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Earth Sciences Division

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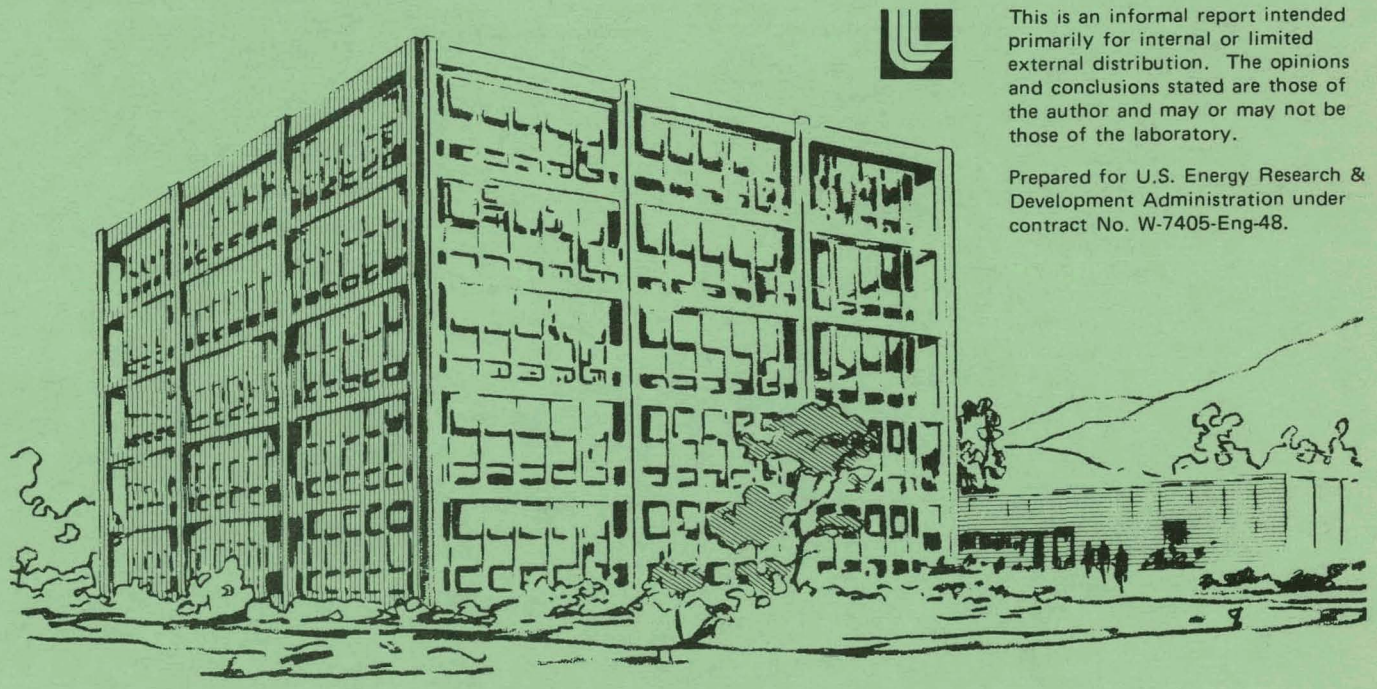

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ANNUAL REPORT -- 1976

ABSTRACT

This compilation lists abstracts of papers, internal reports, and talks presented during 1976 at national and international meetings by members of the Earth Sciences Division, Lawrence Livermore Laboratory. A subject index is included.

ABEY,* A. E., A model for the prediction of the pressure-volume relationship of porous rocks (Sympos. Rock Mechanics, Snowbird, Utah, August 1976) Lawrence Livermore Laboratory, Rept. UCRL-77938, Abstract (1976).

Several models have been suggested to describe the volume behavior of porous materials under hydrostatic loading. The model presented here accounts for variations in both porosity and the amount of fluid contained within that porosity. The model also attempts to predict the one-dimensional strain loading pressure-volume relationship and the stress difference-confining pressure curve. Only the simplest assumptions were used for the development of this model. These assumptions are discussed and the predictions for Mt. Helen tuff are compared to experimental data.

ABEY, A. E., A model for predicting the hydrostatic loading and unloading relationship of porous materials containing various amounts of fluid, Lawrence Livermore Laboratory, Rept. UCRL-78290, Rev. 1, Preprint (1976).

An elastic-inelastic model is presented for the loading and unloading pressure-volume relationship of porous materials containing various amounts of fluid from 0 to 100% saturation. Distributions in both size and separation of connected and unconnected spherical and connected penny-shaped pores are assumed. The number of pores with a given size is assumed to be inversely proportional to the initial volume and independent of the separation between pores. The simple relationships relating the radius of a pore to the applied pressure are discussed. The pressure-volume relationship for

*Names of senior authors appear in full caps. Abstracts follow the entry for the first author listed who is a member of the Earth Sciences Division.

the porous material with any saturation is calculated using the input parameters, shear strength, shear modulus, matrix and fluid pressure-volume relationships, and the pressure-volume data for the dry material. Model predictions agree with the experimental data within experimental error for all saturations and at pressures up to 4 GPa (40 kbar) for Mt. Helen tuff.

Abey, A. E.,SCHOCK, R. N., and Duba, A., Quasistatic deformation of porous beryllium and aluminum, J. Appl. Phys. 47, 53-63 (1976). [UCRL-76587, Preprint]

ACKERMAN, F. J. and Sandholtz, W. A., Oil shale retort experiments simulating in-situ operations (AIME Soc. Petrol. Eng. Ann. Tech. Conf. & Exhib., New Orleans, October 1976) Lawrence Livermore Laboratory, Rept. UCRL-77830, Abstract (1976).

A small 125 kg oil shale retort 0.3 m diameter by 1.5 m long (1' x 5') has been in operation for some time. More recently a 7 tonne retort 0.9 m diameter by 6 m long (3' x 20') has begun operation.

Both retorts are equipped for adiabatic operation by using sidewall heaters to minimize heat loss and thus simulate in-situ operation. A description of both retorts is given, along with a description of the computer system used for on line data display, process control and data acquisition.

Results of non-adiabatic and adiabatic operation of the small retort are presented. Results of the initial large retort run are also given. On-line composition measurements of gas withdrawn from the center of the retorting shale show that oxygen is consumed by char and does not reach the retorting oil. Other aspects of the retorting process can also be seen.

Anderson, G. D., and LARSON, D. B., Shock-wave studies of subbituminous coals, Lawrence Livermore Laboratory, Rept. UCRL-51996 (1976).

BONNER, B. P., A modified ultrasonic pulse-transmission method for simultaneous measurement of t_S and t_P, Trans. Am. Geophys. Union 57, 324 (1976). [UCRL-77646, Abstract]

The time-of-flight technique has been adapted for use with porous, low-Q earth media under confining pressures (0.2 GPa = 2 Kb) with superposed uniaxial stress. Large cylindrical specimens (10 cm by ~18 cm long) are isolated from the pressure medium by polyurethane jackets. Hollow (pressure free) metal pistons (aluminum or hardened steel) contain the polycrystalline Pb $(Zr,Ti)O_3$ elements which generate and receive ultrasonic pulses. The

ceramic transmitter (a 5 cm square with a dominant frequency of 250 kHz) is polarized for transverse shear, but produces ample compressional energy. The receiving transducer acts as a simple array which includes three active elements: a heavily damped stack of two 1 MHz discs which detect the p wave, and two matched 250 kHz shear plates which detect s. Compressional and shear arrivals are separated mechanically at the shear plates, amplified, and then differenced to produce an enhanced shear arrival. Amplitude ratios (s to p) have been improved by a factor of ~2; measurements for unconsolidated, partially saturated, alluvial soil as a function of pressure, and stressed, saturated granodiorite, illustrate the use of the technique. System delays are evaluated by timing with and without a sample between the loading pistons. Accuracy for low-Q media is ~4%, but precision during a single experiment ~2%. All electronic components, or equivalents, are available commercially.

Bonner, B. P., HEARD, H. C., Costantino, M. S., Schock, R. N., and Weed, H. C., Mechanical response of saturated Kemmerer coal to 4 GPa, Lawrence Livermore Laboratory, Rept. UCRL-52063 (1976).

BORG, I. Y. and O'Connell, L. G., Lithium's role in supplying energy in the future, Energy Sources 2, 347-359 (1976). [UCRL-76845, Preprint]

Lithium's unusual properties as a metal have propelled it into the forefront of materials destined to play an important role in the economy of the next century. It promises to be an important component of the breeder blanket of controlled thermonuclear reactors as well as hybrid fission-fusion reactors that may serve to transmute high-level waste generated by conventional fission reactors. About 100-1000 kg of natural lithium are required per megawatt-electric. Lithium-water-air and lithium-sulfide batteries have been tested and show great promise of becoming the batteries for electric automobiles in the future. One of these batteries can just as well serve for local off-peak energy storage in the utility industry. Similarly, they can be used for intermittent energy sources (wind, tidal, and solar power). The current lithium reserves and resources will be hard put to meet customary demands for lithium, which are increasing at a rate of 8-10%/yr, so the U.S. supply will have to be expanded by increased exploration.

BORG, I. Y., Stone, R., Levy, H. B., and Ramspott, L. D., Movement of radioactivity deposited underground at the U.S. ERDA Nevada Test Site, Lawrence Livermore Laboratory, Rept. UCRL-78670, Preprint (1976).

Movement of radioactivity has been minimal at the U.S. ERDA Nevada Test Site (NTS) and relates to the low rain fall in the area and the general phenomenology of nuclear explosions. Most refractory fission products and unspent fuel are captured in lithological glasses produced by the explosion, and there is forceful ejection of water from the immediate vicinity of the explosion. Return of the water into the rubblized site inaugurates leaching processes and consequent mobilization of nuclides. The slow to moderate movement of the ground water in the aquifer within northern portions of NTS, 76 to 180 (maximum) meters/year depending on locale, has contributed to the slow movement of the tritium, the most mobile of the radionuclides. Sorptive processes are especially important in retarding nuclide movement at NTS. The altered tuffaceous rocks, which comprise a large portion of the rock in the saturated zone, are rich in zeolites (clinoptilolite) and clays (montmorillonite and illite) which effectively absorb many radionuclides moving through the formation. To date no radioactivity has been detected beyond the bounds of the Nevada Test Site nor within any of the approximately 32 water wells within or beyond the boundaries of the site. All water used at the site continues to come from wells not far from areas of active underground testing.

BORG, I. Y., Use of reserve/resource estimates by a National ERDA Laboratory, Lawrence Livermore Laboratory, Rept. UCRL-78689, Abstract (1976).

The 1973 embargo and subsequent price increases focused the attention of the nation and the national laboratories on reserve/resource data for energy fuels. Formation of ERDA emphasized the increased interest in long range R&D with the objective of developing novel energy sources.

Planning requires 1) reconnaissance of the extent of this nation's reserves/resources, 2) understanding of what these traditionally tabulated numbers mean and 3) a choice be made between the diverse estimates available. The purpose is to recognize short supply, to estimate lead times available to develop alternative sources and to pinpoint potential resources that require extensive, multidiscipline R&D efforts to develop.

The role of a national laboratory is to pursue long-range projects where initial investment of time and money may be unrealistic from industry's point-of-view. Nonetheless, industrial cooperation is vital to their success.

Before fruitful programs are selected, funded and inaugurated, a new set of information pertaining to fossil reserves/resources is needed. These data tend to be specific and are usually difficult to garner from current sources such as API, AGA, NPC or USGS surveys. They include information on attitude and thickness of continuous sections, e.g., of heavy oil accumulations or oil shale; these data are crucial to the technology chosen for the development of the resource. The depth of these accumulations is pertinent as is location of the resource. Large accumulations in populated areas pose special problems as do diffuse resources spread over hundreds of square miles. There is currently no single recognized data bank containing information of this type. It is largely proprietary and uncollated. Increased cooperation on this score between industry and government is needed in order to develop these novel fuels.

As a consequence of study and reviews at Lawrence Livermore Laboratory, large on-going programs have evolved. They deal with in-situ coal gasification and oil shale retorting, laser enrichment of uranium, utilization of geothermal brines and a transportation program designed to develop alternate automotive fuels (MeOH, MeOH-gasoline, Li-air-H_2O battery) and alternate/hybrid engines for them.

BORG, I. Y., One view of the world's petroleum supplies, Lawrence Livermore Laboratory, Rept. UCRL-52075 (1976).

Using plausible assumptions and recent data, this report outlines a series of circumstances that imply that the OPEC cartel would falter, with the result that world crude-oil prices would be lowered. A further consequence would be that costly pilot-plant projects designed to develop alternative fuels would seemingly be hard to justify and appear to have developed in a less-than-timely fashion. However, ultimate depletion of world supplies at the turn of the century would restore the favorable economic climate for research and development on alternative fuels.

The argument rests on continued and rapid expansion of worldwide crude-oil supplies, a reduced free-world demand dictated by high-priced oil until 1981 (2.9% average annual rate in the period 1974 to 1980 or 5.5% on the basis of the recession year 1975 to 1980), and lastly the fact that the OPEC nations' ambitious long-range plans determine the minimum levels to which they will allow their production to fall. The consequences of lower prices are increased world demand for crude oil and ultimate return to a "seller's market" when world production approaches the point of decline toward the end of the century. No attempt has been made here to analyze the many issues and estimates that have gone into the construction of the argument. The intent of this discussion has been to point up the need for closer study of these issues and estimates since they ultimately affect national planning.

BORG, I. Y., Stone, R., Levy, H. B., and Ramspott, L.D., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 1: review and analysis of existing information, Lawrence Livermore Laboratory, Rept. UCRL-52078 (1976).

This report is a comprehensive, detailed review of what is known concerning migration of radionuclides in ground water at the Nevada Test Site (NTS). A history of NTS is given, the geologic and hydrologic setting is described, and the amount of radioactivity deposited within and near the main aquifers is estimated. The laboratory and field investigations into general processes retarding the movement of radioactivity from the source and dispersing its concentrations are described, together with results of programs designed to monitor the source terms and the movement of radioactivity at the site. The conclusions include: (1) information currently available is insufficient to state categorically that radioactivity will never be carried off the Nevada Test Site by ground water movement; (2) nonetheless, such a migration at levels above the maximum permissible concentration to existing wells and springs is considered unlikely; (3) if offsite migration occurs, it will probably be from the southwestern margins of Pahute Mesa, where there is only a small chance of contaminating existing public water supplies; (4) tritium is the most mobile radionuclide and may be the only long-lived isotope of concern; (5) predictions of migration both within and without NTS are hampered by a lack of values for fundamental parameters used in transport calculations. Recommendations for

future studies to minimize uncertainties are described and given priority ratings. Highest priority is assigned to (1) measurement of tritium and other radionuclides in large water samples taken from nuclear chimneys that water has re-entered after an explosion; (2) expansion of the existing groundwater monitoring program at NTS to include wells with a higher probability of intersecting flow of contaminated water; (3) measurement of groundwater flow velocities and other associated hydrologic parameters. High priority is assigned to (1) production of an inventory of radionuclides deposited near NTS borders, especially beneath Pahute Mesa; (2) determination of amounts of radioactivity deposited directly into the Lower Carbonate Aquifer; (3) a sensitivity analysis of the many parameters that enter into transport calculations; (4) a study of the many unplugged holes that penetrate the Tuff Aquitard; (5) testing of the assumption that radionuclides deposited in the unsaturated zone are isolated from the saturated zone because of limited precipitation and downward movement of moisture; (6) determination of distribution coefficients for NTS alluvium, carbonate, and rhyolitic rocks, which are lacking or poorly represented in the literature. Twelve other recommendations of lesser priority are also given.

BORG, I. Y., Stone, R., Levy, H. B., and Ramspott, L. D., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 2: annotated bibliography, Lawrence Livermore Laboratory, Rept. UCRL-52078, Part 2 (1976).

Part 2 of UCRL-52078 consists of the bibliography and abstracts that were compiled in the course of searching the literature for information on the migration of radionuclides at the Nevada Test Site. Because waste management at reactor sites is a problem encountered in most industrialized countries of the world, the literature on the subject of movement of radioactivity through rock and soils is international and voluminous. In many instances, the research done, both in the laboratory and in the field, has been designed to appraise special situations. The papers which are outgrowths of such studies are frequently parochial and of limited applicability to other sites with different rock types; nonetheless, the exceptional study that comes to grips with general principles governing sorption or diffusion of radioactive species can be found in this same literature. Hence, the bibliography that follows includes numerous references to work

done at foreign nuclear centers or contracted to outside agencies by these same centers.

Interest in the subject of dispersion of radioactivity reached an early zenith in the late 1950's and the 1960's. Many of the fundamentals of the subject were derived and explored during those decades. Unfortunately, the research and the thought lie in reports that are difficult to acquire or, even if they are in hand, may be so poorly reproduced as to be useless. With these circumstances in mind, we decided to abstract all of the literature that we reviewed in compiling Part 1 of this report and to assess its relevance to the situation at the Nevada Test Site.

BORG, I. Y., Stone, R., and Puchlik, K. P., Oil, gas, uranium, and thorium: supply and depletion, with special reference to California, Lawrence Livermore Laboratory, Rept. UCRL-52180 (1976).

This report summarizes information pertinent to the probable future supplies of oil, gas, uranium and thorium to the State of California. To the extent that these supplies are linked to world and U.S. resources, these sources and limitations are also reviewed. Conflicting estimates are analyzed and judgment is made as to the most reliable, current sources of information. Methods used to estimate future undiscovered resources are described. Depletion forecasts made within the last few years are compared and evaluated in terms of the total supply implicit in the forecast.

Borg, I. Y., COOPER, J. F., O'Connell, L. G., Behrin, E., Rubin, B., and Wiesner, H., Lithium requirements of electric vehicles using lithium-water-air batteries, U.S.G.S. Prof. Paper 1005, 9-15 (1976). [UCRL-77440, Preprint]

The lithium-water-air battery is a new primary battery of such exceptional power and energy that it is a candidate to provide propulsion for electric automobiles in the future. In the electrochemical reaction involved, lithium, oxygen, and CO_2 are combined, leaving Li_2CO_3 as a by-product to be removed from the battery and recycled. A subcompact car weighing 910 kg would transform 7.2 kg of lithium in traveling 320 km at 97 km/hr. At least an equal amount of lithium per car would be unavailable because of the need to recycle the by-product (Li_2CO_3). Thus, a minimum of 14.4 kg of lithium per car is required to support a transportation system

based upon this power source. Assuming that in the year 2000, 12 to 16% of all vehicles are powered by lithium-water-air batteries, we will need 234,000 to 425,000 metric tons of lithium. This amount is somewhat less than the total known U.S. lithium reserves, but if the current rate of consumption of lithium for other purposes continues, the supply of lithium will have to be increased.

BRAUN, R. L., Nondestructive determination of oil yield of oil shale blocks, Lawrence Livermore Laboratory, Rept. UCRL-77802, Preprint (1976).

The specific gravity of oil shale is widely used as a rapid and practical method of estimating the Fischer assay oil yield. The method was originally developed for use with crushed shale samples. However, the correlation can also be used as a nondestructive means of estimating the oil yield of uncrushed blocks of shale. The development of the specific gravity-oil yield relationship is reviewed and a possible source of error in applying the relationship to specific gravities measured by water immersion of uncrushed blocks of shale is illustrated.

The block immersion method must therefore be used with caution. It is most effective as a rapid means of screening samples to select candidates that may have the desired oil yield. A better estimate of the oil yield must then be made by alternative methods, such as by chemical analysis or specific gravity measurements of powdered samples prepared from adjacent parts of the starting block.

Braun, R. L., and MALLON, R. G., Reactivity of oil shale carbonaceous residue with oxygen and carbon dioxide, Colo. School of Mines Quarterly 71, 309-333 (1976). [UCRL-77829, Preprint]

Braun, R. L., and RALEY, J. H., Oil degradation during oil shale retorting, Preprints Sympos. Oil Shale, Tar Sands & Related Materials, Div. of Fuel, Am. Chem. Soc. Mtg., San Francisco, August-Sept. 1976, Vol. 21, 137-146 (1976). [UCRL-78098, Preprint]

Braun, R. L., SCHWARTZ, L. L., Cohen, J. J., and Lewis, A. E., High level radioactive waste isolation by incorporation in silicate rock, Lawrence Livermore Laboratory, Rept. UCRL-78746, Preprint (1976).

Bryan, J. B., GOODRICH, M. F., Thomsen, J. M., and Snell, C. M., Final report on a calculational parameter study of soils typical of some ESSEX I cratering sites, Lawrence Livermore Laboratory, Rept. UCRL-52038 (1976).

The one-dimensional computer calculations described in this report were performed to simulate stress-wave propagation and kinetic energy transfer associated with subsurface cratering detonations in soils. A hypothetical 20-ton-yield nuclear explosive was assumed as the energy source, surrounded by a single soil material. Various soil descriptions were selected in order to systematically study the range of soil response to the nuclear detonation. The soils were representative of the layered mixtures of sand and clay found at the ESSEX high-explosive cratering sites near Ft. Polk, Louisiana. Soil properties analyzed in this study include water saturation, bulk density, failure envelope, and low-pressure bulk modulus.

BUTKOVICH, T. R., Correlations between measurements and calculations of high-explosive induced fracture in a coal outcrop, Int. J. Rock Mech. Min. Sci. & Geomech. Abst. 13, 45-51 (1976). [UCRL-76904, Preprint]

A high-explosive fracturing experiment, part of the Lawrence Livermore Laboratory's in situ coal gasification project, was carried out in a coal outcrop near Kemmerer, WY. The primary purpose was to obtain fracture data to which a computer-code-calculated damage-indicating parameter ε_f, called failure shear strain, could be correlated. The radius at which $\varepsilon_f \approx 0.1$ corresponds to 2.8 times the cylindrical cavity radius R_{cc}, which correlates with observations of extent of pervasive fracture around spherical nuclear cavities at 2.0 R_{cs} in various rocks reported by Borg. The radius at which $\varepsilon_f \approx 0.01$ which corresponds to 8.5 R_{cc} relates to the limit of observable enhancement in permeability at 6.7 R_{cc} and other fracture-indicating measurements, such as dye penetration at 8.5 R_{cc}. This value also correlates well with observed maximum extent of horizontal fracture around nuclear cavities at 3.7 R_{cc}, and Kutter & Fairhurst's prediction of extent of radial fracture in rock.

BUTKOVICH, T. R., and Hearst, J. R., Prediction and determination of explosive-induced fracture (Soc. Explo. Eng. Conf. Explosion & Blasting Techniques, Louisville, Ky., Sept. 1976) Lawrence Livermore Laboratory, Rept. UCRL-77659, Preprint (1976).

Explosive-induced fracturing and permeability enhancement far from a free face were studied. A one-dimensional computer program, SOC, was used

to predict the total failure-associated distortional strain, ε_f. Laboratory and field experiments associated the calculated ε_f with the observed fracture and permeability enhancement. An ε_f value of 0.015 corresponded to the observed radius of effect, which was about seven times the cavity radius and was consistent with predictions from SOC and from the literature.

BUTKOVICH, T. R., Calculation of fracture and permeability enhancement from underground explosions in coal, Proc. Second Ann. Underground Coal Gasification Sympos., Morgantown, W. Va., August 1976, MERC/SP-76/3, 285-294. (Mtg. Am. Soc. Mech. Eng., Mexico City, Sept. 1976) [UCRL-77945, Preprint]

We use one- and two-dimensional computer programs to study explosive-induced fracturing and permeability enhancement. The total failure-induced deviatoric strain, a calculable parameter related to rock fracture, is used to correlate calculations with measurements. This parameter is made up of two parts, that associated with pure shear distortion and that associated with shear distortion from tensile failure. The total failure shear strain can be related to intensity of fracture, and the tensile portion can be related to the volume of tensile fractures. The latter value can be considered a measure of the crack volume generated following tensile failure. We correlate our calculations with measurements from field and laboratory experiments for both single and multiple explosions.

BUTKOVICH, T. R., Cavities produced by underground nuclear explosions, Lawrence Livermore Laboratory, Rept. UCRL-52097 (1976).

This investigation studied the displacement of rock that formerly occupied cavities produced by underground nuclear explosions. There are three possible explanations for this displacement: the volume could be displaced to the free surface, it could occupy previously air-filled pores removed from the surrounding rock through compaction, or it could be accounted for by persisting compressive stresses induced by the outgoing shock wave.

The analysis shows it unlikely that stored residual elastic stresses account for large fractions of cavity volumes. There is limited experimental evidence that free surface displacement accounts for a significant

portion of this volume. Whenever the explosion mediums contain air-filled pores, the compaction of these pores most likely accounts for all the volume. Calculations show that 4% air-filled porosity can account for all the cavity volume within about 4 cavity radii and that even 1% can account for a significant fraction of the volume.

Butkovich, T. R., HEARST, J. R., Laine, E., Lake, R., Leach, D., Lytle, J., Sherman, J., Snoeberger, D., and Quong, R., Fractures induced by a contained explosion in Kemmerer coal, Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 13, 37-44 (1976). [UCRL-51790]

CARLEY, J. F., Pressure distribution in beds of oil-shale rubble, Lawrence Livermore Laboratory, Rept. UCRL-51957, Rev. 1 (1976).

The Janssen equation for vertical distribution of pressure in beds of solid particles has been modified for application to beds of broken shale. From a measured angle of repose of sample shale piles of 40°, frictional properties of shale beds were deduced, permitting the constants of the Janssen equation to be computed. Pressure distributions in beds 30, 61, and 76 m (100, 200, and 250 ft) square and up to 427 m (1400 ft) deep were computed. The main finding was that bottom pressures (P_B) at depths of 152 m (500 ft) and more are only slightly affected by overburden pressure and asymptotically approach values given by P_B (psi) $\cong$ D (ft) or P_B (MPa) $\cong$ 0.023D (m) where D is the width of the square rubble column. Because of wall friction, these bottom pressures are generally far less, in thick beds, than the "lithostatic" equivalent of the weight of shale and overburden. Shale grade (density), rubble porosity, and uncertainties in coefficients of friction have only minor effects on the pressure distributions. Since the pressure exerted by unbroken overburdens may be expected to be small [probably less than 1.38 MPa (200 psi)], pressures are not likely to exceed 2.07 MPa (300 psi) anywhere in the bed. The major uncertainty is the temperature dependence of bed properties.

Carlson, R. C., HANSON, M. E., Emerson, D. O., Heard, H. C., and Shaffer, R. J., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, July-September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-3 (1976).

CHIN, R. C. Y. and Hedstrom, G. W., A dispersion analysis for difference schemes: tables of generalized airy functions, Lawrence Livermore Laboratory, Rept. UCRL-78668, Preprint (1976).

This paper contains graphs and tables of the function

$$Ai_{p,q}(\alpha,x) = \int_{-\infty}^{\infty} (2\pi)^{-1} \exp\{ iy^p/p - \alpha y^q/q + ixy \}\, dy$$

and its indefinite integral for p = 3, 5, 7, for q = 2, 4, 6, and for several values of α with $\alpha \geq 0$. It is shown how these tables should influence the choice of an artificial viscosity for a difference scheme for a linear hyperbolic equation.

Chin, R. C. Y. and DENNY, M. D., Gaussian filters for determining group velocities, Geophys. J. R. astr. Soc. 45, 495-525 (1976). [UCRL-76809, Preprint]

CHUNG, D. H., On the composition of the oceanic lithosphere, J. Geophys. Res. 81, 4129-4134 (1976). [UCRL-77525, Preprint]

The composition and elastic properties of the earth's lithosphere beneath the sea floor are fundamental to our understanding of the mechanism of sea floor spreading and continental drift. New experimental information on the elastic properties, as a function of temperature, pressure, and petrology, of eclogite and peridotite is presented. The density and seismic wave velocities in peridotite simulated in the laboratory for the oceanic lithosphere of the first 15-20 km of depth match results of recent seismic investigations very well. The elastic properties of olivine eclogite describe the seismic structure of the remaining lithosphere. The present study favors the idea of a chemical change within the lithosphere, and our laboratory results tend to favor $\bar{m} \sim 22$ for the oceanic lithosphere. In modeling the structure in terms of temperature and pressure coefficients the surface wave studies introduce two complications: First, since partial melting is required by the very low shear wave velocities of the asthenosphere, some consistent and sensible way of treating velocities in mush must be used. Second, the mantle is anisotropic; therefore a systematic crystal orientation has to be considered rather than just the average V_p and V_s for the mantle constituents. The seismic anomalies of azimuth-dependent fluctuations in the velocity of P_n waves along the base of the

oceanic crust are as much as 8%; the high velocity tends to be in the direction of sea floor spreading. A consistent explanation of this effect would be the presence of a sustained extensional strain rate in the spreading direction, applied at the base of the oceanic lithosphere. It would appear that the anisotropy vanishes near the surface of the oceanic plate.

CHUNG, D. H., The use of ultrasonics in geophysical studies (CRC Crit. Rev. in Solid State Sci., invited review & synthesis) Lawrence Livermore Laboratory, Rept. UCRL-77541, Abstract (1976).

The ultrasonic measurement in solids of geological interest, when performed under controlled pressure and temperature conditions, provides a scientific basis for the interpretation of travel times of seismic waves and associated attenuation in the earth and the moon. And further, such measurements provide the input data for the equations-of-state studies of materials in the interior of the earth and other planetary bodies. Because sound velocity is one of the few properties measured directly at depth in the earth and the moon, this ultrasonic task is of fundamental importance in our understanding of the structure, composition and history of the interior and crust of our dynamic earth as well as of the moon.

Since the pioneering work of the late Darrel Hughes in the 1950's and then of Francis Birch in the early 1960's, ultrasonic measurements of velocities of compressional and shear waves in rocks and minerals were made by many investigators. Ultrasonic characterizations of both compressional and shear wave velocities, as a function of pressure, temperature and composition, were also made for selected mantle materials like olivine and pyroxene, as well as oxide minerals like periclase, lime, corundum, rutile, spinel and quartz. In addition, ultrasonic measurements have been made for such high-pressure phases as stishovite and olivine-transformed spinels of magnesium and iron germanates and silicates. For the present task, it is proposed to review these data with particular emphasis on (1) universal velocity-density relationships for minerals of oxides, silicates and germanates as well as for rocks in general, (2) how these universal relationships are related to various forms of "velocity-density systematics" found in literature, (3) a systematic study of effects on the elasticity of heavier atoms substituted for lighter atoms in such mineral systems as the olivine, pyroxene, spinel, corundum and rocksalt structures, (4) a systematic study of the effects of phase changes on the elasticity in such systems as the

quartz → rutile and the olivine → spinel structures. The elasticity of rocks is discussed as well. The equations-of-state of various minerals and rocks important in geoscience are presented and then analyzed showing how these studies are related to our efforts in better understanding the elasticity and constitution of the interiors of the earth and the moon.

Evidently, in making possible the measurement of higher order elastic constants, the ultrasonic techniques have provided a necessary enlargement of elasticity demanded by the conditions of the earth's interior; in combination with the shock-wave experiments, they permit a much more realistic interpretation of geophysical observations than has ever been possible before. There is still much to be learned about the high-pressure phases, and the effects of temperature and also of the higher order terms in the elasticity.

CHUNG, D. H., Equations of state of eclogites, peridotites and pyroxenites, Trans. Am. Geophys. Union 57, 323 (1976). [UCRL-77713, Abstract]

The author reports here equations-of-state of three most common rocks of the mantle constituents. Ultrasonic elasticity data on synthetic eclogites, peridotites and pyroxenites as a function of pressure and also of temperature are presented. The elasticity data include (1) P- and S-wave velocities and their first derivatives with respect to pressure and temperature, (2) the shear and bulk moduli and their first pressure and temperature derivatives, and (3) Poisson's ratio and its first pressure and temperature derivatives, all evaluated at zero pressure and at ambient temperature. The critical thermal gradients in the units of °C per kb for the density and also for the P- and S-wave velocities in these mantle materials are:

	eclogite	peridotite	pyroxenite
density	3.43-3.57	3.31-3.33	3.27-3.37
$\overline{m}$	21.7-22.3	20.9-21.1	20.5-21.5
$\Delta T/\Delta p)_\rho$	29	27	36
$\Delta T/\Delta p)_\Gamma$	18	25	19
$\Delta T/\Delta p)_S$	5	13	11

These values may be compared with the much speculated upper mantle ($\Delta T/\Delta z$). Next, equations-of-state of these compositions are presented. Combining these data with the shock-compression data of McQueen et al, I find the most stable high-pressure phase of these compositions at high pressures is the *oxidemixture* of periclase, wustite and stishovite.

CHUNG, D. H., P_n velocity and partial melting--discussion (Tectonophysics, in press) Lawrence Livermore Laboratory, Rept. UCRL-78924, Preprint (1976).

The seismologically observed P_n velocity anomalies in the conterminous United States are restricted to the lithosphere, but the observed teleseismic delay-time variations are due principally to the regional variations in the physical state (i.e., thickness of low velocity zone and/or percent melt, etc.) of the asthenosphere. The observed low P_n velocity has been attributed to partial melting in the upper mantle, but it is shown that the partial melting model alone cannot explain the seismologically observed P_n velocities in such an anomalous region as the Basin and Range Province. The present structure of the Basin and Range Province is possibly a result of rifting in the western conterminous United States; under it there may lie a mixed structure of old crust and mantle materials. The low velocity zone under the Basin and Range Province would then be caused by downward chemical transition from the sub-Moho pyrolitic mantle material into a plagioclase-rich ophiolitic (old oceanic crust and upper mantle) composition and associated melting, and then into an eclogitic composition at the bottom of the low velocity zone. This mixed material model, with partial melting, would explain the low P_n velocity and low seismic Q in the region, as well as other geophysical observations.

COHEN, J. J., Why partition nuclear waste?, Lawrence Livermore Laboratory, Rept. UCRL-78274, Rev. 1, Preprint (1976).

A cursory review of literature dealing with various separatory processes involved in the handling of high-level liquid nuclear waste discloses that, for the most part, discussion centers on separation procedures and methodology for handling the resulting fractions, particularly the actinide wastes. There appears to be relatively little discussion on the incentives or motivations for performing these separations in the first place. Discussion is often limited to the assumption that we must separate our "long-term" from our "short-term" management problems. This paper deals with that assumption and devotes primary attention to the question of "why partition waste?" rather than the question of "how to partition waste?" or "what to do with the segregated waste?"

Cohen, J. J., SCHWARTZ, L. L., Lewis, A. E., and Braun, R. L., High level radioactive waste isolation by incorporation in silicate rock, Lawrence Livermore Laboratory, Rept. UCRL-78746, Preprint (1976).

Cohen, J. J. and TONNESSEN, K. A., Survey of naturally occurring hazardous materials in deep geologic formations: a perspective on the relative hazard of deep burial of nuclear wastes, Lawrence Livermore Laboratory, Rept. UCRL-52199 (1976).

COSTANTINO, M. S. and Schock, R. N., A constitutive relation to describe the dilatant behavior of a dense sandstone, Trans. Am. Geophys. Union 57, 330 (1976). [UCRL-77647, Abstract]

Stress-strain data for Nugget sandstone, a quartz arenite with 4.1% porosity, over a variety of compressive stress paths have been examined using curve fitting techniques. The purpose of the work was to determine the existence and a form of a simple constitutive relation describing dilatant strain. The dilatant volume strain for the sandstone may be described by

$$\varepsilon_v^e = a_0 + a_1 \sqrt{J_2} + b_0 \exp [b_1 \sqrt{J_2}],$$

where ε_v^e is the difference between the measured volume strain and the hydrostatic volume strain at the same mean stress, and the a_i, b_i regression coefficients are function of I_1, the first stress invariant. A similar relation, exponential in form and with three system variables (volume strain, mean stress, and shear stress) has been suggested in a previous study of a granodiorite. Thus the exponential character of dilatant strain is demonstrated for two dissimilar rocks. The increase in the dilatant strain with J_2, the second invariant of the stress deviator, is believed to be related to the propagation of existing cracks. It has been suggested that a simple relation exists between the electrical resistivity and crack porosity in saturated dilatant rock. Together with the ability to calculate shear stress induced dilatant volume changes, electrical measurements may be useful in deducing the magnitude of stress changes in dilating rock bodies. Acoustic velocities also are affected markedly by dilatant strain and may be utilized similarly.

COSTANTINO, M. S., A lower bound for experimental scatter due to rock variability, Trans. Am. Geophys. Union 57, 1001 (1976). [UCRL-78647, Abstract]

Scatter in experimental data for mechanical properties of geologic materials is due to a combination of instrumental error, failure to control experimental conditions, and the so-called "natural variability". To help set a lower limit on the size of the error due to rock variability, ten "identical" experiments were carried out on Westerly Granite. Principal stresses and strains on loading were measured in hydrostatic compression to 100 MPa and in uniaxial compression ($\sigma_1 > \sigma_2 = \sigma_3 = 100$ MPa) to failure on copper jacketed, right circular cylinder samples 19 mm dia x 50 mm long at strain rates between 1 and 2 x $10^{-6}s^{-1}$. The standard deviation, s, (standard deviation of the mean, s_m) of the volume strains at P = 50 and 100 MPa were 21% (7%) and 15% (5%), respectively, of the mean hydrostat $\overline{\varepsilon}_H = 202.2\ P^{0.6182}$. When the three experiments that showed large deviations from the mean were deleted from the analysis, $s(s_m)$ was decreased to 9% (3%) and 5% (2%) for P = 50 and 100 MPa, respectively. The bulk modulus agreed with the mean to within 4% for all experiments. Analysis of the dilatant strain region showed that the volume strain could be written as

$$\varepsilon_v = \overline{\varepsilon}_H - [\overline{a}_0 + \overline{a}_1\tau + \overline{a}_2 \exp(\overline{a}_3\tau)]$$

where the coefficient $\overline{a}_i$ is the average of the coefficients for all ten experiments and τ is the shear stress. The data (well over 1000 ε_v - τ pairs) were satisfied by this expression to $\pm$ 20% at stresses up to 80% of failure. The failure curve $(\overline{\sigma},\tau)$ was reproducible to 2% in τ and 3% in the mean stress, $\overline{\sigma}$. These results suggest that a lower bound for "acceptable accuracy" in predictive, constitutive modeling of rocks is of the order of 20% in absolute volume strain and that efforts to describe limited experimental data more closely are not justified at this time.

COSTANTINO, M. S. and Schock, R. N., A constitutive relation for compressive loading in Nugget sandstone, Lawrence Livermore Laboratory, Rept. UCRL-52036 (1976).

Stress-strain data for Nugget sandstone (a quartz arenite with 4.1% porosity) over a variety of compressive stress states have been examined by

curve-fitting techniques. The purpose of the work was to determine the existence and a form of a simple constitutive relation describing dilatant strain. The dilatant volume strain for this sandstone can be described by

$$\varepsilon_v^e = a_0 + a_1 J_2^{1/2} + b_0 \exp(b_1 J_2^{1/2}),$$

where ε_v^e is the difference between the measured volume strain and the hydrostatic volume strain at the same mean stress and the regression coefficients a_i, b_i are functions of the first stress invariant. The increase in the dilatant strain with J_2, the second invariant of the stress deviator, is believed to be related to two mechanisms: (1) a "differential crack closure," which involves the response of each crack with respect to orientation to the principal stresses, and (2) an exponentially divergent region due to the propagation of existing cracks.

In the Nugget sandstone, the boundary between nondilatant and dilatant behavior for a variety of loading paths is described fairly well by the curve in mean stress-shear stress space for uniaxial strain. The fracture surface is found to be independent of loading path.

COSTANTINO, M. S., Constitutive modeling of Climax Stock granodiorite under compressive loading, Lawrence Livermore Laboratory, Rept. UCID-17246 (1976).

Described here is a constitutive relation for the stress-volume strain states of Climax Stock granodiorite under nonhydrostatic loading conditions. The simple functional form

$$\varepsilon_v^e = a_0 + a_1\tau + b_0 \exp(b_1\tau)$$

is found using standard curve-fitting techniques; ε_v^e-- the "excess volume strain"-- is the difference between the volume strains under hydrostatic and nonhydrostatic conditions at the same mean stress, τ is the shear stress, and a_i, b_i are fitting parameters. By comparison with Nugget sandstone under similar loading conditions, for which this functional form fitted the data, we find no relationship for Climax Stock granodiorite between the fitting parameters and other system variables such as mean stress

or confining pressure. Therefore, this relation is not yet suitable for use in computer codes that attempt to predict the response of rocks to stress.

Costantino, M. S., HEARD, H. C., Bonner, B. P., Schock, R. N., and Weed, H. C., Mechanical response of saturated Kemmerer coal to 4 GPa, Lawrence Livermore Laboratory, Rept. UCRL-52063 (1976).

CROW, N. B., First observations of tritium in ground water outside chimneys of underground nuclear explosives, Yucca Flat, Nevada Test Site, Lawrence Livermore Laboratory, Rept. UCRL-52073 (1976).

Abnormal levels of radionuclides had not been detected in ground water at the Nevada Test Site beyond the immediate vicinity of underground nuclear explosions until April 1974, when above-background tritium activity levels were detected in ground-water inflow from the tuff beneath Yucca Flat to an emplacement chamber being mined in hole U2aw in the east-central part of Area 2. No other radionuclides were detected in a sample of water from the chamber. In comparison with the amount of tritium estimated to be present in the ground water in nearby nuclear chimneys, the activity level at U2aw is very low. To put the tritium activity levels at U2aw into proper perspective, the maximum tritium activity level observed was significantly less than the maximum permissible concentration (MPC) for a restricted area, though from mid-April 1974 until the emplacement chamber was expended in September 1974, the tritium activity exceeded the MPC for the general public. Above-background tritium activity was also detected in ground water from the adjacent exploratory hole, Ue2aw. The nearest underground nuclear explosion detonated beneath the water table, believed to be the source of the tritium observed, is Commodore (U2am), located 465 m southeast of the emplacement chamber in U2aw. Commodore was detonated in May 1967. In May 1975, tritium activity significantly higher than regional background was detected in ground water from hole Ue2ar, 980 m south of the emplacement chamber in U2aw and 361 m from a second underground nuclear explosion, Agile (U2v), also detonated below the water table, in February 1967. This paper describes these occurrences of tritium in the ground water. A mechanism to account for the movement of tritium is postulated. It is believed that the tritiated water passed through a network of induced and natural fractures in the tuff beneath Yucca Flat which formed a pathway from the sources of tritium to the sites where it was detected, and that hydraulic pressures induced by forces related to the explosions significantly augmented

the natural hydraulic gradient in moving the tritiated water outward from the explosion sites. The implications of induced fractures, which might create a pathway for the leakage of tritiated water downward from the tuff of Yucca Flat into the underlying regional aquifer in the Paleozoic carbonate rocks, are discussed.

DENGLER, L. A., Scanning electron microscope studies of an experimentally deformed Graywacke sandstone, Trans. Am. Geophys. Union 57, 1010 (1976). [UCRL-78649, Abstract]

Uniaxial-strain and uniaxial-stress tested samples of Graywacke sandstone were examined with an SEM to study the relation among microstructure, dilatancy, and brittle versus ductile failure. Uniaxial-strain loading caused occasional short transgranular cracks. Clay minerals have been compacted perpendicular to the axis of maximum principal stress (σ_1). The uniaxial strain loading path coincides with the onset of dilatancy in a uniaxial stress test and these samples should represent predilatant deformation. However, pore compaction effects are present. The density of transgranular fracturing is little increased over the unstressed rock, but the clay and matrix structure of the intergranular areas has been significantly altered. Loading to failure at <50 MPa confining pressure in uniaxial stress produced one or two throughgoing faults. Near the fault, a narrow zone of grain and matrix fracturing occurred. Transgranular crack formation is restricted to this zone. In some areas away from this zone, clays have been aligned at ~45° to σ_1 and welded into continuous sheets; in other areas, clays appear undisturbed. With increased confining pressure, the width of the fractured zone increases and more grains away from this zone are fractured. At confining pressures >500 MPa, a localized fault no longer occurs and sample deformation is more uniform, all grains being fractured to some degree. Clay and matrix structure has been broken down throughout the sample.

DENGLER, L. and Piwinskii, A. J., A study of core chips from the State of California well no. 1, Salton Sea Geothermal Field using petrographic, x-ray diffraction and scanning electron microscopy techniques, Lawrence Livermore Laboratory, Rept. UCID-17184 (1976).

Rock chips from depths of 1380 to 1478 m from the State of California well no. 1 in the Salton Sea Geothermal Field were examined using conventional petrographic, x-ray diffraction, and scanning electron microscopy techniques. Mineral composition, pore configuration and the nature of the fine-grained matrix materials were determined.

Dengler, L., and PIWINSKII, A. J., Pore structure and mineralogy of core chips from the State of California Well No. 1, Salton Sea Geothermal Field, Trans. Am. Geophys. Union 57, 1017 (1976). [UCRL-78637, Abstract]

DENNY, M. D., and Chin, R. C. Y., Gaussian filters for determining group velocities, Geophys. J. R. Astr. Soc. 45, 495-525 (1976). [UCRL-76809, Preprint]

The problem of filtering dispersed wavetrains by Gaussian filters has been examined. Asymptotic expressions for small bandwidths are obtained for the centroid and for the variance of the filtered signal about its centroid. The forms of the expressions suggest the use of an extrapolation algorithm to estimate the group arrival time. An optimal filter is introduced to aid in selecting a set of corresponding pairs of centroid and bandwidth values for use in the algorithm. For a finite time series, only those pairs whose variances are well within the length of the time series are considered. In this way, the estimated group arrival times are consistent with the information content of the data and are independent of the data extension technique. The method is applied to both synthesized and real signals. The corresponding errors in the group velocity are less than 0.1 and 2 percent, respectively.

Denny, M. D., and SPRINGER, D. L., Seismic spectra of events at regional distances, Lawrence Livermore Laboratory, Rept. UCRL-52048 (1976).

DUBA, A., Heard, H. C., and Schock, R. N., Electrical conductivity of orthopyroxene to 1400°C and the resulting selenotherm, Proc. Seventh Lunar Sci. Conf., Vol. 3, 3173-3181 (1976). [UCRL-77655, Preprint]

The electrical conductivity of orthopyroxene from Bamle, Norway has been measured in the [100], [010], and [001] directions to 1550°C. Measurements were made at 0.5 GPa (5 kb) in an Ar-CO_2-CO mixture. The resulting oxygen fugacity allowed orthopyroxene to be maintained within its stability field at this pressure to at least 1400°C. Multiple measurements in each direction were reversible with no hysteresis to 1400°C. At higher temperatures, electrical conductivity became time-dependent and irreversible, presumably due to phase transformation(s).

Assuming that orthopyroxene is the dominant conductor in the moon, a selenotherm may be derived from these data and from the electrical conductivity vs. depth observations of Apollo magnetometer experiments. This

selenotherm approaches the solidus within about 150°C at 400 to 600 km. These results agree with previous selenotherms based on extrapolated σ data for pyroxene.

DUBA, A., Heard, H. C., Piwinskii, A. J., and Schock, R. N., Geothermal prospecting and the electrical conductivity changes associated with melting (Panel Mtg. Expl. Meth. of Dry Hot Rock, Los Alamos, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78261, Abstract (1976).

The relevance of electrical conductivity surveys as an exploratory tool for partial melt zones within the earth's crust and mantle is discussed using results from σ measurements prior to and during partial fusion, under controlled oxygen fugacity, of basalt and the plagioclase feldspar, albite. Field measurements of electrical conductivity anomalies have often been cited as evidence for the existence of melt at depth. Laboratory data on the large σ increase associated with melting of albite or basalt and granite, which contain plagioclase feldspar (albite is the Na-end member of this solid solution series) as a major component, are listed as justification for this interpretation.

The σ of single crystal albite measured at temperatures below melting as a function of time and the σ of powdered albite measured upon melting show that the σ increases subsolidus, given sufficient time, to account for all the increase observed upon melting.

The σ, measured at temperatures below melting and upon partial fusion of basalt under controlled oxygen fugacity, is a complicated function of temperature, time, and oxygen fugacity. Generally, the σ decreases with time below approximately 900°C if oxygen fugacity is near the quartz-fayalite-magnetite buffer. Above 900°C, the σ increases with time for all oxygen fugacities studied. It is obvious that the σ change upon partial fusion (T = 1050°C) is dependent upon the time the sample resided at temperatures below the beginning of melting.

These results suggest that field measurements cannot reliably distinguish between partial melt and a solid of similar composition, but slightly below the solidus. The situation is changed, however, if we assume a melt of basaltic composition present in a rock in which σ is controlled by either olivine or pyroxene. Utilizing σ measured for olivines

and pyroxenes under controlled fugacity as the most likely σ for the host rock, a σ contrast of two to four orders of magnitude would be observed between a zone where the σ is dominated by partial melt and one where the σ is controlled by either olivine or pyroxene.

DUBA, A., A review of the relevance of laboratory electrical conductivity data to the earth (Third. Int. Workshop Electromagnetic Induction, Sopron, Hungary, July 1976) Lawrence Livermore Laboratory, Rept. UCRL-78275, Preprint (1976).

Before laboratory data on the electrical conductivity of rocks and minerals can be used to interpret field electromagnetic data, one must realize that the laboratory results may not be truly representative of the prevailing conditions in the earth. The time required for solid-solid reactions to approach equilibrium and the changes in the oxidation state of predominant mineral ions are especially important conditions that must be considered but, all too often, are neglected. Contamination of samples under laboratory conditions also complicates the interpretation of these data. Recent studies have taken into consideration the time dependence of conductivity at high temperatures and the effect of oxidizing environments on this phenomenon. These studies, applied to the earth's upper mantle, are reviewed and the shortcomings inherent in laboratory data are carefully considered.

DUBA, A., The electrical conductivity of coal and coal char, Trans. Am. Geophys. Union 57, 1006 (1976). [UCRL-78648, Abstract] Lawrence Livermore Laboratory, Rept. UCRL-78648, Preprint (1976).

The electrical conductivity (σ) of coal, at either 1kHz or dc, was measured at 24°C on samples recovered from pyrolysis experiments aimed at modeling conditions during in situ gasification of coal. From an initial value of 10^{-3} S/m (when the coal is saturated with formation water), the σ decreases to 10^{-8} S/m when the coal is heated to 110°C in vacuum. This low value of σ, presumably due to dehydration of the coal, prevails for samples heated as high as 500°C in dry argon. Samples of char recovered after pyrolysis to 800°C or more have σ of 10^{2} S/m. Capitalizing on the large contrast between the σ of coal and char produced during gasification, electrical probing may be a sensitive tool for monitoring "burn-front" progress during in situ coal gasification.

Duba, A., HO, P., and Piwinskii, A. J., Dielectric properties and the monoclinic-triclinic inversion in albite, Trans. Am. Geophys. Union, 57, 1005 (1976). [UCRL-78639, Abstract]

Dielectric properties (ε', real part of complex permittivity; ε'', imaginary part of complex permittivity; tan δ, loss tangent = $\varepsilon''/\varepsilon'$) of single crystal Amelia albite have been measured parallel to the b-axis under controlled oxygen fugacity near the QFM buffer in the temperature range 1000-1373 K at frequencies (ν) of 0.2 to 10 kHz. Plots of ε' and ε'' as a function of temperature exhibit minima which depend on time and ν in this albite. In addition, plots of tan δ as a function of temperature develop maxima which are also time-dependent. When ε', ε'', and tan δ were investigated between 1220 and 1320 K as a function of time, a break in these dielectric parameters with temperature was found. ε' and ε'' increased with time above this break, while they decreased with time below the break. Values of loss tangent were also non-linear functions of temperature. ε' and ε'' minima, tan δ maxima, and the temperature break in these dielectric properties were found to converge at approximately 1283 K as time increases. Assuming that the ε' and ε'' increase and the tan δ decrease are the result of increasing disorder in this albite, these experimental data suggest that 1283 $\pm$ 20 K is the temperature of the monoclinic-triclinic transition in this albite. This agrees well with electrical conductivity results which indicate 1253 $\pm$ 30 K.

DUBA, A., and Hornady, B., Annual report, Geoscience and Engineering Section, Inorganic Materials Division, Chemistry and Materials Science Department, Lawrence Livermore Laboratory, Rept. UCID-17301 (1976).

This compilation lists abstracts of papers, internal reports, and talks presented during 1975 at national and international meetings by members of the Geoscience and Engineering Section, Inorganic Materials Division, Chemistry and Materials Science Department, Lawrence Livermore Laboratory. Titles of talks at university and local meetings are also listed when available. The subjects range from the in situ retorting of coal to the temperature profile of the moon. A subject classification is included.

DUBA, A., Piwinskii, A. J., Heard, H. C., and Schock, R. N., The electrical conductivity of forsterite, enstatite, and albite, in Physics and Chemistry of Minerals and Rocks, R. G. J. Strens, Ed. (John Wiley & Sons, New York, 1976), pp. 249-260. [UCRL-75790, Preprint]

Duba, A., SCHOCK, R. N., and Abey, A. E., Quasistatic deformation of porous beryllium and aluminum, J. Appl. Phys. 47, 53-63 (1976). [UCRL-76587, Preprint]

Duba, A., and PIWINSKII, A. J., The permittivity and electrical conductivity of oil shale, Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 13, 165-166 (1976). [UCRL-76789, Preprint]

Duba, A., PIWINSKII, A. J., and Ho, P., The electrical conductivity of low and high albite throughout its melting interval at atmospheric pressure (Min. Asso. Canada Ann. Mtg., Edmonton, May 1976) Lawrence Livermore Laboratory, Rept. UCRL-77662, Abstract (1976). [UCRL-78777, Preprint]

Duba, A. G., SCHOCK, R. N., HEARD, H. C., and Stromberg, H. D., The electrical conductivity of polycrystalline olivine and pyroxene under pressure, in High-Pressure Research, Applications to Geophysics, M. H. Manghnani and S. Akimoto, Eds. (Academic Press, New York, in press). [UCRL-78048, Preprint]

Duba, A., PIWINSKII, A. J., and Weed, H. C., Electrical conductivity studies and geothermal diagnostics (Conf. Geothermal Resources of Imperial Valley, Calif., Riverside, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78293, Abstract (1976).

Duba, A. G., HEARD, H. C., and Schock, R. N., Geotherms based on electrical conductivity of olivine, pyroxene, and pyrolite (U.S.-Japan Sem. High Pressure Res. Appli., Honolulu, July 1976) Lawrence Livermore Laboratory, Rept. UCRL-78294, Abstract (1976).

EMERSON, D. O., In-situ coal gasification, Geol. Soc. Am. Abst., Denver, Nov. 1976, Vol. 8, 854 (1976). [UCRL-78350, Abstract]

A significant amount of coal which is not suitable for conventional recovery may be amenable to in-situ gasification. An estimated 240 trillion standard cubic feet of pipe-line quality gas could be produced by this method from thick western U. S. coal beds at depths of 600 to 3000 feet. The packed bed concept, being studied by the Lawrence Livermore Laboratory (LLL), is one of three approaches to underground coal gasification being field tested by the U.S. Energy Research and Development Administration (ERDA). Guided by earlier studies in the U. S. and Great Britain, as well as continuing projects in Russia, LLL plans to gasify an explosively fractured bed of coal near Gillette, Wyoming. The Laramie Energy Research Center plans to test a line drive between parallel sets of vertical holes near Hanna, Wyoming, and the Morgantown Energy Research Center plans to gasify between deviated holes that parallel each other and the bedding of

the Pittsburgh coal bed near Princeton, Wyoming. The actual technique used depends on the coal deposit. However, both high ash and steeply dipping coal beds may be utilized. Current estimates of the cost of gas produced by these underground processes place it below the cost of surface plant gasification. While avoiding the hazards of underground mining, these techniques should have less of an impact on the environment.

Emerson, D. O., HANSON, M. E., McKee, C. R., Montan, D. N., and Hearst, J. R., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-1 (1976).

Emerson, D. O., HANSON, M. E., McKee, C. R., Qualheim, B. J., Hearst, J. R., and Terhune, R. W., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-2 (1976).

Emerson, D. O., HANSON, M. E., Heard, H. C., Shaffer, R. J., and Carlson, R. C., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, July-September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-3 (1976).

GLENN, H. D. and Thomsen, J. M., Computer simulation of a high explosive cratering experiment in a complex multilayered geology, Lawrence Livermore Laboratory, Rept. UCRL-78155, Preprint (1976).

Computer codes were used to simulate a 42-GJ (10 ton) high explosive cratering experiment in a complex, multilayered geology. The calculated predictions were compared to actual dynamic experimental measurements taken well within the final crater radius. Geologic layering interaction has a definite effect on energy coupling, shock propagation, and final crater dimensions. Results from the various computer codes agreed well with the experimental results. This study significantly broadens the theoretical approach to high explosive cratering problems and will aid future investigations in the field.

GLENN, H. D., Spall study in one dimension, Lawrence Livermore Laboratory, Rept. UCID-17144 (1976).

A SOC one-dimensional calculation of an underground nuclear test is presented to exemplify the shock propagation and spall phenomenology commonly predicted. Then to examine the effects of spherical

divergence on spall, a series of SOC calculations, at different radii of curvature, are conducted and prediction of depth and velocity for the first spall zone are compared with predictions from simple analytical theory. The excellent agreement in this comparison verifies that the SOC code accurately represents the physics of spalling. This study also indicates that the total spall depth is independent of divergence because of the compensating effect that subsequent convergence has on the reflected wave. The latter result implies that the total depth of spall calculated for each underground nuclear test must be critically examined and evaluated. Finally, SOC calculations for nuclear detonations in tuff and granite are performed to demonstrate the significant effect that variations in material response under shock loading have on shock propagation and spall.

Glenn, H. D., THOMSEN, J. M., and Germain, B. K., Airblast prediction progress report, Lawrence Livermore Laboratory, Rept. UCID-17019, CFRD (1976).

HANNON, W. J., Rodean, H. C., and Barnett, C. S., Earthquake triggering by earthquakes and nuclear explosions at rates of less than 1°/day, Lawrence Livermore Laboratory, Rept. UCRL-52096 (1976).

We have examined seismicity data at teleseismic distances for periods of one year following ten selected nuclear explosions using a parameter called the "rate" (the distance from a selected "trigger" event to a subsequent "triggered" event divided by the time interval between the two events). The use of this parameter to look at long time periods and teleseismic distances was originally suggested to ERDA by D. A. Walker of the University of Hawaii. We were unable to distinguish the distribution of rates in the range 0.01 to 1.00°/d following these explosions from distributions which we calculated for years without explosions. Thus, we observed no evidence for earthquake triggering by explosions in this previously unexamined time and distance range.

Furthermore, we have done additional work that suggests that the features of the distributions of rates observed in the case of earthquakes being "triggered" by other earthquakes at these slow rates can be directly related to geometric constraints imposed by the fact that the earthquakes occur in relatively fixed locations

along plate boundaries. Thus, we question the inference of causal "triggering" at rates of 0.01 to 1.00°/d at teleseismic distances.

HANSON, M. E. and Petschek, A. G., A boundary condition for significantly reducing boundary reflections with a Lagrangian mesh, J. Comp. Phys. 21, 333-339 (1976).[UCRL-76842, Rev. 1, Preprint]

A modified damper system for terminating a Lagrangian mesh in a plane geometry is analyzed and found to reduce the boundary reflections significantly. With the comparison criterion used, the resulting reflections from this technique are found to be 11% of those for a fixed or free boundary. The reflections were reduced to 33% of those for the scattering technique used previously as a terminating boundary condition.

HANSON, M. E., McKee, C. R., Emerson, D. O., Montan, D. N., and Hearst, J. R., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, February-March 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-1 (1976).

This report summarizes the work accomplished during the first quarter (February through March 1976) of our program for gas stimulation by massive hydraulic fracturing (MHF). We discuss the need for MHF research, our program, and progress made in the first quarter toward programmatic goals. Our progress this quarter includes: (1) preliminary calculations to determine the effects of Poisson's ratio on a suddenly released fracture; (2) summary of the CER-Industry-ERDA meeting for the Rio Blanco MHF well, observation of the Columbia Gas-ERDA project in West Virginia, and summary of the Appalachian Basin Devonian Shale meetings in Morgantown, West Virginia; (3) progress on a coupled elastic-porous flow model for hydraulic fracturing; (4) progress on acquisition of a prototype dry-hole sonic logging tool for application to Eastern Devonian shales; and (5) initial reservoir analysis of the first MHF stimulation in the Rio Blanco well.

HANSON, M. E., McKee, C. R., Emerson, D. O., Qualheim, B. J., Hearst, J. R., and Terhune, R. W., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-2 (1976).

This report summarizes the work accomplished during the second quarter (April through June 1976) of our program for gas stimulation

by massive hydraulic fracturing (MHF). This quarter we: (1) continued to develop an elastic-porous flow model for hydraulic fracturing; (2) acquired and interpreted geologic and geophysical data on the tight western gas reservoirs and the Devonian shales; (3) contracted for a dry-hole sonic logging tool, and adapted and operated a ray-tracing numerical code to help us interpret data obtained with this tool; and (4) developed a theory to predict permeability enhancement from single and multiple charges fired in boreholes.

HANSON, M. E., Emerson, D. O., Heard, H. C., Shaffer, R. J., and Carlson, R. C., Quarterly Report: the LLL massive hydraulic fracturing program for gas stimulation, July-September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-3 (1976).

This report summarizes work accomplished during the third quarter (July through September 1976) of our program for gas stimulation by massive hydraulic fracturing (MHF) and other stimulation methods. In this quarter, we: (1) continued to develop an elastic-porous flow model to simulate and analyze the MHF process; (2) continued to acquire and interpret geological and geophysical data on the tight western gas reservoirs and the eastern Devonian shales; (3) began measuring the low-stress mechanical properties of Devonian shale using cores from a recently drilled well in West Virginia; and (4) began analyzing sonic-log data from the West Virginian Devonian shale.

Hanson, M. E. and MCKEE, C. R., Predicting explosion-created permeability around geothermal wells (Workshop Geothermal Eng., Stanford, January 1976) Lawrence Livermore Laboratory, Rept. UCRL-77673, Preprint (1976).

Hanson, M. E., MCKEE, C. R., and Terhune, R. W., Permeability from single and multiple detonations of explosive charges (World Mining & Metal Tech. Conf., Joint MMIG-AIME Mtg., Sept. 1976; ERDA Sympos. Enhanced Oil & Gas Recovery, Tulsa, Sept. 1976) Lawrence Livermore Laboratory, Rept. UCRL-78207, Rev. 1, Preprint (1976).

HEARD, H. C., Comparison of the flow properties of rocks at crustal conditions, Phil. Trans. R. Soc. Lond. A. 283, 173-186 (1976). [UCRL-76267, Preprint]

It is inferred that, although both primary and tertiary creep may be important in certain regions, large-scale ductile deformation

in the Earth's crust must be governed by secondary creep (steady state). This flow involves plastic deformation resulting from dislocation motion and diffusion. Geological, geophysical and geochemical observations constrain the temperature (T), strain rate ($\dot{\varepsilon}$), and stress difference (σ) for rocks undergoing secondary creep to: -30-800°C, 10^{-7}-$10^{-15}s^{-1}$, and up to 300 MPa (3 kbar). The actual conditions of secondary creep are strongly dependent on rock type and depth of deformation.

Useful laboratory data on rocks obtained over wide ranges of T, $\dot{\varepsilon}$ and σ are limited to ice, halite, marble, dolomite, quartzite and dunite. Steady-state flow results are available for both wet and dry rocks; H_2O strongly affects the behaviour of both quartzite and dunite, but has a negligible effect on halite and marble. Secondary creep data for each rock are well fitted by $\dot{\varepsilon} = A \exp(-Q/RT)\ \sigma^n$, where Q is an activation energy for creep (diffusion) and A, R, n are constants.

Comparison between those rocks expected in the deep crust indicates that at the highest T and at $\dot{\varepsilon}$ of 10^{-12}-$10^{-15}s^{-1}$, σ is largest for dry dunite and dolomite, followed by dry quartzite, marble and wet quartzite. Equivalent viscosities (η) range from 10^{18}-10^{22} Pa s (10^{19}-10^{23}P). At intermediate depths (at T = 300-500°C), σ in dolomite is slightly greater than dry quartzite; both are much stronger than marble. In the shallow crust, secondary creep is expected only in marble (T > 250°C) and in halite (T > 25°C). The η of halite at 25-250°C, range from 10^{21}-10^{17}Pa s. At the surface and at $\dot{\varepsilon}$ of 10^{-7}-$10^{-10}s^{-1}$ (glacier flow), η of ice would be 10^{15} to 10^{12} Pa s between -30 and 0°C. Values of η for all rocks examined appear insensitive to T except wet quartzite and all dunite.

HEARD, H. C., Mascon ages and sinking rates, Seventh Lunar Sci. Conf., Houston, Part I, 360 (1976). [UCRL-77658, Abstract] Lawrence Livermore Laboratory, Rept. UCRL-77658, Preprint (1976).

The long-term mechanical stability of strongly positive gravity anomalies (mascons) on the moon is evaluated from relevant physical characteristics of these bodies, from paleoselenotherms and from the flow behavior of the lunar mantle.

The high near-surface temperatures associated with igneous activity at 3.3 - $4 \cdot 10^9$y b.p., when taken together with the mantle flow behavior yields equivalent viscosities of 10^{15} - 10^{16} poise. The resulting high settling rates indicate that all mascons must have been formed at later times when the near-surface had partially cooled. By $3 \cdot 10^9$y b.p., mantle viscosities had increased sufficiently to maintain any mascon in the uppermost 30 km in an essentially static position. The present viscosities of the lunar mantle at depths of 120 - 150 km are still too low by 10^6 to support mascons for periods as short as 10^6y.

In order that any mascon occurring to 120 km sink less than 10% of its present depth over $3 \cdot 10^9$y, maximum temperatures could not have exceeded 450°C for an extended period. For sinking a like amount over periods of 10^8y, temperatures must have been no more than 500°C.

HEARD, H. C., Duba, A. G., and Schock, R. N., Geotherms based on electrical conductivity of olivine, pyroxene, and pyrolite (U.S.-Japan Sem. High Pressure Res. Appli., Honolulu, July 1976) Lawrence Livermore Laboratory, Rept. UCRL-78294, Abstract (1976).

In addition to composition and heat transfer mechanisms, knowledge of the present thermal state of the earth is vital to the interpretation of earth history. Thermal profiles have been based primarily on heat flux, mechanical and thermal properties of rocks, and on phase equilibria for the appropriate chemical composition (x). Geotherms may also be constructed from laboratory electrical conductivity (σ) - temperature (T) measurements on purported mantle rocks and minerals together with σ-depth data for the earth. Recently, progress has been made in determining σ of minerals and aggregates thought to exist at pressures (P), T and x in the upper mantle.

The σ for olivine and orthopyroxene single crystals has been determined to 1660° and 1400°C, respectively, over a range of oxygen fugacities (f_{O_2}), P, mineral compositions and crystal direction. The σ of either mineral was demonstrated to be sensitive primarily to T, provided f_{O_2} is controlled within the stability field for that phase. For olivine (Fo 91), σ measured at f_{O_2}

$\sim 10^{-3}$ Pa (1200°C) varied from $10^{-5.0}$ S/m at 800° to $10^{-1.4}$ at 1660°C. The σ of orthopyroxene (En 86) at similar f_{O_2} is higher by $10^{0.3}$ and $10^{0.1}$ at 800° and 1400°C, respectively.

Measurement of σ on a hot-pressed aggregate of olivine (Fo 92) at P to 5.0 GPa but at unknown f_{O_2} yielded values of $10^{-4.0}$ S/m at 800° and $10^{-2.6}$ at 1200°C. Similar measurements on an orthopyroxene aggregate (En 86) under identical conditions revealed similar σ: $10^{-3.8}$ S/m at 800° and $10^{-2.5}$ at 1200°C. All results are essentially independent of P over values corresponding to 70-160 km depth. Each aggregate is only slightly more conductive than its respective mineral component at comparable f_{O_2}.

Hot-pressed pyrolite (57% olivine, 29% orthopyroxene, 14% garnet) has also been measured at P to 5.0 GPa and T to 1240°C. Measurements of σ range from $10^{-5.0}$ S/m at 800°C to $10^{-3.2}$ at 1240°C. These values are about a factor of 10 less than the σ determined for each single phase aggregate at comparable T. Again, σ of pyrolite is nearly independent of P.

When combined with σ-depth measurements, geotherms based on olivine single crystal σ-T yield 1600°C at 100 km and 1750°C at 400 km. Uncertainties of ±100°C associated with these values are due principally to the field data. A similar geotherm based on monotonically extrapolated σ-T data for orthopyroxene crystals, single-phase aggregates of either mineral or pyrolite raise the calculated T significantly. σ data at higher T and under controlled f_{O_2} for likely mantle materials are required in order to calculate mantle T from σ data.

HEARD, H. C., Bonner, B. P., Costantino, M. S., Schock, R. N., and Weed, H. C., Mechanical response of saturated Kemmerer coal to 4 GPa, Lawrence Livermore Laboratory, Rept. UCRL-52063 (1976).

The stress-strain behavior of a water-saturated sub-bituminous coal from Kemmerer, Wyoming has been determined at 25°C for several loading conditions to 4.0 GPa. Data presented include: hydrostatic pressure-volume (P-V) loading-unloading paths to 1.5 GPa; quasi-hydrostatic P-V behavior to 4.0 GPa; loading moduli, failure strengths and ductility normal and parallel to bedding in uniaxial

stress loading to 0.7 GPa confining pressure; and uniaxial strain loading-unloading paths to confining pressures of 0.3 GPa. Dynamic (1 MHz) shear moduli (μ) and bulk moduli (K) were also derived from acoustic velocity measurements to 1.2 GPa confining pressure for comparison with the static values.

Quasihydrostatic compression produced a $\Delta V/V_o$ of 25% at 4.0 GPa with little or no permanent compaction or hysteresis upon unloading. Even though this coal contained ~22% H_2O, no water-ice phase transitions were observed, indicating this H_2O is chemically bound in the coal and does not exist as free H_2O. Values of K ranged from about 2 GPa at atmospheric pressure to 20 GPa at 2.5 GPa pressure. In uniaxial stress loading, the failure envelope defined by the shear strengths at failure increased monotonically with pressure for compression both normal and parallel to bedding. These envelopes were linear and identical above 50 MPa pressure. Failure occurred by shear and tensile fracture in every case after 0.5 to 2.5% permanent strain. Depending on loading direction, tensile strengths ranged from 0.7 to 1.2 MPa. The onset of dilatancy as measured in uniaxial stress loading appeared to be somewhat directionally dependent. Values for μ determined on initial loading varied from 1.2 to 2.1 GPa and depended slightly on confining pressure as well as on orientation.

Uniaxial strain loading paths for the coal oriented parallel and normal to bedding approached the failure envelope at 0.1 to 0.2 GPa confining pressure, then deviated from it at higher pressures. The dynamically determined K was somewhat greater than that determined statically; μ values by either method were approximately the same. Comparison among all determinations of K and of μ indicate that the elastic properties of Kemmerer coal are approximately isotropic.

Heard, H. C., DUBA, A., Piwinskii, A. J., and Schock, R. N., The electrical conductivity of forsterite, enstatite, and albite, in Physics and Chemistry of Minerals and Rocks, R. G. J. Strens, Ed. (John Wiley & Sons, New York, 1976), pp. 249-260. [UCRL-75790, Preprint]

Heard, H. C., DUBA., and Schock, R. N., Electrical conductivity of orthopyroxene to 1400°C and the resulting selenotherm, Proc. Seventh Lunar Sci. Conf., Vol. 3, 3173-3181 (1976). [UCRL-77655, Preprint]

Heard, H. C., SCHOCK, R. N., Duba, A. G., and Stromberg, H. D., The electrical conductivity of polycrystalline olivine and pyroxene under pressure, in High Pressure Research, Applications to Geophysics, M. H. Manghnani and S. Akimoto, Eds. (Academic Press, New York, in press). [UCRL-78048, Preprint]

Heard, H. C., DUBA, A., Piwinskii, A. J., and Schock, R. N., Geothermal prospecting and the electrical conductivity changes associated with melting (Panel Mtg. Expl. Meth. of Dry Hot Rock, Los Alamos, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78261, Abstract (1976).

Heard, H. C., HANSON, M. E., Emerson, D. O., Shaffer, R. J., and Carlson, R. C., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, July-September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-3 (1976).

HEARST, J. R. and McKague, H. L., Structure elucidation with borehole gravimetry, Geophysics 41, 491-505 (1976). [UCRL-76316, Rev. 1, Preprint]

The observed densities, assuming infinite homogeneous-horizontal beds, computed from borehole gravimetry were as much as 15 percent greater than those derived from gamma-gamma density logs in the lower portion of several clustered boreholes at the U.S. Energy Research & Development Administration (USERDA) Nevada Test Site. A model having a single high-density buried scarp to the west of the holes was constructed, the gravimetric density calculated, and the model varied in an attempt to improve agreement between measurement and calculation. Only slight improvement was obtained. Newly acquired geologic information made it possible to construct a more complex multiscarp model, providing much better agreement between measurement and calculation. In turn, this more complete model was refined with the help of the calculations.

This method permits one to choose between qualitatively different models and, given a qualitatively correct model, to improve it quantitatively.

HEARST, J. R., Effects of mudcake and sonde angle on a simple two-detector density sonde, The Log Analyst 17, 11 (1976), [UCRL-77302, Preprint]

A simple analysis is made of a well-collimated two detector density sonde with a tight energy window, the simplest form of two-

detector sonde. Under these circumstances density can be obtained either in the presence of a constant unknown thickness of mudcake of unknown properties or in the presence of an unknown angle between the sonde and the borehole wall, with the source in contact. If both a mudcake (or a gap) and an angle are present, the problem cannot be solved unless the angle or the gap is measured. If the gap (or mudcake thickness) is measured, the solution is probably too complex for field use. If washouts are present, the problem cannot be solved, but can sometimes be dealt with by averaging.

HEARST, J. R., Butkovich, T., Laine, E., Lake, R., Leach, D., Lytle, J., Sherman, J., Snoeberger, D., and Quong, R., Fractures induced by a contained explosion in Kemmerer coal, Intl. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 13, 37-44 (1976). [UCRL-51790]

A cylindrical high-explosive charge, 5·5 m long, and 0·1 m in dia and weighing 59 kg, was fired with its axis vertical and its center 15 m deep in a 26 m thick sub-bituminous coal seam near Kemmerer, Wyoming. The experiment attempted to associate a parameter ε_f, the total failure-induced deviatoric strain, calculated by the one-dimensional Lagrangian computer program SOC with shot-induced fracture- and permeability-enhancement. Further purposes of the experiment were to test diagnostics for future in situ coal gasification work. Gross effects of the explosion were increased permeability, increased fracturing, decreased sound speed, easier drilling, and migration of dye from the shot hole. These effects were found out to a radius corresponding to values of $\varepsilon_r \gtrsim 0.01$. Values of ε_r of this order have been associated in the past with microscopic fracture. Subtler effects were decreased resistivity as well as changes in the character of the acoustic logs. The latter were found out to a radius corresponding to $\varepsilon_r \gtrsim 0.001$. Diagnostic tests indicated satisfactory performance of the experimental techniques.

Hearst, J. R. and BUTKOVICH, T. R., Prediction and determination of explosive-induced fracture (Soc. Explo. Eng. Conf. Explosion & Blasting Techniques, Louisville, Ky., Sept. 1976) Lawrence Livermore Laboratory, Rept. UCRL-77659, Preprint (1976).

Hearst, J. R., HANSON, M. E., McKee, C. R., Emerson, D. O., and Montan, D. N. Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-1 (1976).

Hearst, J. R., HANSON, M. E., McKee, C. R., Emerson, D. O., Qualheim, B. J., and Terhune, R. W., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-2 (1976).

HOWARD, J. H., House, P. A., Johnson, P. M., and Towse, D. F., Geology and potential uses of the geopressure resources of the Gulf Coast, Am. Assoc. Pet. Geol. 60, 682 (1976). [UCRL-77434, Abstract] Lawrence Livermore Laboratory, Rept. UCID-17163 (1976).

The United States Energy Research and Development Administration has supported efforts to evaluate the potential contribution to the national energy supply of geopressured geothermal resources in the Gulf Coast. Efforts include a program of resource assessment and programs to examine utilization of the resource for the production of electricity and as a source of industrial-process heat.

Work on resource assessment has suggested the presence of perhaps as much as 6,000 MW-centuries of recoverable electric energy and of 200 Tcf of methane. This program has emphasized finding significantly large sand bodies within the geopressured stratigraphic section in addition to defining the distribution of abnormal fluid pressures and formation temperatures. Regional sand facies analyses conducted thus far indicate five locations in the Frio formation of Central and South Texas where adequately large geopressured geothermal resources may be present.

Engineering studies of energy-conversion systems based on total-flow, flashed-steam, and binary-cycle concepts show that development of electric power from the Gulf Coast geopressure resource is technically feasible. However, such recovery is only marginally economic in view of the relatively low temperatures involved (less than 300°F or 149°C), and especially if dissolved methane is not present at saturation levels. Under favorable circumstances, investment in exploitation of the complete geothermal resource can produce rates of return of 15 to 30 percent. Rates of return as large as 10 percent appear unlikely under present and near-term future circumstances if only electric energy is recovered from the resource.

Study of use of the resource as process heat in pulp and paper mills and new sugar refineries has shown that these uses also are technically sound. The thermal content of a barrel of geothermal brine can cost as

little as 9 mills when credited for recoverable hydraulic energy and methane. The value of heat approaches 50 mills per bbl for certain applications. Again, under favorable circumstances, the use of geopressure resources for these nonelectric applications is economically attractive.

All programs have pointed out clearly the need for better specific understanding of the resource, especially its dissolved methane content and its ability to produce for tens of years.

HOWARD, N. W., The Lawrence Livermore Laboratory nuclear test effects and geologic data bank (Geol. Soc. Am. Ann. Mtg., Denver, Nov. 1976) Lawrence Livermore Laboratory, Rept. 78799, Abstract (1976).

Nuclear explosives have been tested underground at the USERDA Nevada Test Site (NTS) since 1957. All U.S. tests have been conducted underground in drill holes and tunnels since 1963, when the Limited Test Ban Treaty went into effect. Since then, data have been collected on the geology at NTS to evaluate the possibility of release of radioactivity at specific sites for proposed nuclear tests. Data on both the rock physical properties and geologic structure and stratigraphy of a large number of drill hole sites are stored in the Lawrence Livermore Laboratory Earth Science Division Test Effects Data Bank. Retrieval of data from the bank allows geological and geophysical comparison of a particular site with other sites where successful containment of radioactivity was experienced. Sorting, comparing and averaging of data are done by standard data bank programs. They conveniently list information according to site location, drill hole construction, rock units, depth to key horizons and the water table, and distance to faults. These programs also make possible ordered listings of the geophysical properties of interval bulk density, overburden density, interval velocity, velocity to the surface, grain density, water content, carbonate content, porosity and saturation of the rocks. Data is used in presenting proposed nuclear tests for approval to the USERDA Nevada Operations Office Containment Evaluation Panel (CEP). This Panel relies on past experience with similar tests and on modelling of nuclear phenomenology. The Data Bank is an invaluable aid in providing the necessary geologic data quickly.

HOWARD, N. W., The Lawrence Livermore Laboratory nuclear test effects and geologic data bank (Geosci. Info. Soc. Sympos., Geol. Soc. Am. Mtg., Denver, Nov. 1976) Lawrence Livermore Laboratory, Rept. UCRL-78799, Preprint (1976).

Data on the geology of the USERDA Nevada Test Site have been collected for the purpose of evaluating the possibility of release of radioactivity at proposed underground nuclear test sites. These data, including both the rock physical properties and the geologic structure and stratigraphy of a large number of drill-hole sites, are stored in the Lawrence Livermore Laboratory Earth Sciences Division Nuclear Test Effects and Geologic Data Bank. Retrieval programs can quickly provide a geological and geophysical comparison of a particular site with other sites where radioactivity was successfully contained. The data can be automatically sorted, compared, and averaged, and information listed according to site location, drill-hole construction, rock units, depth to key horizons and to the water table, and distance to faults. These programs also make possible ordered listings of geophysical properties (interval bulk density, overburden density, interval velocity, velocity to the surface, grain density, water content, carbonate content, porosity, and saturation of the rocks). In this paper, we discuss the characteristics and capabilities of this data bank.

KASAMEYER, P. W. and Schroeder, R. C., Thermal depletion of a geothermal reservoir with both fracture and pore permeability, Lawrence Livermore Laboratory, Rept. UCRL-77323, Preprint (1976).

The useful lifetime of a geothermal resource is often calculated from the volume of available hot water. The lifetime may actually be longer if reinjected fluid is heated by the rock matrix and produced again. For reservoirs containing only porous material and for reservoirs consisting entirely of fractured impermeable rock, that extended lifetime has been estimated. We present here a method for estimating the useful lifetime of a reservoir in porous rock where the injection and production wells intersect a fracture system. Equations are derived for the pore-fluid and fracture-fluid temperatures averaged over large regions of the geothermal field. Problems such as incomplete areal sweep and interfingering of cool and hot fluids are ignored. We develop approximate equations relating average temperatures to the heat flowing from rock to fluid, and we justify their use by comparing our results with solutions of the exact equations. Our equations for the temperature decline can be solved quickly.

In our model, fractures are characterized by three parameters: aperture w, permeability k_{fr}, and spacings between fractures D. For certain values of these parameters, cool reinjected fluid in fractures may reach the production wells long before all the warm pore fluid has been tapped,

shortening the useful lifetime of the field. We ignore the traditional (and important) problems of reservoir engineering, flow rate determination, drawdown, sweep patterns, etc. Thus, our results are most useful in providing a correction factor which can be applied to lifetime estimates obtained from a detailed simulation of a field assuming porous rock. That correction factor is plotted for clean fractures ($k_{fr} = w^2/12$) as a function of w and D for several lifetime ranges.

Small-scale fractures seen in cores from the Salton Sea Geothermal Field are too closely spaced to reduce lifetime estimates. However, large-scale fault systems exist within that field, and they are attractive drilling targets because they produce large flow rates. If large scale faults communicate between injection and production wells, they may reduce the useful lifetime of those wells.

KASAMEYER, P. W., Preliminary interpretation of resistivity and seismic refraction data from the Salton Sea Geothermal Field, Lawrence Livermore Laboratory, Rept. UCRL-52115 (1976).

Seismic refraction and electrical resistivity surveys have been conducted in the Salton Sea Geothermal Field. The resistivity data are used to infer the boundaries of a reservoir of saline fluid. One lateral boundary closely coincides with a fault that was located by seismic refraction.

KELLY, R. E., Atmospheric dispersion and noise propagation at Imperial Valley geothermal fields, Lawrence Livermore Laboratory, Rept. UCRL-52053 (1976).

Quantitative estimations are made for the atmospheric dispersion of gases, heat, and noise due to geothermal energy sources in Southern California's Imperial Valley. In particular, gas concentration per unit source strength, change in mixing ratio, relative humidity, temperature, and the ratio of heat flux to solar constant are calculated. The possibility of atmospheric refraction of source noise is also considered.

LARSON, D. B, Explosive energy coupling in ice and frozen soils, Lawrence Livermore Laboratory, Rept. UCRL-78962, Preprint (1976).

Small scale high explosive experiments, using spherical charges as energy sources, have been conducted in ice and three frozen soils. Data obtained from these experiments have provided evidence for a shock wave induced melting transition in ice and ice saturated frozen soils. Explosive energy coupling parameters have been derived from these data. Comparison

of these coupling parameters with those of water suggest that coupling in ice is less because of dissipation of energy in the melting transition. An even larger decrease in coupling observed in ice saturated soils is attributed to the introduction of soil into the ice matrix. This leads to lowering of the transition stress due to the presence of stress concentration at soil grain boundaries. However, the tremendous decoupling observed for 50% ice saturated soil is attributed to the weak ice matrix undergoing yielding. This permits pore collapse effects to dominante over transition effects and allows decoupling to very low stresses.

LARSON, D. B, and Anderson, G. D., Shock-wave studies of subbituminous coals, Lawrence Livermore Laboratory, Rept. UCRL-51996 (1976).

Plane and spherical shock-wave experiments were performed on saturated subbituminous coals obtained from Kemmerer, Wyoming, and Decker, Montana. Plane shock waves up to a stress of 3.0 GPa were generated using a 4-inch diameter gas gun. Particle-velocity histories behind the shock wave were recorded by magnetic particle-velocity gages. Hugoniot and release curves obtained from a Lagrangian analysis of the gage data indicate a small, permanent volume decrease on unloading. Spherical shock waves were generated by the detonation of a small, spherical high-explosive charge embedded in a block of coal. Particle-velocity and stress histories were recorded behind the shock wave using magnetic particle-velocity gages and piezoresistive stress gages, respectively. Plane and spherical one-dimensional calculations were performed with a Lagrangian computer code to simulate the experiments. Particle-velocity profiles in the plane calculations agreed with the profiles obtained from the gas-gun experiments at the higher stresses when a shear-failure-relaxation model was used to describe the coal. Agreement was poor at lower stress, where hysteresis occurred. The disagreement between computed and measured profiles is attributed to hysteresis resulting from the crushing out of dry porosity introduced by water loss during sample fabrication. The same model used in spherical calculations produced wave shapes that agreed well with the measured profiles in experiments using a 1.9 cm-radius sphere of explosive as a source. Agreement was poorer when calculations were compared to the results of an experiment using a 0.95 cm-radius explosive charge. The experimentally measured peak particle velocities decayed in the spherical geometry as $R^{-1.56}$, while the computed peaks decayed as $R^{-1.46}$ at higher

levels and as $R^{-1.20}$ at lower levels, where elastic behavior is approached. This disagreement cannot be associated with dry porosity, and it is therefore attributed to dispersion.

Larson, D. and FINGER, M., Use of explosives in deep rock mining: in situ energy and mineral recovery (Conf. Explosives Eng., Explosion & Blasting Tech., Louisville, Ky., Jan. 1976) Lawrence Livermore Laboratory, Rept. UCRL-77721, Preprint (1976).

Chemical explosives may become a key element in many of the in situ energy and mineral recovery methods under development. This paper discusses the potential role of explosives in deep rock mining for resource recovery. Several energy and mineral recovery programs described are an outgrowth of the Plowshare Program and Explosives R&D conducted as part of the AEC/ERDA mission at Lawrence Livermore Laboratory. Several important aspects of the use of explosives in deep rock mining are reviewed. First, the status of knowledge of deep rock fracturing to create permeability underground is discussed. Completely contained blasting has not been a widely applied tool used in the mining industry. We conclude that data available on deep rock fracture is minimal and that the mechanisms that control the processes must be understood before technical and economic feasibility can be established. We also discuss the unusual problems in the selection of an explosive or blasting agent for deep rock applications including emphasis on the functioning at depth and safety aspects. Finally, a brief review of similar activities within the U.S. is given.

Leach, D., HEARST, J. R, Butkovich, T., Laine, E., Lake, R., Lytle, J., Sherman, J., Snoeberger, D., and Quong, R., Fractures induced by a contained explosion in Kemmerer coal, Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 13, 37-44 (1976). [UCRL-51790]

LEWIS, A. E., In-situ extraction of shale oil: recent advances in technology (AEChE Mtg., Kansas City, Mo., April 1976) Lawrence Livermore Laboratory, Rept. UCRL-77500, Abstract (1976).

The technology of in-situ rubblization and retorting is very promising as an economical method of obtaining oil from oil shale. An experimental program to develop the retorting technology is underway at the Lawrence Livermore Laboratory.

Recent results from laboratory experiments and retorts (including a 6 tonne "adiabatic" retort) will be summarized. The application of the results to field scale in-situ retorting and requirements for

commercialization of the process will also be discussed.

Lewis, A. E., and ROTHMAN, A. J., Research and development on oil recovery from oil shale by a rubble in-situ extraction (RISE) process (Ann. Energy Sympos. Los Angeles Council of Eng. & Sci., Los Angeles, May 1976) Lawrence Livermore Laboratory, Rept. UCRL-77564, Abstract (1976).

Lewis, A. E. and ROTHMAN, A. J., Recovery of oil from oil shale by rubble in-situ extraction (RISE) process (Am. Inst. Aeronautics & Astronautics Sympos. Alternate Fuel Resources, Santa Maria, Calif., March 1976) Lawrence Livermore Laboratory, Rept. UCRL-77565, Abstract (1976).

Lewis, A. E., SCHWARTZ, L. L., Cohen, J. J., and Braun, R. L., High Level radioactive waste isolation by incorporation in silicate rock, Lawrence Livermore Laboratory, Rept. UCRL-78746, Preprint (1976).

MALLON, R. G. and Braun, R. L., Reactivity of oil shale carbonaceous residue with oxygen and carbon dioxide, Colo. School of Mines Quarterly 71, 309-333 (1976). [UCRL-77829, Preprint]

Pyrolysis of the organic material in oil shale results in the formation of a carbonaceous residue (char) in the spent shale. This char represents an important fuel component, which upon further reaction can contribute a substantial amount of the energy required for advancing the retorting front.

The reactivity of char was investigated by performing experiments on individual blocks of oil shale (15 cm diameter and 15 to 25 cm length) under conditions of controlled temperature and gas environment. The results illustrated that the char-O_2 reaction rate is limited by the rate of O_2 diffusion. The effective diffusivity of O_2 scales with the square of the kerogen concentration of the raw shale, as predicted by theoretical considerations. However, the measured diffusivities are appreciably greater than theoretical. The difference is attributed to the network of small cracks which develop during the early part of the retorting process.

The results also clearly demonstrated another important mechanism for consumption of char within the oil shale block, namely, reaction of char with the CO_2 produced from the decomposition of dolomite and calcite. This reaction is important in accurate retort modeling, since it constitutes a mechanism for removal of char from the interior of the oil shale block at a rate which, at elevated temperatures, is much greater than the diffusion-limited rate of the char-O_2 reaction. Although the char-CO_2 reaction is itself endothermic, the CO produced can subsequently readily react with O_2 in the exterior gas stream to provide additional heat.

A calculational model for oxygen diffusion, carbonate decomposition, and the simultaneous removal of char by reaction with O_2 and CO_2 is presented. The calculational results are in good agreement with the experimental data.

Mallon, R. G. and ROTHMAN, A. J., An economic study of the rubble in-situ extraction (RISE) process for extraction of oil from shale (ACS Sympos. Comparative Economics of Synthetic Fuels Processing, New York City, April 1976) Lawrence Livermore Laboratory, Rept. UCRL-77344, Abstract (1976).

McKague, H. L., and KNOWLTON, G., A study of the water content in zeolitic tuffs from the USERDA Nevada Test Site, Proc. Zeolite "76" Conf., Tucson, June 1976, 40-41 (1976). [UCRL-78013, Abstract]

Thermal gravimetric analyses (TGA) was employed to gain quantitative information about absorbed, zeolitic (in channels and cages), and coordinated water present in powdered zeolitic tuffs from the U.S. Energy Research and Development Administration's Nevada Test Site.

TGA of 50 - 70 mg of powdered tuff samples, ranging from 40 to 60 percent clinoptilolite, was performed under N_2 atmosphere and vacuum using a 2°/min. heating rate. The TGA plots exhibit three linear portions; each is assumed to represent a specific type of water being lost over a given temperature range. The linear portions are separated by curved sections which represent a transition in the type of water being evolved. Evaluation of these plots suggests that absorbed water is lost between 25° and 90°C, zeolitic water between 70° and 300°C, and coordinated water between 200° and 700°C. All absorbed water could be removed in 1 to 2 hours at ambient temperature (~25°C) using vacuum only (0.8-1.0 mm Hg), while removal of significant amounts of zeolitic water required increasing the temperature above ambient.

The clinoptilolite content of the samples, based on the percent zeolitic water, when normalized against the measured zeolitic water content of pure clinoptilolite, generally agrees with the amount of clinoptilolite as estimated by x-ray diffraction analysis. The powdered tuff samples analyzed in this study contain an average of 4.6 ± 0.2% absorbed water, 4.9 ± 0.3% zeolitic water, and 1.7 ± 0.1% coordinated water, for an average total weight loss at complete dehydration of 11.1 ± 0.4%.

McKague, H. L., and HEARST, J. R., Structure elucidation with borehole gravimetry, Geophysics 41, 491-505 (1976). [UCRL-76316, Rev. 1, Preprint]

MCKEE, C. R. and Hanson, M., Predicting explosion-created permeability around geothermal wells (Workshop Geothermal Eng., Stanford, January 1976) Lawrence Livermore Laboratory, Rept. UCRL-77673, Preprint (1976).

A theoretical expression showing the radial dependence of permeability in geologic media as a function of the distance from the point of detonation has been derived. This relationship shows that created permeability decreases as a function of radius ($1/r^5$ around a spherical blast and $1/r^4$ around a cylindrical shot). Excellent correlation was found when this prediction was compared with permeability measurements made around the site of the Hardhat nuclear event fired in granodiorite and a chemical explosive detonated in coal.

MCKEE, C. R., Hanson, M. E., and Terhune, R. W., Permeability from single and multiple detonations of explosive charges (World Mining & Metal Tech. Conf., Joint MMIF-AIME Mtg., Sept. 1976; ERDA Sympos. Enhanced Oil & Gas Recovery, Tulsa, Sept. 1976) Lawrence Livermore Laboratory, Rept. UCRL-78207, Rev. 1, Preprint (1976).

Relationships describing the permeability enhancement caused by explosive detonations in boreholes have been derived and combined to yield

$$k = k_c \left[\frac{r_d^{-3f-3}}{\left(r_d^{-f-m} + n_o/n_c \right)^2} \right] + k_o,$$

for the case in which the stress decays asymptotically as a power law, k_c and n_c represent permeability and fracture density at the edge of the pulverized region near the cavity wall; f is a geometric attenuation factor; m is the dissipation due to real material effects; k_o is the original permeability, n_o the initial fracture density, and r_d the scaled radius. This relationship has been compared with available measurements from the American "Hardhat" nuclear shot, the French nuclear events in Hoggar granite, and a chemical explosive shot in coal near Kemmerer, Wyoming. Significant correlation between theory and experimental measurements is observed. A comparison between single and multiple detonations shows that permeability enhancement falls off steeply near the shot; however, enhancement can be considerable midway between two shots spaced 10 cavity radii apart. The degree to which enhancement can be significant depends on material properties and initial fracture density. Porosity distribution from the explosive is the dominant parameter in permeability enhancement.

McKee, C. R., HANSON, M. E., Emerson, D. O., Montan, D. N., and Hearst, J. R, Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-1 (1976).

McKee, C. R., HANSON, M. E., Emerson, D. O., Qualheim, B. J., Hearst, J. R, and Terhune, R. W., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-2 (1976).

Montan, D. N., HANSON, M. E., McKee, C. R., Emerson, D. O., and Hearst, J. R, Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-1 (1976).

OWEN, L. B. and Jackson, D., Precipitation of amorphous silica from high-temperature-hypersaline geothermal brine, Trans. Am. Geophys. Union 57, 354 (1976). [UCRL-77628, Abstract]

Siliceous scale, formed during the adiabatic expansion of hypersaline brine from the Salton Sea Geothermal Field (SSGF), has been studied. Typical scale deposits consist of Si and Fe (in roughly equal molar proportions) with lesser amounts of S, Cu, Ag, and other metals. Field experiments were performed at the Sinclair #4 site, located in the southwest portion of the SSGF. The average wellhead temperature, pressure, and total dissolved solids content of brine produced at this site are 210°C, 220 PSIG, and 256,000 ppm, respectively (full flow through a 6-inch diameter line).

Scale deposition rates were measured in a long (73 cm) converging-diverging nozzle with a 1° aperture. The nozzle was operated for a period of 5 hours and 45 minutes at a flow rate of ~4 lbs of brine per second. Scaling rates abruptly increased, from less than 30 μ/hour to 350 μ/hour, when the measured brine temperature, which varied along the length of the nozzle, fell below 170°C. These observations are consistent with the anticipated temperature at which a brine containing 500 ppm dissolved silica would become supersaturated with respect to amorphous silica (assuming a steam quality of 32%).

A comparative study of the microstructure of siliceous scale and other forms of amorphous silica was also completed. The scale is a gel composed of colloidal silica particles as small as 5 mμ in diameter. Gel formation is promoted by coagulation of colloidal silica by Fe, Al and other elements. The sulfides in scale can be attributed, in part, to post-depositional

diffusion of heavy metals and sulfur through a porous silica gel and their subsequent recrystallization.

OWEN, L. B. and Palmer, T. D., Chemical geothermometry: accuracy of subsurface temperature estimates for the Salton Sea Geothermal Field, Lawrence Livermore Laboratory, Rept. UCRL-78289, Preprint (1976).

The accuracy of subsurface temperature estimations by Na-K-Ca and silica geothermometers has been investigated. Data from wells in the Salton Sea Geothermal Field have provided a comparison between the estimated and observed maximum bottomhole temperatures. The advantages and problems encountered with each technique are discussed.

Owen, L. B. and GOLDBERG, A., Pitting corrosion and scaling of plain carbon steel exposed to geothermal brine, Lawrence Livermore Laboratory, Rept. UCRL-78247, Abstract (1976).

Well casings and surface pipes fabricated from plain carbon steel were perforated by pitting corrosion during exposure to hypersaline brine at the Salton Sea geothermal area in southern California. These pipes had been used in connection with various field activities at the Sinclair #4 well, where an acidic (pH ~5.5), reducing brine is produced at a temperature of 200°C. At depth, the dissolved-solids content of the brine is about 25 wt%. However, as the brine flows to the surface, flashing occurs so that salinities reach 30 wt% at the wellhead. The brine consists primarily of Na, K, and Ca chlorides, with minor constituents including transition metals, Si, CO_2, and H_2S. It is likely that during intermittent operation of the well over a period of several months, metal surfaces had been exposed to atmospheric oxygen. Furthermore, surface pipes were inadvertently flushed with oxygenated irrigation water on at least one occasion. Perforated pipe sections totalling about 4 m in length were sent to our laboratory for analysis.

A continuous layer of corrosion product (hydroxides and oxides of iron) was found on brine-exposed surfaces. Within this layer, numerous bowl-shaped pits were observed. In the surface pipes, most of the pits were less than 0.5 mm deep. Although several pits penetrated the entire 7.2 mm-thick pipe wall, only one pit of intermediate depth (~ 1 mm) was found. In the well casing, however, several pits within the 1 mm to 7.2 mm range were found. Penetration of wedge-like intrusions of corrosion product into the metal substrate was common, especially within the pits. This suggests that

corrosion may have been assisted by a wedging stress-corrosion-cracking mechanism made possible by the intrusion of low-density corrosion products. Etching techniques revealed that the pearlite in the steel was preferentially attacked and that the dissolution of ferrite grains occurred at a slower rate. Throughout the pipe, the corrosion product itself had been partially dissolved and replaced by scale consisting of iron-rich amorphous silica with entrained galena (PbS) and some chalcopyrite ($CuFeS_2$). Thick scale-rich deposits were observed in the pits that had perforated the pipe.

Corrosion rates had been greatly accelerated by the introduction of atmospheric oxygen during shut-down intervals. With brine flowing through the system, pitting may have been promoted by crevice-type corrosion resulting from variations in scale-deposit thickness along the surface of the corrosion product. Such variations would affect transport and local concentration of species participating in the corrosion process. Since scale thickness increased with pit depth, the process was self-perpetuating. At some small critical pit depth, the rate of pitting increased catastrophically, ultimately resulting in wall penetration. When the pipe was breached, brine erupted violently through the orifice. As a consequence, the corrosion product was eroded and replaced by a thick deposit of siliceous scale.

Owen, L. B. and GRENS, J. Z., Inhibiting deposition of siliceous scale, (Sympos. Scale Management in Geothermal Energy Development, San Diego, August 1976) Lawrence Livermore Laboratory, Rept. UCRL-78420, Abstract (1976).

Lawrence Livermore Laboratory is developing the TOTAL FLOW process for efficient utilization of the thermal energy stored in high temperature-high salinity brines from the Salton Sea Geothermal Field (SSGF) for electric power production. Energy conversion is accomplished by flowing brine through mixed phase expanders and directing the high velocity exhaust jets onto the blades of an impulse turbine. Previous field experience, however, at the Sinclair # 4 site in the SSGF indicated that deposition of siliceous scale (heavy metal sulfides and iron-rich amorphous silica) in nozzles and on turbine blades would be a serious problem when hypersaline brine is flash evaporated. An experimental program, therefore, was established to develop scale control techniques. Preliminary results indicate that scaling is a pH-dependent process that can be inhibited when brine is acidified with hydrochloric acid.

A mobile field test unit has been established at the ERDA-SDG&E test site in the southwestern part of the SSGF. Brine from the Magmamax No. 1 well was flowed through a steam separator that isolated vapor and liquid fractions formed as the brine moved from the geothermal reservoir, up the wellbore to the surface. Although the separated liquid phase was used for the initial brine modification experiments, subsequent work will involve remixing of liquid and vapor fractions prior to chemical additions. Average temperature and pressure of the brine were about 220°C and 265 psi, respectively. System through-put varied between 18,000 to 24,000 pounds of brine per hour. Flow through nozzles (8:1 expansion ratio, 1/4 inch diameter throat)was 1.25 pounds of brine per second. The nominal pH of unmodified brine flowing from the separator varied from 5.5 to 5.8. Dissolved solids content of the brine prior to and after expansion through nozzles was 18 weight percent to 22 weight percent, respectively. Nozzles and wearplates were fabricated from Ti-6Al-4V alloy. Three independent nozzles were operated simultaneously. During each acidification run, at least one nozzle was always operated as a control station flowing unmodified brine.

Thus far, four experiments, each of 20 hours duration, have been completed. Nominal scaling (copper sulfide, native silver, and iron-rich amorphous silica) from unmodified brine resulted in closure of up to 10% of the cross-sectional areas of nozzle throats. Thickness of scale formed on wearblades ranged between 0.019 mm to 0.04 mm. However, when brine was acidified to pH 1.5, 2.3, and 4.0, scaling in nozzles was eliminated and substantially reduced on wearblades. Acidified brine effluents remained clear several hours after collection. However, unmodified brine was slightly turbid when collected, with precipitates forming a few minutes after samples were taken.

Palmer, T. D. and OWEN, L. B., Chemical geothermometry: accuracy of sub-surface temperature estimates for the Salton Sea Geothermal Field, Lawrence Livermore Laboratory, Rept. UCRL-78289, Preprint (1976).

Palmer, T. D. and TOWSE, D. F., Summary of geology at the ERDA-MAGMA-SDG&E geothermal test site, Lawrence Livermore Laboratory, Rept. UCID-17008 (1976).

PIWINSKII, A. J. and Duba, A., The permittivity and electrical conductivity of oil shale, Int. J. Rock. Mech. Min. Sci. & Geomech. Abstr. 13, 165-166 (1976). [UCRL-76789, Preprint]

In situ retorting of oil shale present in subsurface reservoirs in the western United States is potentially an immense source of hydrocarbon fuels. In an attempt to establish methods which would be helpful in developing this resource, we have undertaken an investigation of the electrical conductivity (σ) and the real part of the complex permittivity (ε') of oil shale. Electrical methods long have been useful in field prospecting and it seems logical to attempt to apply them as a diagnostic tool during in situ processing. Relatively inexpensive surface measurements would be ideal for monitoring the progress of an in situ reaction. We report here the results of our study on oil shale under ambient conditions prior to, and after, retorting to temperatures of 800 K.

PIWINSKII, A. J., Geochemical and geophysical aspects of compressional and extensional tectonic regimes (invited lecture, University of Calif., Berkeley, May 5, 1975) Lawrence Livermore Laboratory, Rept. UCRL-78101, Abstract (1976).

Mutual interrelationships of mobile, lithospheric plates define two fundamentally different tectonic settings: compressional and tensional regions. The former occur at loci of plate convergence; they are zones of crustal shortening and loci of orogenesis. The latter define loci of plate divergence; they are zones of crustal tension and reveal no regional penetrative deformation. The rock types of compressional regimes are andesitic volcanogenic sequences and batholithic granitoids. Tensional regimes are characterized by tholeiitic or alkali basalt with rhyolite, trachyte or phonolite, local development of ultramafic, nephelinitic and carbonatitic members and bimodal basic-acid complexes. Both compressional and extensional regimes develop characteristic geophysical signatures. For the latter region (i.e.,Basin and Range Province), the following are observed: high heat flow, low Pn velocity, thin crust, approximately 25 to 30 km, large positive mantle Vp and Vs delays and broad negative Bouger gravity anomalies. In addition, high conductivity structures are present under the Basin and Range and Southern Rockies. Recent geochemical and geophysical laboratory studies will be discussed and a model will be presented to explain the observed geochemical and geophysical variations in both tectonic regimes.

PIWINSKII, A. J. and Weed, H., A study of rock-solution interaction and its effect on Archie's Law, IEEE Trans. Geosci. Electron. GE-14, 221-223 (1976). [UCRL-78110, Preprint]

The electrical conductivity (σ) of cylindrical cores of 25.4 mm diameter and length Pictured Cliffs sandstone (permeability range, 7×10^{-4}-4×10^{-1} millidarcy (md); porosity range, 3.8-4.9 percent) was measured at a frequency of 1 kHz under ambient conditions after saturation in tap water. Kinetics of rock-water interaction and the effect of Soxhlet extraction on the σ of the rock were also investigated. Formation factors (F) and the σ display time-dependent behavior up to 4500 h. Smooth asymmetrical conductivity maxima occur for all samples at times which increase with increasing porosity. The observed time-dependence of F in Archie's Law ($F = \phi^{-n}$, ϕ = porosity, n = a parameter) is influenced by the kinetics of ion transport between the Pictured Cliffs sandstone and the aqueous pore fluid. Soxhlet extraction lowers F, but does not significantly change its time dependence.

PIWINSKII, A. J., The influence of sedimentary rock-solution equilibria on Archie's Law (invited lecture, University of Calif., Berkeley, April 29, 1976) Lawrence Livermore Laboratory, Rept. UCRL-78117, Abstract (1976).

As part of a laboratory programme to explore the range of applicability of Archie's Law, $\frac{\sigma_s}{\sigma_r} = F = \phi^{-n}$ where σ_s is electrical conductivity of the solution, σ_r is the electrical conductivity of the rock immersed in solution, F is the "formation factor", ϕ is porosity and n is a parameter, the electrical conductivity of cylindrical, 25.4 mm diameter cores cut from Pictured Cliffs sandstone (porosity range 3.8% to 4.9%) was measured at a frequency of 1 kHz under ambient conditions after submersion in tap water. The σ_s was also measured. Formation factors and σ_r displayed time-dependent behavior up to 7,500 hrs. The time required for σ_r to reach maximum values was found to increase with the porosity of the rock sample. The observed time-dependence of F was influenced by the kinetics of ion transport between the Pictured Cliffs sandstone and the aqueous pore fluid.

PIWINSKII, A. J., Duba, A., and Weed, H. C., Electrical conductivity studies and geothermal diagnostics (Conf. Geothermal Resources of Imperial Valley, Calif., Riverside, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78293, Abstract (1976).

The electrical conductivity (σ) of igneous and sedimentary rocks has been investigated as a function of frequency (ν), porosity (ϕ), pore fluid

composition, specimen size, and time. Sample size and ν affects the σ of rocks saturated in 0.1 M/NaCl solution least. No simple correlation was found between log σ and log ϕ for rocks saturated in tap or distilled water. For the Pictured Cliffs sandstone ($\bar{\phi}$ ≈4.0%), kinetics of rock-water interaction and the effect of Soxhlet extraction on the σ of the rock were also investigated. The σ of the rocks and solutions displays time-dependent behavior up to 7,500 hours and is influenced by the kinetics of ion transport between the sandstone and aqueous pore fluid. Thus, care needs to be taken when applying relationships such as Archie's Law to obtain porosity for a given geologic formation.

The σ of albite, a predominant constituent of geothermal reservoir rocks, and basalt was investigated as a function of temperature, ν, and oxygen fugacity (f_{O_2}) under ambient total pressures. The σ of albite is a function of time and ν at temperatures below melting. After 3,200 hours at temperatures between 1080 and 1111°C, the σ increases approximately four decades. These results indicate that the degree of disorder attained in the solid state prior to melting controls the rise in σ and that melting need not be invoked to produce large changes in the σ. The laboratory data suggest that large conductivity anomalies detected by field geophysical measurements could represent lateral variations in plagioclase feldspar content under isothermal conditions rather than partial melt zones or rising thermal plumes, provided that this same behavior persists in fluid-saturated regimes.

The σ of basalt at the QFM buffer is an order of magnitude lower than previously reported for basalt. A kinetic study at 1053°C (solidus temperature = 1020°C) indicates that an approximate equilibrium σ is attained after about 130 hours and that only 50% of the total increase in σ is observed in the first 15 hours. These results indicate that both time and oxygen fugacity are critical parameters in the interpretation of σ changes associated with phase transitions.

PIWINSKII, A. J. and Dengler, L., Pore structure and mineralogy of core chips from the State of California well no. 1, Salton Sea Geothermal Field, Trans. Am. Geophys. Union 57, 1017 (1976). [UCRL-78637, Abstract]

Rock chips in the depth interval 1380-1478 m were examined using scanning electron microscopy, x-ray diffraction, and petrographic techniques. All samples are dense, well-indurated siltstones. Principal mineral constituents are quartz and K-feldspar, detrital and authigenic, with minor amounts of

chlorite and plagioclase. Calcite is present in all samples except the 1400 m horizon; specimens from this horizon also possess epidote veins. Pyrite is found in all samples both as large isolated crystals and as a replacement mineral in foraminifera tests. Coexisting authigenic quartz and iron sulfides suggests a reducing environment at pH greater than 3.5 at a temperature of 200°C for a brine of Sinclair No. 4 composition. Pore structure is heterogeneous and closely linked to rock fabric and bedding. The average pore diameter is approximately 1 μm, due to the fine-grained nature of these samples and the tendency of clay minerals to surround grains and fill grain boundaries.

PIWINSKII, A. J., Duba, A., and Ho, P., The electrical conductivity of low and high albite throughout its melting interval at atmospheric pressure (Min. Asso. Canada Ann. Mtg., Edmonton, May 1976) Lawrence Livermore Laboratory, Rept. UCRL-77662, Abstract (1976). [UCRL-78777, Preprint]

The electrical conductivity (σ) of single crystal Amelia albite has been measured parallel to the b-axis under controlled oxygen fugacity near the QFM buffer up to 1406 K. Prior to melting, triclinic ordered albite was cycled between 673 and 1223 K, temperatures below the triclinic - monoclinic inversion. The σ of low triclinic albite was then measured as a function of time during melting at 1406 K and frequencies (ν) from 200 Hz to 10 kHz. Within the first 100 hours, the σ measured at 1 and 10 kHz increased by approximately 2.5 orders of magnitude; the σ measured at 200 Hz increased by 2.0 orders of magnitude. This is to be contrasted with the increase in σ of high monoclinic albite during melting at 1406 K of approximately half an order of magnitude at 1 and 10 kHz and a decrease in σ of high albite by less than a factor of two at 200 Hz. These results indicate that the crystal structures of low and high albite preceding melting exert a control over the ν-dependence of the σ observed on melting. Furthermore, in this disordered monoclinic albite, the degree of disorder attained in the solid state before melting appears to control the σ change observed upon melting.

Piwinskii, A. J., JACKSON, D., and Miller, D., Computational methods for estimating precipitation from geothermal brines (Sympos. Scale Management in Geothermal Energy Development, San Diego, August 1976) Lawrence Livermore Laboratory, Rept. UCRL-78391, Abstract (1976).

Laboratory experiments using Salton Sea Geothermal Field brines at elevated temperatures are costly, time-consuming, and potentially difficult to

perform. The LLL Geothermal Program is therefore also attempting to predict equilibria in the SSGF brines by computation.

Two approaches to this problem are being taken. Modeling of chemical reactions in the brines is being carried out using the Helgeson-Herrick (HH) code. In addition, the precipitation of many solids is being studied individually using effective activity coefficients which take chloride complexing into account.

The results of both methods are consistent with one another in predicting precipitation behavior in the temperature range 100-300°C. For example, results for Sinclair No. 4 brines at 200°C indicate that at low pH, SiO_2, MnO_2, and Fe silicates precipitate. As pH increases, Cu and Fe sulphides, Fe silicates and Fe oxides also precipitate.

For the San Diego Gas and Electric Magmamax brine at 200°C, the HH code predicts results quite similar to those described above for the Sinclair No. 4 brine with one notable exception, PbS precipitated at pH greater than 4.0. This correlates with observations on the scale examined from the San Diego Gas and Electric test site.

Piwinskii, A. J. and SCARFE, C. M., Physics and chemistry of silicate melts and magmas, Lawrence Livermore Laboratory, Rept. UCRL-78595, Preprint (1976).

"The Physics and Chemistry of Silicate Melts and Magmas" was the subject of a one-day session held during the Annual Joint Meeting of the Geological and Mineralogical Associations of Canada, Edmonton, May 19-21, 1976. The session brought together geochemists, geophysicists and materials scientists presently working on experimental and theoretical aspects of silicate melts and magmas. The papers covered various aspects of diffusion, nucleation, crystal growth, viscosity, volatile component solubility, electrical conductivity, thermodynamic properties, and the structure of silicate melts and magmas and are summarized in the report.

Piwinskii, A. J., MAGGETTI, M., Keller, P., and Weed, H., Hornblende and biotite as geobarometers in granitoid rocks, Trans. Am. Geophys. Union 57, 1021 (1976). [UCRL-78638, Abstract]

Results of recent experimental hydrothermal investigations (oxygen fugacity regulated, but not controlled) on rocks of granitoid and gabbroic composition at elevated temperatures and water pressures to 1 GPa suggest that hornblende and biotite may be used as geobarometers if certain criteria

are fulfilled. They are as follows: (1) hornblende and/or biotite are liquidus, or near-liquidus phases as determined from petrographic examination of rocks in thin section, (2)they are not relict phases from some earlier magmatic, metamorphic or metasomatic episode, (3) chemical analyses and CIPW weight norms of the rocks are available. Stability fields of biotite and hornblende together with plagioclase are then a function of water pressure, temperature, and rock composition when portrayed in three-dimensional space using a computer program written for CDC 7600 machines. Projection on to the pressure-Differentiation Index plane (where Differentiation Index = normative albite + orthoclase + quartz and indicates rock composition) yields linear relationships for both biotite and hornblende.

Piwinskii, A. J., JACKSON, D., and Miller, D., Computer modelling of geothermal brines from the Salton Sea Geothermal Field, California, Trans. Am. Geophys. Union 57, 1016 (1976). [UCRL-78640, Abstract]

To produce electric power from energy stored in the hypersaline brines of the Salton Sea Geothermal Field, methods must be developed for controlling the sulfides and silicates which precipitate as scale deposits on process equipment. To circumvent costly, time-consuming, and potentially difficult laboratory experiments, we have attempted to predict equilibria in these brines by two different computational techniques, the Helgeson-Herrick code and individual reaction calculations using effective activity coefficients which take into account chloride complexing. The results of both methods are consistent with one another in predicting precipitation behavior in the temperature interval 100-300°C. For example, results for the Magmamax No. 1 brines indicate that quartz, pyrrhotite, galena, chalcopyrite, sphalerite, and Fe-silicates can precipitate. This predicted sulfide-silicate assemblage agrees generally with observations on scale from the field test site, although the silica-silicate scale matrix is amorphous. Carbonate equilibria are especially interesting; large Ca^{+2} and CO_2 concentrations in the Magmamax No. 1 brine suggest that the reservoir fluid is saturated with respect to calcite. At a downhole temperature of 260°C using the calcite curve as a guide, saturation would occur at pH of 3.5-4.0.

Piwinskii, A.J., DUBA, A., Heard, H. C., and Schock, R. N., The electrical conductivity of forsterite, enstatite, and albite, in Physics and Chemistry of Minerals and Rocks, R. G. J. Strens, Ed. (John Wiley & Sons, New York, 1976), pp. 249-260. [UCRL-75790, Preprint]

Piwinskii, A. J. and WEED, H. C., Electrical conductivity of Pictured Cliffs sandstone saturated with tap water under ambient conditions, Trans. Am. Geophys. Union 57, 322 (1976). [UCRL-77638, Abstract]

Piwinskii, A. J., DUBA, A., Heard, H. C., and Schock, R. N., Geothermal prospecting and the electrical conductivity changes associated with melting (Panel Mtg. Expl. Meth. of Dry Hot Rock, Los Alamos, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78261, Abstract (1976).

Piwinskii, A. J., HO, P., and Duba, A., Dielectric properties and the monoclinic-triclinic inversion in albite, Trans. Am. Geophys. Union 57, 1005 (1976). [UCRL-78639, Abstract]

Piwinskii, A. J. and WEED, H. C., Electrical conductivity of water in contact with mixtures of char and ash from Wyodak coal, in LLL In Situ Coal Gasification Program quarterly progress report, D. R. Stephens, Ed., Lawrence Livermore Laboratory, Rept. UCRL-50026-76-2, p. 22-23 (1976).

Piwinskii, A. J. and WEED, H.C., Electrical conductivity of rock-solution systems under ambient conditions: Pictured Cliffs sandstone in tap water, Lawrence Livermore Laboratory, Rept. UCRL-52005 (1976).

Piwinskii, A. J. and DENGLER, L., A study of core chips from the State of California well no. 1, Salton Sea Geothermal Field using petrographic x-ray diffraction and scanning electron microscopy techniques, Lawrence Livermore Laboratory, Rept. UCID-17184 (1976).

Puchlik, K. P., BORG, I. Y., and Stone, R., Oil, gas, uranium, and thorium: supply and depletion, with special reference to California, Lawrence Livermore Laboratory, Rept. UCRL-52180 (1976).

Qualheim, B. J., HANSON, M. E., McKee, C. R., Emerson, D. O., Hearst, J. R., and Terhune, R. W., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL 50036-76-2 (1976).

RALEY, J. H. and Braun, R. L., Oil degradation during oil shale retorting, Preprints Sympos. Oil Shale, Tar Sands & Related Materials, Div. of Fuel, Am. Chem. Soc. Mtg., San Francisco, August-Sept. 1976, Vol. 21, 137-146 (1976). [UCRL-78098, Preprint]

The varied temperature-time regimes anticipated for in-situ retorting of oil shale deposits may have important effects on oil yield. This paper reviews recent experimental data demonstrating the effects of varied thermal histories on oil yield from powdered Colorado shale. The reported losses in overall yield resulting from interruption of a rapid heating schedule with an isothermal holding period are directly related to the amounts of oil that are produced during the holding period. These amounts are also correlated with the inert gas flow rates required to raise the yields to the assay value.

The results show that degradation of oil outside the shale particles is the major determinant of oil yield from powdered shale. Maximum thermal degradation rates are calculated from these data and compared with pyrolysis rates for petroleum fractions and other organic compounds.

Raley, J. H., STOUT, N. D., Koskinas, G. J., Santor, S. D., Opila, R. J., and Rothman, A. J., Pyrolysis of oil shale: effects of thermal history on oil yield (Ninth Oil Shale Sympos., Golden, Colo., April 1976) Lawrence Livermore Laboratory, Rept. UCRL-77831, Preprint (1976)

In-situ retorting of oil shale will subject the shale to heating periods ranging from hours to months. The oil yields resulting from such thermal histories are needed for the modeling and economic evaluation of in-situ processing.

In this work, the effect of thermal history on the oil yield of a powdered, 22 gallon per ton Colorado shale was studied by heating at Fischer assay rate (12°C/min) to test temperature, holding at test temperature for varying times up to 33 days, and finally heating to 500°C at 12°C/min. Test temperatures covered the range 150 to 450°C. Both autogenous and inert, sweep gas atmospheres were used. Under self-generated atmospheres, at test temperatures of 250°C or below, yields obtained were 100% of Fischer assay. Heating at 300 to 425°C resulted in yield losses, maximizing at 19% after a 33 day exposure at 350°C.

In the inert gas sweep experiments, increasing flow rates gave increasingly higher oil yields, finally approaching 100% of assay. This beneficial effect is attributed to reduced thermal degradation of oil in the retort. In these experiments the total yield appears to be determined by the temperature-time exposure of the liberated oil and is essentially uninfluenced by the thermal history of the kerogen.

RAMBO, J. T., Slifers revisited: a method for determining yields independent of radiochemical measurements, Lawrence Livermore Laboratory, Rept. UCID-17292 (1976).

It would be very desirable if an independent method other than radiochemical measurement were available to determine the yields of low-yield events in the alluviums and tuffs of areas 2, 9, and 10 at the Nevada Test Site. The successful application of slifers to the measurement of yields from high-yield events suggests that under some conditions they may also be

usable with low-yield events. This view is supported by the evidence discussed here, which is based on direct experience with slifer yield measurements for low-yield events in porous media. Suggested methods for improving slifer yield determinations and a method for determining yields independent of radiochemical measurements are offered.

RAMSPOTT, L. D., Preliminary design of a waste isolation experiment in the Climax Stock, Nevada Test Site (distribution limited) Lawrence Livermore Laboratory, Rept. UCID-17335 (1976).

This report documents the preliminary design of a waste isolation experiment in the Climax Stock, Nevada Test Site. The purpose of such an experiment is to demonstrate that a cannister of simulated radioactive waste can safely be emplaced, monitored, and retrieved in a dry granite environment, and to measure the in situ effects of the emplaced waste. Its design is expected to produce generic data about waste isolation in granite and similar crystalline rocks.

To this end it is proposed to emplace such a cannister in a mockup of an actual vault in granite and to monitor the effects for two years before removing it from its surroundings. The principal technical measurements proposed are temperature, permeability, and rock stress/strain and displacement, with pre- and post-test sampling to examine physical changes in the rock. A preliminary experimental plan has been developed in sufficient detail to permit time and cost estimates to be made. Material about the proposed stimulated waste source has been used, together with literature values for the thermal properties of granite, to produce estimates of the expected temperature rise. Background material on the Climax Stock, the differences between salt and granite, and a bibliography have also been assembled.

Ramspott, L. D., BORG, I. Y., Stone, R., and Levy, H. B., Movement of radioactivity deposited underground at the U. S. ERDA Nevada Test Site, Lawrence Livermore Laboratory, Rept. UCRL-78670, Preprint (1976).

Ramspott, L. D., BORG, I. Y., Stone, R., and Levy, H. B., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 1: review and analysis of existing information, Lawrence Livermore Laboratory, Rept. UCRL-52078 (1976).

Ramspott, L. D., BORG, I. Y., Stone, R., and Levy, H. B., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 2: annotated bibliography, Lawrence Livermore Laboratory Rept. UCRL-52078, Part 2 (1976).

RODEAN, H. C., Thermodynamic relations for shock waves in materials with a linear relation between shock wave and particle velocities, Lawrence Livermore Laboratory, Rept. UCRL-77441, Rev. 1, Preprint (1976).

The Rankine-Hugoniot relations for shock waves and the empirical linear relation between the shock wave and particle velocities define an incomplete thermodynamic description of the states along the Hugoniot curve. This incomplete description defines the following along the Hugoniot: (1) internal energy and pressure as functions of specific volume, (2) the ratio of enthalpy to internal energy, (3) the ratio of the changes in enthalpy and internal energy across a shock wave, and (4) the relation between the Gruneisen coefficient and the effective isentropic exponent. We use the Dugdale-MacDonald relation for the Gruneisen coefficient at low pressure, an assumed constant value for the specific heat at constant volume, and reasonable physical assumptions for extremely strong shock waves together with the incomplete thermodynamic state description to define the following along the Hugoniot: (5) the Gruneisen coefficient, (6) the effective isentropic exponent, (7) the ratio of specific heats, and (8) thermal and elastic components of pressure, temperature, and entropy. We present representative numerical values of these parameters as functions of reduced volumetric compression. We show how the solutions for these parameters define tangent planes to the surfaces of the incomplete E,P,V and P,V,T equations of state at each point along the Hugoniot curve.

RODEAN, H. C., Seismic yield verification and a regional M_S vs m_b anomaly, Lawrence Livermore Laboratory, Rept. UCID-17006 (1976).

The surface-wave magnitude (M_S) and body-wave magnitude (m_b) data for explosions in the western United States are anomalous with respect to such data for the Aleutians, the Sahara, and the USSR. The degree of this anomaly is such that it has significant implications with respect to using magnitude vs yield data from the Nevada Test Site to estimate the yields of explosions in other parts of the world. This report presents the results of a literature survey of seismic and other geophysical evidence relating to this anomaly. The geology and geophysics of three regions are considered: (1) the Basin and Range province in the western United States, (2) the Baikal rift zone in the USSR, and (3) central Kazakhstan in the USSR. Complete geophysical models, which would be of value in explaining the M_S vs m_b anomaly, have not been developed for any of these regions.

Rodean, H. C., HANNON, W. J., and Barnett, C. S., Earthquake triggering by earthquakes and nuclear explosions at rates of less than 1^{o}/day, Lawrence Livermore Laboratory, Rept. UCRL-52096 (1976).

ROTHMAN, A. J. and Mallon, R. G., An economic study of the rubble in-situ extraction (RISE) process for extraction of oil from shale (ACS Sympos. Comparative Economics of Synthetic Fuels Processing, New York City, April 1976) Lawrence Livermore Laboratory, Rept. UCRL-77344, Abstract (1976).

A method is described for the in-situ production of oil from shale. Underground mining operations are used to produce a column of rubblized shale. A flame front moving downward through the rubble releases the oil. Details of the mining procedures are described. The capital and operating costs of these procedures are presented on the basis of cost per barrel of product. The effect on costs of varying the shale bed thickness, the rubble column size, and the rubble void ratio are considered. Other costs involved in the process are discussed.

ROTHMAN, A. J. and Lewis, A. E., Research and development on oil recovery from oil shale by a rubble in-situ extraction (RISE) process (Ann. Energy Sympos. Los Angeles Council of Eng. & Sci., Los Angeles, May 1976) Lawrence Livermore Laboratory, Rept. UCRL-77564, Abstract (1976).

A domestic oil resource equal to the Middle East petroleum reserve is potentially available in the form of oil shale in the U.S. West. A proposed rubble in-situ extraction process (RISE) can make available an estimated 350 billion barrels of oil at rates of 2 to 5 million barrels a day, at a relatively low cost economically and environmentally.

The process consists in a continuous mining procedure to produce large beds of oil shale rubble underground. The oil shale is then retorted to oil by means of hot gas, produced by combustion in place or externally heated.

Retorting aspects of the process have been under study at the Lawrence Livermore Laboratory. Some recent developments in this research are outlined in this paper. Plans are outlined for a laboratory and field program leading to commercial scale retorts in six years. It appears that this process has a high likelihood of success.

ROTHMAN, A. J. and Lewis, A. E., Recovery of oil from oil shale by rubble in-situ extraction (RISE) process (Am. Inst. Aeronautics & Astronautics Sympos. Alternate Fuel Resources, Santa Maria, Calif., March 1976) Lawrence Livermore Laboratory, Rept. UCRL-77565, Abstract (1976).

An enormous domestic potential supply of oil is available in the form of oil shale. Estimated recoverable oil from this resource by the RISE (rubble

in-situ extraction) process is 350 billion barrels, a quantity approximately equal to the Middle East petroleum reserves.

Development of the RISE process for eventual commercial recovery of oil from oil shale is described. The process would utilize continuous mining methods to produce oil shale rubble underground. The rubble is heated either by hot gases or by combustion in place using a supply of air. The product oil formed is recovered at the surface. Research and development requirements are outlined, including studies of retorting (pyrolysis) of oil shale, rubblization, and a series of proposed field tests leading to commercial size operations. The program could be completed in six years after an expenditure of about $80 million, and has a high likelihood of success. Successful development would produce oil at lower cost (~$8/barrel) than conventional surface retorting and at higher production rates that are less limited by water supply, population influx, and capital requirements, and so would have substantial impact on domestic availability of oil.

Although the program is not currently funded as such, research is well under way at the Lawrence Livermore Laboratory on retorting aspects of the process.

ROTHMAN, A. J., ed., Quarterly report, LLL oil shale program, January-March 1976, Lawrence Livermore Laboratory, Rept. UCID-16986-76-1 (1976).

ROTHMAN, A. J., ed., Quarterly report, LLL oil shale program, April-June 1976, Lawrence Livermore Laboratory, Rept. UCID-16986-76-2 (1976).

ROTHMAN, A. J., ed., Quarterly report, LLL oil shale program, July-September 1976, Lawrence Livermore Laboratory, Rept. UCID-16986-76-3 (1976).

Rothman, A. J., STOUT, N. D., Raley, J. H., Koskinas, C. J., Santor, S. D., and Opila, R. J., Pyrolysis of oil shale: effects of thermal history on oil yield (Ninth Oil Shale Sympos., Golden, Colo., April 1976) Lawrence Livermore Laboratory, Rept. UCRL-77831, Preprint (1976).

Sandholtz, W. A. and ACKERMAN, F. J., Oil shale retort experiments simulating in-situ operations (AIME Soc. Petrol. Eng. Ann. Tech. Conf. & Exhib., New Orleans, October 1976) Lawrence Livermore Laboratory, Rept. UCRL-77830, Abstract (1976).

SCHATZ, J. F., Models of inelastic volume deformation for porous geologic materials, Lawrence Livermore Laboratory, Rept. UCRL-78227, Preprint (1976).

Porous geologic materials are highly inelastic. With hydrostatic loading, they compact irreversibly. When shear stresses are imposed, they may either compact or dilate with increasing mean stress. This paper reviews

models of inelastic deformation with emphasis placed on hydrostatic loading and unloading of dry material. Purely phenomenological models are common and very useful, but more physical insight can be gained from models which attempt to incorporate the actual internal mechanisms of deformation. Most mechanistic models are based on a concept of material being either an assemblage of objects in contact or voids distributed throughout a continuum. Void deformation models which use spherical pores are at this time the most powerful and convenient.

SCHOCK, R. N., Abey, A. E., and Duba, A., Quasistatic deformation of porous beryllium and aluminum, J. Appl. Phys. 47, 53-63 (1976). [UCRL-76587, Preprint]

Loading and unloading of two types of porous beryllium and a porous aluminum under conditions of uniaxial strain, proportional loading, and hydrostatic pressure indicate that yielding is dominated by porosity. Analysis of the data prior to yielding indicates that aspherical pores cause increased compressibility on initial loading. All materials exhibit enhanced compaction when loaded under nonhydrostatic stress conditions. Models which treat the collapse of spherical pores do not agree with the beryllium data, probably because of the influence of aspherical pores and pore-size distribution.

SCHOCK, R. N., A constitutive relation describing dilatant behavior in Climax Stock granodiorite, Intl. J. Rock Mech. Min. Sci. & Geomech. Abstr. 13, 221-223 (1976). [UCRL-77204, Preprint]

Climax Stock granodiorite was compressively loaded along different paths to failure at a fixed strain rate and at mean pressures to 0.7 GPa. These data are used to develop a constitutive relation. The expression relates dilatant volume strain ε_d to mean pressure P and shear stress τ in the form:

$$\varepsilon_d = \exp\left[\frac{\delta P}{x(\tau)} - A(\tau)\right],$$

where x and A are explicit functions of τ. The equation has the advantage of simplicity and of expressing the actual behavior in terms of measured physical parameters.

SCHOCK, R. N., Duba, A. G., Heard, H. C., and Stromberg, H. D., The electrical conductivity of polycrystalline olivine and pyroxene under pressure, in High Pressure Research, Applications to Geophysics, M. H. Manghnani and S. Akimoto, Eds. (Academic Press, New York, in press). [UCRL-78048, Preprint]

Electrical conductivity (σ) measurements on polycrystalline olivine and

pyroxene were made at pressures up to 5.0 GPa and at temperatures up to 1200°C to examine the effect of grain boundaries on conduction. Values of σ were observed within one-half order of magnitude of those for single crystals at lower pressures and under controlled oxygen fugacity (f_{O_2}). If this difference prevails over the entire temperature range, these values result in temperature profiles for the earth and moon that are lower than profiles from single-crystal data by no more than 200°C. However the small σ differences between single and polycrystals most probably are due to a higher f_{O_2} in the experimental apparatus rather than the presence of grain boundaries. The data indicate pressure has a small effect on conductivity and activation enthalpies associated with conduction.

SCHOCK, R. N., The response of rocks to large stresses (Sympos. Planet. Cratering Mech., Houston, September 1976; Pergamon Press, in press) Lawrence Livermore Laboratory, Rept. UCRL-78587, Preprint (1976).

To predict the dimensions and characteristics of impact- and explosion-induced craters, one must know the equation of state of the rocks in which the crater is formed. Recent experimental data shed light upon inelastic processes that influence the stress/strain behavior of rocks. We examine these data with a view to developing models that could be used in predicting cratering phenomena. New data is presented on the volume behavior of two dissimilar rocks subjected to tensile stresses.

Schock, R. N., DUBA, A., Piwinskii, A. J., and Heard, H. C., The electrical conductivity of forsterite, enstatite, and albite, in Physics and Chemistry of Minerals and Rocks, R. G. J. Strens, Ed. (John Wiley & Sons, New York, 1976), 249-260. [UCRL-75790, Preprint]

Schock, R. N. and COSTANTINO, M. S., A constitutive relation to describe the dilatant behavior of a dense sandstone, Trans. Am. Geophys. Union 57, 330 (1976). [UCRL-77647, Abstract]

Schock, R. N., DUBA, A., and Heard, H. C., Electrical conductivity of orthopyroxene to 1400°C and the resulting selenotherm, Proc. Seventh Lunar Sci. Conf., Vol. 3, 3173-3181 (1976). [UCRL-77655, Preprint]

Schock, R. N., DUBA, A., Heard, H. C.,,and Piwinskii, A. J., Geothermal prospecting and the electrical conductivity changes associated with melting (Panel Mtg. Expl. Meth. of Dry Hot Rock, Los Alamos, June 1976) Lawrence Livermore Laboratory, Rept. UCRL-78261, Abstract (1976).

Schock, R. N., HEARD, H. C., and Duba, A. G., Geotherms based on electrical conductivity of olivine, pyroxene, and pyrolite (U.S.-Japan Sem. High Pressure Res. Appli., Honolulu, July 1976) Lawrence Livermore Laboratory, Rept. UCRL-78294, Abstract (1976).

Schock, R. N. and COSTANTINO, M. S., A constitutive relation for compressive loading in Nugget sandstone, Lawrence Livermore Laboratory, Rept. UCRL-52036 (1976).

Schock, R. N., HEARD, H. C., Bonner, B. P., Costantino, M. S., and Weed, H. C., Mechanical response of saturated Kemmerer coal to 4 GPa, Lawrence Livermore Laboratory, Rept. UCRL-52063 (1976).

Schroeder, R. C. and KASAMEYER, P. W., Thermal depletion of a geothermal reservoir with both fracture and pore permeability, Lawrence Livermore Laboratory, Rept. UCRL-77323, Preprint (1976).

SCHWARTZ, L. L., Cohen, J. J., Lewis, A. E., and Braun, R. L., High level radioactive waste isolation by incorporation in silicate rock, Lawrence Livermore Laboratory, Rept. UCRL-78746, Preprint (1976).

A number of technical possibilities for isolating high level radioactive materials have been theoretically investigated at various times and places. Isolating such wastes deep underground to insure long term removal from the biosphere is one such possibility which has been investigated. The present concept involves as a first step creating the necessary void space at considerable depth, say 2-5 km, in a very low permeability silicate medium such as shale. Waste in dry, calcined or vitrified form is then lowered into the void space, and the access hole or shaft sealed. Energy released by the radioactive decay raises the temperature to a point where the surrounding rock begins to melt. The waste is then dissolved in it. The extent of this melt region grows until the heat generated is balanced by conduction away from the molten zone. Resolidification then begins, and ends when the radioactive decay has progressed to the point that the temperature falls below the melting point of the rock-waste solution. Calculations are presented showing the growth and resolidification process. The use of a nuclear explosion presents one alternative way of creating the void space.

Shaffer, R. J., HANSON, M. E., Emerson, D. O., Heard, H. C., and Carlson, R. C., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, July-September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-3 (1976).

Snell, C. M., COODRICH, M. F., Bryan, J. B., and Thomsen, J. M., Final report on a calculational parameter study of soils typical of some ESSEX I cratering sites, Lawrence Livermore Laboratory, Rept. UCRL-52038 (1976).

SPRINGER, D. L. and Denny, M. D., Seismic spectra of events at regional distances, Lawrence Livermore Laboratory, Rept. UCRL-52048 (1976).

About 40 underground nuclear explosions detonated at NTS were chosen for

analysis of their spectra and any relationships they might have to source parameters such as yield, depth of burial, etc. The sample covered a large yield range (<20 kt to >1 Mt). Broadband (0.05-20 Hz) data recorded by the four-station seismic network operated by Lawrence Livermore Laboratory were analyzed in a search for unusual explosion signatures in their spectra. Long time windows (total wave train) as well as shorter windows (for instance, P_n) were used as input to calculate the spectra. Much variation in the spectra of the long windows is typical although some gross features are similar, such as a dominant peak in the microseismic window. The variation is such that selection of "corner frequencies" is impractical and yield scaling could not be determined. Spectra for one NTS earthquake showed more energy in the short periods (<1 sec) as well as in the long periods (>8 sec) compared to those for NTS explosions.

Springer, D. L. and MARSHALL, P. D., Is the velocity of P_n an indicator of Q_α?, Nature 264, 531-533 (1976). [UCRL-78701, Preprint]

It is suggested that P_n velocity may be a geophysical parameter that is an indicator of the quality of the upper mantle and therefore related to Q_α of the upper mantle. A relationship of P_n velocity and average seismic amplitude residuals is developed using published data which supports the suggestion.

STONE, R. and Snoeberger, D. F., Evaluation of the native hydraulic characteristics of the Felix coal (Eocene, Wasatch Formation) and associated strata, Hoe Creek Site, Campbell County, Wyoming, Lawrence Livermore Laboratory, Rept. UCRL-51992 (1976).

The native hydraulic characteristics of the shallow (35- to 50-m-deep) Felix coal and adjacent strata have been estimated from the results of comprehensive field tests at the Campbell County, Wyoming, site of proposed in situ coal-gasification experiments. The field tests involved withdrawal of water from and water injection into wells completed in the Felix coal. Measurement of the effects of these hydraulic perturbations in terms of water-level fluctuations in wells completed in the coal and adjacent strata provided the data used in the analysis. At the proposed gasification site, the Felix coal consists of two seams. The estimates of hydraulic conductivity of the 3-m-thick Felix No. 1, the shallower of the two seams, range from about 0.3 to 1 m/day. The coefficient of storage of the Felix No. 1 is approximately 2×10^{-2}. Test results indicate that the Felix No. 1 behaves as a very

leaky aquifer.

The 7.6-m-thick Felix No. 2 was found to be hydraulically anisotropic. Its maximum horizontal hydraulic conductivity is estimated to be approximately 0.3 m/day along a direction of N 59°E, while its minimum horizontal hydraulic conductivity of about 0.15 m/day is developed in a direction of N 31°W. The principal conductivity axes of the Felix No. 2 correspond with the orientation of two sets of near vertical fractures found in oriented cores taken from the seam. The maximum horizontal conductivity is developed along the more prominent fracture set. The vertical hydraulic conductivity of the Felix No.2 is apparently greater than its minimum horizontal conductivity and may be as great as the sum of its maximum and minimum horizontal conductivities. The average vertical hydraulic conductivity of the strata between the two coal seams is estimated to be from 0.015 to nearly 0.3 m/day. The first 2 m of strata below the Felix No. 2 coal have a vertical hydraulic conductivity of less than 1×10^{-3} m/day. The Felix No. 2 behaves as a leaky to very leaky aquifer. Coefficients of storage estimated for the Felix No. 2 range in value from about 1×10^{-3} to 1.6×10^{-2}, with the larger values being associated with greater vertical leakage. The saturated strata from the base of the Felix No. 2 upward to the water table make up a multiple-leaky-aquifer system. The hydraulic character of the Felix coal shows less variability than that of adjacent strata.

Stone, R., BORG, I. Y., Levy, H. B., and Ramspott, L. D., Movement of radioactivity deposited underground at the U.S. ERDA Nevada Test Site, Lawrence Livermore Laboratory, Rept. UCRL-78670, Preprint (1976).

Stone, R., BORG, I. Y., Levy, H. B., and Ramspott, L. D., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 1: review and analysis of existing information, Lawrence Livermore Laboratory, Rept. UCRL-52078 (1976).

Stone, R., BORG, I. Y., Levy, H. B., and Ramspott, L. D., Information pertinent to the migration of radionuclides in ground water at the Nevada Test Site. Part 2: annotated bibliography, Lawrence Livermore Laboratory, Rept. UCRL-52078, Part 2 (1976).

Stone, R., BORG, I. Y., and Puchlik, K. P., Oil, gas, uranium, and thorium: supply and depletion, with special reference to California, Lawrence Livermore Laboratory, Rept. UCRL-52180 (1976).

Terhune, R. W., MCKEE, C. R., and Hanson, M. E., Permeability from single and multiple detonations of explosive charges (World Mining & Metal Tech. Conf., Joint MMIJ-AIME Mtg., Sept. 1976; ERDA Sympos. Enhanced Oil & Gas Recovery, Tulsa, Sept. 1976) Lawrence Livermore Laboratory, Rept.

UCRL-78207, Rev. 1, Preprint (1976).

Terhune, R. W., HANSON, M. E., McKee, C. R., Emerson, D. O., Qualheim, B. J., and Hearst, J. R., Quarterly report: the LLL massive hydraulic fracturing program for gas stimulation, April-June 1976, Lawrence Livermore Laboratory, Rept. UCRL-50036-76-2 (1976).

THOMSEN, J. M., Glenn, H. D., and Germain, B. K., Airblast prediction progress report, Lawrence Livermore Laboratory, Rept. UCID-17019, CFRD (1976).

(U) The shallow-earth penetrator (SEP) is a weapon designed to produce a combination of airblast, ground motion, and cratering damage by a nuclear or high-explosive detonation at a shallow depth of burial (DOB). Existing data on nuclear events is applied to the SEP concept. Airblast production is investigated with one-dimensional calculations and analytical techniques. The long-standing goals of the ESSEX (effects of Subsurface Explosions) and NEST (Nuclear Explosive Shock Tube) projects are examined to see if they are compatible with the goals of the proposed low yield SEP test.

Thomsen, J. M. and GLENN, H. D., Computer simulation of a high explosive cratering experiment in a complex multilayered geology, Lawrence Livermore Laboratory, Rept. UCRL-78155, Preprint (1976).

Thomsen, J. M., GOODRICH, M. F., Bryan, J. B., and Snell, C. M., Final report on a calculational parameter study of soils typical of some ESSEX I cratering sites, Lawrence Livermore Laboratory, Rept. UCRL-52038 (1976).

TONNESSEN, K. A. and Cohen, J. J., Survey of naturally occurring hazardous materials in deep geologic formations: a perspective on the relative hazard of deep burial of nuclear wastes, Lawrence Livermore Laboratory, Rept. UCRL-52199 (1976).

Hazards associated with deep burial of solidified nuclear waste are considered with reference to toxic elements in naturally occurring ore deposits. This problem is put into perspective by relating the hazard of a radioactive waste repository to that of naturally occurring geologic formations. The basis for comparison derives from a consideration of safe drinking water levels. Calculations for relative toxicity of fast breeder reactor (FBR) waste and light water reactor (LWR) waste in an underground repository are compared with the relative toxicity indices obtained for average concentration ore deposits. Results indicate that, over time, nuclear waste toxicity decreases to levels below those of naturally occurring hazardous materials.

TOWSE, D., Economics of geothermal heat as an alternate fuel, Trans. Soc. Min. Eng. 260, 322-326 (1976). [UCRL-77031, Rev. 1, Preprint]

Geothermal energy can substitute for and compete with other fuels, but until now it has been used only in special situations where it costs much less than alternate fuels. Geothermal heat is expected to be developed where it can: (1) compete with alternate fuels, (2) replace scarce fuels, (3) be more environmentally acceptable, or (4) is especially adapted to local needs. Economic problems in development include the often high capital costs of wells and gathering systems and the long lead-times required for electric generating plants. The large investment and long payout times for large industrial uses adversely affect the economics.

TOWSE, D., Geology of Salton Sea Geothermal Field, Am. Asso. Pet. Geol. 60, 728 (1976). (Also No. Calif. Geol. Soc. Mtg., Sept. 1976) [UCRL-77435, Abstract]

The Salton Sea field in Imperial County, California, covers 46.6 sq km (18 sq mi) south of the Salton Sea. Drilling indicates the presence of 2×10^{18} J (2×10^{15} Btu) of heat contained in 1.3×10^{9} M.T. of hot salty water at temperatures above 230°C that could in principle be used to generate 400 MW of electric power for 20 years.

Brines with temperatures of more than 300°C and salinities of more than 30 percent are in fractured sandstone sections of the nonmarine Palm Springs Formation. These lie under a 260-650 m (840-2,130 ft) layer of Pleistocene and Pliocene (?) shale and clay that traps the water and minimizes conductive heat loss. Source of heat is young rhyolitic intrusive rocks in the subsurface and at the surface near the shore of the Salton Sea. Reservoir-fluid temperatures increase with increasing thickness of overlying clay and are modified by variations in permeability caused by original sedimentation and by faulting. Delta, stream, beach, and lacustrine environments can be recognized in the reservoir section.

Measured well flows of 5×10^{-2} to 8×10^{-2} cu m/s (800-1,300 gpm) indicate flow through fractures at an effective reservoir permeability as high as 10^{-12} sq m (1 darcy).

Structure is dominated by a series of northwest-southeast strike-slip faults with several hundred feet of apparent vertical separation. Variations in thickness and sandstone distribution indicate that these faults were active during deposition, and some are seismically active today.

TOWSE, D. F. and Palmer, T. D., Summary of geology at the ERDA-MAGMA-SDG&E geothermal test site, Lawrence Livermore Laboratory, Rept. UCID-17008 (1976).

The test facility uses four wells in S 1/2 section 33-11S-13E in Imperial County. The Salton Sea Wildlife Refuge adjoins the property on the north edge.

Two shallow wells (Magmamax 1 and Woolsey 1) are planned as producing wells, and two deeper ones (Magmamax 2 and Magmamax 3) are to be used for disposal. These are shown on the attached sections.

The reservoir rocks are a series of sandstones below a shaly sequence. The reservoir sandstones are divided by several major shale beds over 40 feet thick that, in the absence of fracturing, would provide impermeable barriers and separate the reservoir into several separate hydrologic systems. The most important shale occurs at depths between 2000 and 2500' in all four wells. The section below that barrier is called here the 'Lower Reservoir.'

Towse, D. F., HOWARD, J. H., House, P. A., and Johnson, P. M., Geology and potential uses of the geopressure resources of the Gulf Coast, Am. Asso. Pet. Geol. 60, 682 (1976). [UCRL-77434, Abstract] Lawrence Livermore Laboratory, Rept. UCID-17163 (1976).

WALTON, O. R. and Holt, A. C., Characterization of two porous cermets: a status report (Joint JOWOG-6/SUBWOG-268 Mtg., Albuquerque, Sept. 1976) Lawrence Livermore Laboratory, Rept. UCRL-78726, Preprint (1976).

A material characterization effort designed to develop a model capable of predicting the stress time response of two plasma sprayed ceramic-metal mixtures is described. The preliminary models were developed, before material fabrication, using only the known and estimated properties of the components of each cermet. Predictions based on these preliminary models were within factors of two or three of the underground exposure "proof-tests." Significant improvements in the "predictions" have been realized by incorporating the as-fabricated compositions and porosity and the results of hydrostatic P-V measurements into the model descriptions. As electron-beam and gas gun data become available, they will be incorporated into the model, hopefully to produce even better agreement with the underground stress-time behavior. Results to date have provided us with improved methods to use in predicting the properties of new or hypothetical materials in the future.

WALTON, O. R., An equation of state model for a porous tungsten micro-sphere composite, Lawrence Livermore Laboratory, Rept. UCIR-1040 (1976).

An empirical equation of state and porous model is developed for a mixture of ∿ 86% W, 8% WO_3, with an initial porosity of about 28%. A second order polynomial in μ with a linear energy dependence is found to adequately fit the available Hugoniot data. A two parameter exponential P-α relationship is fit to the static crushing data and the initial porous and solid Hugoniots to 1Mb are calculated. The possibility of melting as low as 0.5 Mb on the Hugoniot is discussed. Examples of calculated two-wave structures are presented.

WEED, H. C. and Piwinskii, A. J., Electrical conductivity of Pictured Cliffs sandstone saturated with tap water under ambient conditions, Trans. Am. Geophys. Union 57, 322 (1976). [UCRL-77638, Abstract]

The electrical conductivity (σ) of cylindrical cores of 25.4 mm diameter Pictured Cliffs sandstone (L/D = 1; permeability range, 7×10^{-4} to 4×10^{-1} md; porosity range, 3.8% to 4.9%) was measured at a frequency of 1 kHz under ambient conditions after saturation in tap water. Kinetics of rock-water interaction and the effect of Soxhlet extraction on the σ of the rock were also investigated. Formation factors (F) and the σ of rock specimens display time-dependent behavior up to 4,500 hours. Smooth, unsymmetrical conductivity maxima occur for all samples at times which increase with increasing porosity. The observed time-dependence of F and, therefore, of Archie's Law ($F = \phi^{-n}$, ϕ = porosity, n = a parameter) is influenced by the kinetics of ion transport between the Pictured Cliffs sandstone and the aqueous pore fluid. Soxhlet extraction lowers F, but does not significantly change its time-dependence.

WEED, H. C., Jackson, D. D., and Koskinas, G., The distribution of radioactivity between rock materials and water at Nevada Test Site, Trans. Am. Geophys. Union 57, 1016 (1976). [UCRL-78644, Abstract]

Static leaching experiments were performed on radioactive debris from Nevada Test Site. Two levels of tracer were used in the leach solution, which was well water from NTS. Debris consisted of puddle glass (samples 1 and 3) and chimney materials (samples 2 and 4). The maximum leaching time was 384 days. High values of K_{DA}, the ratio of the activity per unit area of solid to the activity concentration in the leach solution, are associated with high values of pH for samples 1, 2, 3, but not 4. A correlation between high K_{DA} and high pH suggests that as the solid particles dissolve during the leaching experiments, the acid used in making up the tracer solutions is neutralized. However, the behavior of sample 4 indicates that other factors besides pH can influence the K_{DA}. Insofar as K_{DA} increases with time or with pH, this has

favorable practical consequences for NTS hydrology since a species with a high K_{DA} tends to remain associated with the debris near its point of origin. Such association would be expected to inhibit transport of the species by ground water. The effect of debris type is smallest for ^{85}Sr and ^{60}Co: K_{DA} for these species is approximately the same for both puddle glass and chimney material. The effect of tracer level is not noticeable for ^{85}Sr and ^{60}Co, but in the case of ^{134}Cs and ^{152}Eu, high tracer level is associated with high K_{DA}.

WEED, H. C. and Piwinskii, A. J., Electrical conductivity of rock-solution systems under ambient conditions: Pictured Cliffs sandstone in tap water, Lawrence Livermore Laboratory, Rept. UCRL-52005 (1976).

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WEED, H. C. and Piwinskii, A. J., Electrical conductivity of water in contact with mixtures of char and ash from Wyodak coal, in LLL In Situ Coal Gasification Program quarterly progress report, D. R. Stephens, Ed., Lawrence Livermore Laboratory, Rept. UCRL-50026-76-2, p. 22-23 (1976).

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σ = (0.2724 ± 0.0134) S/m, which is not significantly different from the original value (0.2728 S/m) for Hoe Creek water before mixing. This conductivity is so low that Archie's Law may not apply to systems in which Hoe Creek water is the saturating liquid.

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CLASSIFICATION BY SUBJECT

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