of blasting, by determining the off-hours rate of natural activity, assuming a long-term rate of natural activity that is independent of time of day, and then adding a proportionate number of probable natural events during the normal hours of blasting. The MicroGeophysics study identified distinctive seismic signatures for natural events and subsequently used this criterion for identification of the specific natural earthquakes that occurred outside the normal hours of blasting. Of 1069 logged seismic events, it is stated that 32 local events of probable natural origin were located (Table 5.1 shows 34 such events, Figure 5.1 shows 36 such events. The reason for this discrepancy is unclear.) These events, within about 25 km (S-P time $\leq$ 3.0 s) of the dam site, were located using a local velocity model consisting of a 1.95 km-thick surface layer of V_p = 5.1 km/s overlying a half-space of 5.95 km/s, that was developed for this study from local blast data. Local magnitudes were determined for each of these probable microearthquakes. The 10 largest of these local earthquakes had magnitudes greater than +0.85, four of these having magnitudes larger than +1.00, and the largest magnitude being +1.82. Average magnitudes were determined using a local magnitude scale based on the maximum amplitudes recorded for each earthquake.

After the baseline seismicity monitoring period there occurred two significant local crustal earthquakes, each with several recorded aftershocks. The first of these occurred on January 6, 1979 and was a magnitude-2.9 earthquake (NEIS, 1979) approximately 30 km south of the proposed Strontia Springs reservoir. This natural earthquake caused slight damage at the town of Cripple Creek (MM=VI) and was felt in Teller, Fremont, El Paso, and Park Counties. The epicenter of this earthquake (38.963° N, 105.160° W) is near the town of Divide, Colo. and may possibly be associated with the Divide fault, which is a high-angle, north-trending fault that has been active recently enough to displace Pleistocene glacial deposits (Glenn

Scott, personal communication, 1979). The second of these earthquakes occurred on November 2, 1981 (UTC) and was a magnitude 2.8 event (NEIS, 1981). Its approximate epicenter (39.513°N, 105.257°W, NEIS, 1981) is about 15 km northwest of the proposed Strontia Springs reservoir and about 15 km southeast of the community of Evergreen, Colo. This natural earthquake was widely felt in Jefferson and Park Counties.

The level of microearthquake activity found during this baseline study is significant. It implies that the regional level of stress immediately west of the Front Range border faults is sufficient to lead to the occurrence of natural earthquakes. This is a much higher level of background seismicity than found in the specific area of the Chatfield dam and reservoir, east of the Front Range border faults and approximately 10 km from the Strontia Springs dam site (Fasset, 1975).

The MicroGeophysics microearthquake baseline study found two important space-time groupings of microearthquakes (figure 2). The first group is a 7 km-long trend of 13 events, that is north and subparallel to the Platte Canyon, slightly upstream from the dam site. The hypocenters of this group are generally between 11 and 16 km deep (figures 3 and 4) and the largest event has a magnitude of about +0.6. Nearly half of these events occurred during a 1-month period in February and early March 1978. The first group of hypocenters indicate a definite northeast-trending, mid-crustal lineation. These events are <u>within</u> the station network and have good location resolution. The second group is a cluster of 9 events, centered approximately at a point 7 km northwest of the dam site. The hypocenters of this group are generally between 3 and 8 km deep (figures 3 and 4) and the largest has a magnitude of about -0.2. Nearly half of the second group of events occurred during a one-month period in late May and early June. These events do not

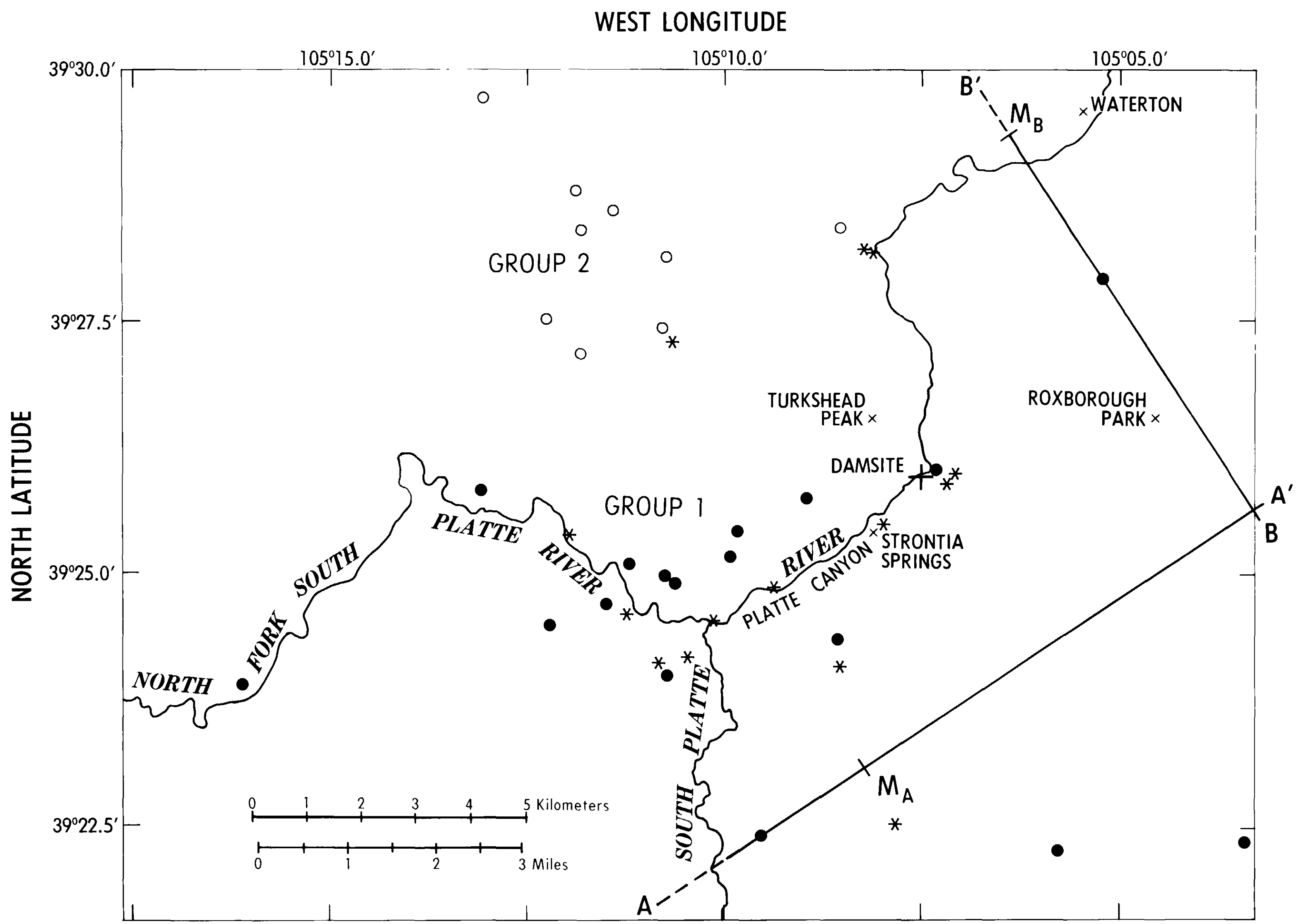

Figure 2.--Epicenter map of 22 natural microearthquakes occurring within about 12 km of the Strontia Springs dam site during January 1, 1978, through July 12, 1978. Seismic station locations shown by asterisks, Group 1 epicenters shown by solid circles, and Group 2 epicenters shown by open circles. Hypocenters are projected on vertical sections taken through A-A' and B-B' (midpoints of each line indicated as M_A and M_B and are shown in figures 3 and 4.

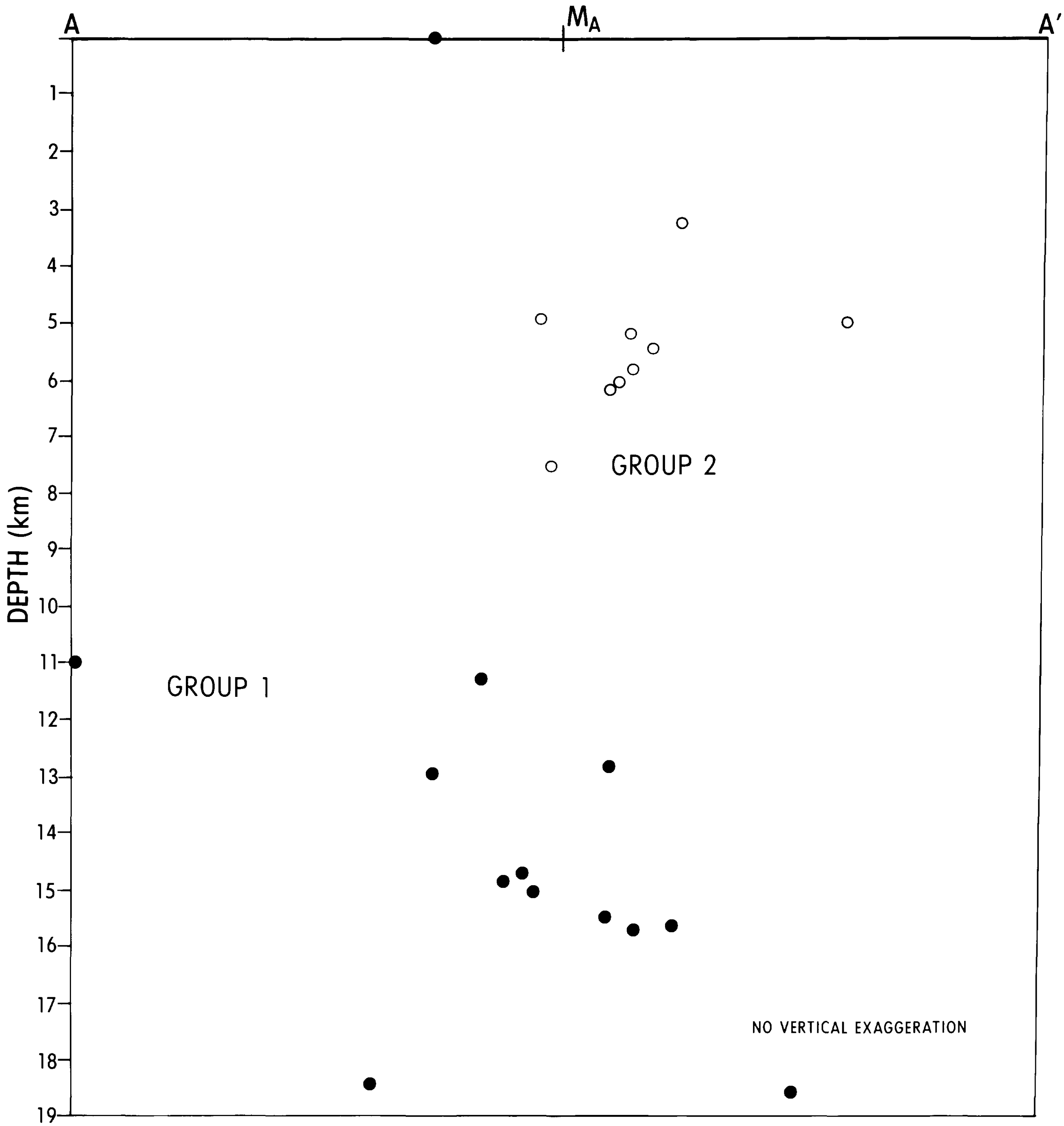

Figure 3.-- Hypocenter cross-section of earthquakes in figure 2, taken perpendicular to the local strike of the Front Range. Midpoint of section indicated by M_A here and in figure 2. Seismic station locations shown by asterisks, Group 1 hypocenters shown by solid circles, and Group 2 hypocenters shown by open circles.

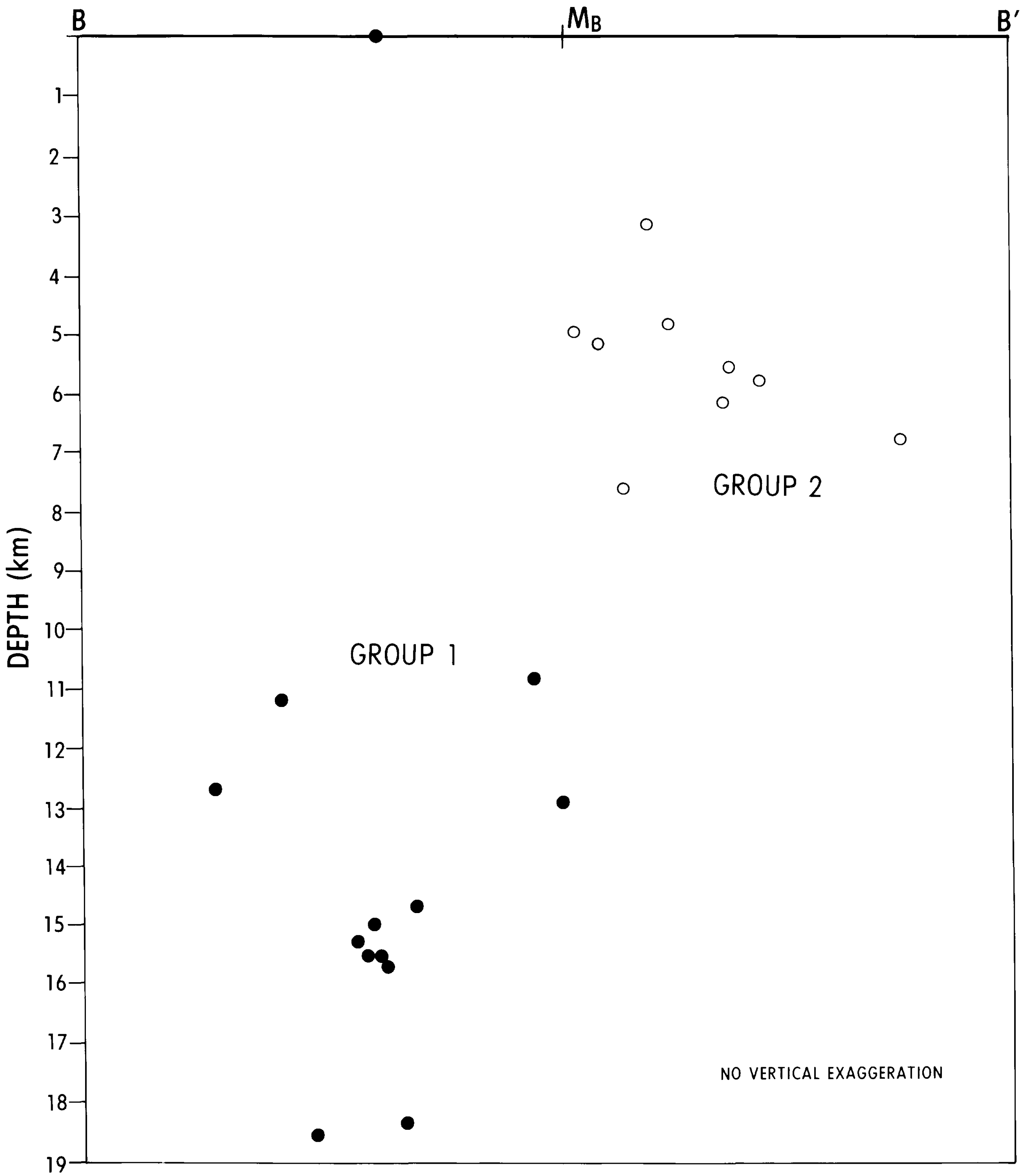

Figure 4.--Hypocenter cross-section of earthquakes in figure 2, taken parallel to the local strike of the Front Range. Midpoint of section indicated by M_B here and in figure 2. Seismic station locations shown by asterisks, Group 1 hypocenters shown by solid circles, and Group 2 hypocenters shown by open circles.

define a planar surface but appear to be distributed throughout a source volume. The data in the MicroGeophysics report are not adequate to evaluate how much of this location distribution could be due to lack of resolution in the location of these events which are on the outside periphery of the station network.

There is an unambiguous spatial gap between these two groups of microearthquakes, both in their epicenters and in their depth distributions (Figures 2, 3, and 4). Likewise, these two groups of microearthquakes are strongly clustered at different time intervals. One must assume that if the high-resolution microearthquake monitoring were to be extended for an indefinite time interval that still other space-time groupings of earthquake activity would be observed. Possibly such natural activity could occur directly beneath the Strontia Springs Dam and reservoir site.

The baseline seismicity study conducted for the Denver Water Department could be made more useful if each of the five following suggestions for further analysis could be addressed:

1. Provide versions of table 5.1 and plate 5.3 that are cross-indexed, such that each earthquake in plate 5.3 clearly corresponds to an earthquake in table 5.1 (document 9).
2. Attempt to determine a composite focal mechanism for the microearthquakes identified as grouping north and sub-parallel to the Platte Canyon (group one) and discuss the results. If an actual focal mechanism solution is not possible, discuss internal consistencies of the first motion data and the focal mechanisms with which these data are consistent.
3. State exactly which station configuration was used for the computation of the theoretical threshold of detection contours shown in figure 5.2

(document 9). Also provide some statement as to how these threshold contours change with the actual changes in station configuration.

4. In document 9 the located microearthquakes of table 5.1 are broken up into three classes of location quality. In figure 5.6 and plate 5.3 the theoretical confidence ellipses are indentical for all located microearthquakes. Show the actual confidence ellipses for each located microearthquake, corresponding to the actual location accuracy that is indicated in table 5.1 or, minimally, indicate the range of confidence ellipse sizes that correspond to each class of location quality given in table 5.1.
5. Determine a recurrence curve in the manner of figures 5.3-5.5, for all local (L) earthquakes located during the seismicity baseline monitoring, and discuss.

A Comprehensive Induced Seismicity Program

If reservoir-induced earthquakes occur during or following the "rapid filling" stage of the Strontia Springs reservoir, how can these earthquakes be interpreted to indicate some probability of the occurrence of a damaging earthquake? This question must be addressed to fulfill the Right-of-Way-Grant stipulations: "If at any time during the initial filling of the reservoir (there is) an abnormal increase or localization of seismic activities, the Grantee shall take those measures approved by the Grantor." It is assumed that the Grantor may request extension of the recording period beyond the initial filling stage, although the DWD has informally questioned such authority by the Grantor. We note that the five largest reservoir induced earthquakes known to have occurred world-wide by the time of Simpson's (1976) study ranged in magnitude from 5.7 to 6.3 and occurred an average of 3.8 years following reservoir filling (ranging in time from 0.6 to 7.2 years). The 1975

Oroville, Calif., main shock is the smallest of these and occurred 6 years following the filling of Lake Oroville (Bufe and others, 1976). The Lake Oroville epicenter was located 11 km downstream from the Oroville dam and the aftershocks occurring during the following 2 months migrated up to the dam itself (Bufe and others, 1976). Given the complexities of a real fault zone, the determination of the probability of a damaging induced earthquake on the basis of an "abnormal increase or localization of seismic activities" is obviously a difficult task.

However, knowledge of certain physical properties of the crustal zone of interest could improve the validity of any interpretations of the space and time patterns of induced seismicity in regard to the probability of a damaging induced earthquake. In an experiment on earthquake control, Raleigh, Healy, and Bredehoeft (1976) found that earthquake occurrence and distribution could be linked to changing pore pressures at depth, provided that the local stress state was significantly high. Bell and Nur (1978) concluded from theoretical grounds that simple in situ borehole estimates of pore pressure, permeability, and stress could be of great use in evaluating induced seismicity. Zoback, and others (1979) and Zoback (1980) measured in situ stress, pore pressure and permeability, and the distribution of natural fractures and joints in 1-km deep wells drilled into each of two clusters of induced microearthquakes beneath the Monticello reservoir, South Carolina. They found that an increase of subsurface pore pressure of only 2 bars was sufficient to trigger near-surface earthquakes. The Monticello reservoir is only 52 m deep but experienced over 100 events per day for a brief period after impoundment. The largest reported event had a magnitude of 3.0, resulting in a peak acceleration of 0.25 *g* at the base of the dam structure. Two other South Carolina reservoirs have had significant induced seismicity: Clark Hill (max.

depth = 67 m, max. magnitude = 4.3; Talwani, 1976 and 1979) and Lake Jocassee (max. depth = 102 m, max. magnitude = 3.2; Talwani, 1977 and 1979). The importance of detailed geologic information on the arrangement of permeable and impermeable strata is discussed in the paper by Leith, Simpson, and Alvarez (1981).

Data on in situ pressure, permeability, the arrangement of permeable and impermeable strata, and stress do not exist for the Strontia Springs site -- neither at very near surface nor at subsurface depths. Pumping tests could provide estimates of bulk permeability and hydraulic transmissibility. We know that surface faults and shear zones strike northwest, which presumably act as hydraulic conduits, whereas the MicroGeophysics microearthquake study suggests an earthquake distribution at depths of 11-16 km beneath and parallel to the section of the South Platte Canyon that is to be flooded by the Strontia Springs reservoir. We do not know the pore pressure distribution at depth beneath the proposed reservoir. It seems reasonable that this pore pressure could be hydrostatic, assuming that waters of the South Platte River permeate to depth and that an equilibrium hydrostatic condition exists there. If so, 7.2 bars excess pore pressure (0.098 bars/m of water depth) could arise from the filling of the Strontia Springs reservoir. However, the results from the Rocky Mountain Arsenal suggest that barriers to water flow leave crustal sections that are sub-hydrostatic. In this case much larger pore pressure changes at depth could occur. We cannot now determine with certainty the likelihood that when the pore pressure at depth is increased the local stress field is of sufficient magnitude and "oriented" such as to trigger movement on existing faults. The regional axis of least compressive stress is inferred to be oriented northeast-southwest; there is no information on the local state of stress in the immediate zone of the Strontia Springs reservoir.

It is possible that an observed rate of migration of microearthquake hypocenters could be linked to the rate of migration of pore pressure changes, as controlled by the formation permeability. Clearly, the larger the zone involved in microearthquake activity, the larger may be the maximum size of a possible induced earthquake. If induced microearthquakes occur beneath the Strontia Springs reservoir, it is also possible that a statistical treatment could suggest future characteristics of earthquake behavior (Papazachos, 1973 and 1974). To accomplish this a permanent seismic network should be established at least 1 year prior to impoundment.

We conclude that in situ borehole measurements of formation permeability, stress, and pore pressure are very important data in the interpretation of the probability for induced seismicity to occur. Such measurements could prove important in regard to estimation of the maximum size of a possible induced earthquake, by permitting interpretation of the statistical characteristics of possible induced earthquakes and to provide a basis for physical interpretation of the space-time distribution of possible induced earthquakes.

Acknowledgments

The critical comments of Mark Zoback, Frederick Houser, Robert Engdahl, and Louis Pakiser were most helpful in preparing this review. This review was supported under contract from the Bureau of Land Management.

References Cited

Algermissen, S. T., and Perkins, D. M., 1976, A probabilistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geological Survey Open-File Report 76-416, 45 pp.

Bell, M. L., and Nur, A., 1978, Strength changes due to reservoir-induced pore pressure and stresses and application to Lake Oroville: Journal of Geophysical Research, 83, 4469-4483.

Bufe, C. G., Lester, F. W., Lahr, J. C., Seekins, L. C., Hanks, T. C., 1976, Oroville earthquakes: normal faulting in the Sierra Nevada foothills: Science, 192, 72-74.

Byerlee, W., 1978, Friction of rocks, Pure Appl. Geophys., 116, 615-626.

Evans, D. M., 1966, The Denver earthquakes and the Rocky Mountain Arsenal disposal well: The Mountain Geologist, 3, 23-26.

Fasset, J. W., 1975, Seismicity near the Chatfield Dam, Denver, Colorado: M.S. Thesis, T-1676, Colorado School of Mines, Golden.

Griggs, D. T., 1967, Hydrolitic weakening of quartz and other silicates: Roy. astron. Soc. Geophys. J., 14, 19-31.

Hadsell, F. A., 1968, History of earthquakes in Colorado: Quarterly Colorado School Mines, 63, 57-72 (with 2 plates).

Healy, J. H., Rubey, W. W., Griggs, D. T., and Raleigh, C. B., 1968, The Denver earthquakes: Science, 161, 1301-1310.

Herrmann, R. B., S-K Park, and C-Y Wang, 1981, The Denver earthquakes of 1967-1968, Bull. Seism. Soc. Am., 71, 731-745.

Hsieh, P. A., and Bredehoeft, J. D., 1981, A reservoir analysis of the Denver earthquakes: a case of induced seismicity, J. Geophys. Res., 86, 903-920.

Jacob, K. H., Pennington, W. D., Armbruster, J., Seeber, L., and Fahratulla, S., 1979, Tarbela reservoir, Pakistan: A region of compressional tectonics with reduced seismicity upon initial reservior filling: Bull. Seism. Soc. Am., 69, 1175-1192.

Kirkham, R. M., and Rogers, W. P., 1978, Earthquake Potential in Colorado, a preliminary evaluation: Colorado Geological Survey Open-File Report 78-3, Denver, Colorado, 135 pp.

Leith, W., D. W. Simpson, and W. Alvarez 1981, Structure and permeability: Geologic controls on induced seismicity at Nurek reservoir, Tadjikistan, USSR, Geology 9, 440-444.

Major, M. W., and Simon, R. B., 1968, A seismic study of the Denver (Derby) earthquakes: Quarterly Colorado School of Mines, 63, 9-55.

NEIS (National Earthquake Information Service), 1979, Preliminary Determination of Epicenters, Monthly Listing January, 1979: U.S. Geol. Survey, Arlington, Va., 22202.

Orowan, E., 1944, Fatigue of glass under stress, Nature, 154, 341-343.

Papazachos, B. C., 1973, The time distribution of the reservoir associated foreshocks and its importance to the prediction of the principal shock: Bull. Seism. Soc. Am., 63, 1973-1978.

Papazachos, B. C., 1974, On the relation between certain artificial lakes and the associated seismic sequences: Engr. Geol., 8, 39-48.

Presgrave, B. W., 1979, The seismicity of Colorado: An Estimate of Hazard Derived from Instrumental Data: M.S. Thesis, T-1790, Colorado School of Mines, Golden, Colorado, 81 pp.

Raleigh, C. B., Healy, J. H., and Bredehoeft, J. D., 1976, An experiment in earthquake control at Rangely, Colorado: Science, 191, 1230-1237.

Scott, G. R., 1970, Quaternary faulting and potential earthquakes in east-central Colorado: U.S. Geological Survey Professional Paper 700-C, C11-C18.

Simon, R. B., 1969, Seismicity of Colorado: consistency of recent earthquakes with those of historical record: Science, 165, 897-899.

Simpson, D. W., 1976, Seismicity changes associated with reservoir loading: Engineering Geology, 10, 123-150.

Stesky, R. M., 1978, Rock friction effect of confining pressure, temperature, and pore pressure, Pure Appl. Geophys., 116, 690-704.

Talwani, P., 1976, Earthquakes associated with the Clark Hill reservoir, South Carolina--a case of induced seismicity: Engineering Geology, 10, 239-253.

Talwani, P., 1977, Stress distribution near Lake Jocassee, South Carolina: Pure and Applied Geophysics, 115, 275-281.

Talwani P., 1979, Induced seismicity and earthquake prediction studies in South Carolina: Final Technical Report, USGS Contract No. 14-08-0001-14553 Department of Geology, University of South Carolina, 36 pp.

Zoback, M. D., 1980, In-situ study of the mechanism of reservoir triggered earthquakes in the southeastern United States: Proc. Res. Conf. on Intra-continental earthquakes, Ohrid, Yugoslavia, Sept. 17-21, 1979 (in press).

Zoback, M. D., Roller, J. C. Svitek, J., Seeburger, D., and Amick, D. C., 1979, The mechanism of induced seismicity at Monticello reservoir, South Carolina: in situ studies at hypocentral depth: EOS, 60, 881-882.

APPENDIX--REPORTS ON THE STRONTIA SPRINGS SEISMICITY PROJECT

furnished by the Denver Water Department to the Bureau of Land Management and reviewed under USGS contract

Document No.	Date of Report	Title
1	Sept. 23, 1977	Seismological Investigation of the South Platte River Canyon: Foothills Treatment Plant
2	Feb. 14, 1978	Progress Report for January 1978 Strontia Springs Seismicity Project
3	Not known	Progress Report for February 1978 Strontia Springs Seismicity Project
4	Not known	Progress Report for March 1978 Strontia Springs Seismicity Report
5	May 23, 1978	Summary Status Report for January, February, and March 1978 Strontia Springs Seismicity Project
6	May 16, 1978	Progress Report for April 1978 Strontia Springs Seismicity Project
7	June 12, 1978	Progress Report for May 1978 Strontia Springs Seismicity Project
8	Aug. 10, 1978	Progress Report for June and 12 days of July 1978 Strontia Springs Seismicity Project
9	Dec. 14, 1978	Strontia Springs Project Seismicity Report (with separate volume of appendices)