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How We Remember Him: A Biography of Richard H. Jahns 1915 – 1983

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PREFACE

During the gathering of material for the Memorial to Richard H. Jahns, which appeared in the February 1985 issue of the AEG Bulletin, it became apparent that Dick Jahns' life was too varied and interesting to include all the information we had accumulated into a brief Memorial. Several of Dick's friends also indicated they would like to tell of their personal experiences with Dick. Therefore, we decided to solicit personal comments from some of Dick's close friends, so as to create an anthology of both the personality and the professional accomplishments of a true giant among geologists. We have also included some of Dick's unique and humorous lab problems, plus several shorter publications from hard-to-obtain sources.

This biography is in five parts: a) A biographic sketch; b) personal insights and reminiscences from colleagues and former students; c) Dick's imaginative engineering geology lab problems; d) a comprehensive bibliography of Dick's published works, with asterisks marking those that should be of most interest to engineering geologists; and e) selected reprints from less available sources.

Biographies of geologists are not a common feature in professional Bulletins, but, as we think you will realize as you read this, Dick Jahns' influence on general geology and engineering geology was so profound that we feel special recognition is warranted.

DICK JAHNS: THE PERSON AND THE SCIENTIST

Richard H. Jahns was born in Los Angeles on March 10, 1915, the oldest of three children. Some of Dick's most vivid memories of the first eleven years of his life were of Sundays spent riding around the Los Angeles Basin on the old "Red Car Line." These trips probably initiated his life-long fascination with railroads; as his trademark, Dick always wore a railroad engineer's cap when doing field work.

In 1926, when Dick was eleven, the Jahns family moved to Seattle where Dick was to spend his next six years. Early on, he became fascinated with the profuse and varied marine life found in nearby Puget Sound, and he actually considered marine biology as a career. However, Dick's father was a ceramic engineer and during his high school years Dick spent the summers smelting enamels in his father's porcelain enameling plant, thereby acquiring an interest and knowledge of chemistry.

Dick's high school grades were excellent, and it was generally assumed in the Jahns family that Dick would go to college, probably the nearby University of Washington. However, he became attracted to Caltech when Ernie Watson, a physics professor from that institution, gave a guest lecture at Dick's high school. As a result of this exposure, Dick took and passed the Caltech entrance examination, was accepted as a freshman, and was awarded a scholarship. Upon graduation from high school Dick returned to Los Angeles, where he lived with his grandparents in Alhambra and began work on an undergraduate program in chemistry.

Despite the rigors of a strenuous academic program, Dick participated in both intramural and varsity sports at Caltech, earning letters in track, baseball and basketball (Figure 1). He also found time to work as a motorman for the Pacific Electric Railroad. As he was junior man on the seniority list, Dick's consigns usually were the ones the more senior motormen didn't want. His most frequent assignment was the "paper train" that left Los Angeles at 2:10 a.m. to carry the morning papers to the San Gabriel and San Bernardino Valleys. The train returned to Los Angeles in time for Dick to go directly to his 8:00 a.m. class.

During his junior year, Dick took an elective in crystallography, that was taught by Ian Campbell. Fortuitously, this course fell in conjunction with a particularly odorous (literally) chemistry laboratory course, and the contrast caused Dick to ponder whether or not he wanted to spend his professional life in a chemical laboratory or in the field. He opted for a career outdoors, and transferred to geology at the beginning of his senior year. Amazingly, Dick was able to satisfy the undergraduate geology requirements in one year, and graduated, with honors, in 1935, at the end of his fourth year at Caltech.

Dick's enthusiasm for his new profession was reflected by his decision to attend graduate school, and on the basis of his record during his senior year at Caltech and a strong recommendation from Ian Campbell, Dick was admitted to the graduate geology program at Northwestern University. Indeed the response from Northwestern was so positive that Dick was included as a member in a research project in South Park, Colorado, during the summer following his graduation from Caltech.

At the end of the summer, Dick traveled to Evanston and began work on a two-year program [illegible] to his MS degree. During his first year he met a fellow geology student, Max Willard, and thus began a friendship that would last the remainder of their lives. In 1936, after his first year at Northwestern,

Figure 1. Dick Jahns about 22 years old, with Caltech letterman's sweater and his dog "Babe".

Dick married Frances Hodapp, who he had met and dated while a junior at Caltech. When Dick and Frances returned to Evanston for Dick's second year they had trouble finding an apartment. Max and his wife Violet invited the Jahns to share their apartment, and Dick and Frances accepted. The fact that the apartment had only one bedroom did not prove to be a serious problem; one week the Jahns would occupy the bedroom while the Willards slept on the day bed in the living room; the next week their roles would be reversed. This arrangement apparently proved satisfactory, for both Dick and Max received MS degrees in 1937. Dick's MS thesis subject was the Precambrian rocks of South Park Colorado and Tertiary intrusions of the Chalmers area.

During his second year at Northwestern, Dick took and passed the U. S. Geological Survey's (USGS) application examination and was offered a position in the Hydrology Branch. By the end of the academic year, he received yet another offer from the Geologic Division of the Survey; and after receiving an acceptance letter from Caltech as a PhD candidate, Dick went to work for the Survey for $1,800 per year.

Dick's offer from the USGS Geologic Division indicated he would be assigned to the northern Rocky Mountain states of Idaho, Montana and Wyoming, and in anticipation of this new location, Frances and he left Evanston for an extended visit with his family in Seattle. Upon their arrival in Seattle, Dick received a telegram from the Survey telling him to report for work in Nashua, New Hampshire. Dick immediately left for New England; and after her visit in Seattle, Frances returned to southern California.

At that point Dick and Frances made a major decision; they were married and, field work notwithstanding, they wanted to be together. So, despite the Survey's policy then of no wives in the field, Frances traveled to New England to join Dick. Apparently, the "no wives" policy was not rigidly enforced, for Frances stayed on while Dick was in New England. Once the precedent was set, Frances went with Dick everywhere he was assigned, and in the first 11 years of their marriage set up housekeeping in 47 different places, sometimes in a tent.

Dick's New Hampshire assignment consisted of mapping granite quarries throughout New England, and stimulated his mind to speculate on the origins of granitic rocks, particularly pegmatites. Indeed, the study of pegmatites was a major focus of his endeavors throughout his career.

In the fall of 1937 Dick and Frances returned to Caltech, where Dick spent the next two years pursuing his PhD, and in 1939 they left Caltech to return to full-time Survey work in New England. At this point Dick had completed his PhD course requirements but had not completed the thesis.

After the outbreak of World War II, Dick was assigned to the Survey's Strategic Minerals Program; and for the duration of the war Dick and Frances journeyed throughout the United States searching for and evaluating mineral deposits for such things as mica, beryllium, and tantalum. It was during this phase of his career that Dick first became exposed to what many feel was his favorite state, New Mexico (Figure 2).

During most of 1943 Dick found himself again at Caltech, this time to prepare several strategic minerals reports for the Survey. In addition, with the approval of both Caltech and the Survey, he also completed his PhD dissertation, a comprehensive study of the beryllium and tungsten deposits of the Iron Mountain Mining District of New Mexico.

Following completion of his PhD, Dick was promoted to USGS District Supervisor, and was put in charge of a group Survey project evaluating strategic minerals in pegmatite deposits in the southeastern United States. Once again Dick and Frances broke camp, and this time they headed for Ashville, North Carolina. Dick remained on this project for approximately three years and his effort was published as USGS Professional Paper 248, *Mica Deposits of the Southeastern Piedmont*. Two of the six chapters of this study were co-authored with AEG Honorary Member Richard W. Lemke.

Dick and Frances made many friends in North Carolina. One of the more memorable was his landlord, Captain John Hastings, who was a conductor on the Southern Railroad. On numerous weekends Dick and Captain Hastings would tour the Carolinas via train, courtesy of the Southern.

Following the end of World War II, Dick decided he would like to teach at the college level; and after considering several offers, decided to return to his Alma Mater, Caltech. Once again Dick and Frances headed west, this time for a more longer-lived stay, for they were to remain at Caltech for 14 years. Dick rose rapidly through the academic ladder from Assistant Professor through Associate Professor to Full Professor in three years (Figure 3). Also during this period their two children, Alfred and Jeanette, were born.

In addition to establishing a well-deserved reputation as an outstanding teacher at Caltech, Dick continued to do research on the origin of granites

Figure 2. Porter Irwin, Frances Jahns, Lauren Wright and Dick Jahns at Harding Mine, New Mexico, 1943.

and pegmatites. His research was rewarded with the publication of his chapter, "The Study of Pegmatites," in the Fiftieth Anniversary Volume of *Economic Geology*. This paper remains perhaps the most comprehensive single publication on pegmatites. Another formidible publication, The *Geology of Southern California*, had been published as Bulletin 170 by the California Division of Mines the previous year. Dick was editor of the volume and personally contributed seven articles. Although now out-of-print, Bulletin 170 is still regarded as the most comprehensive single source of information on the geology of this region.

During his tenure at Caltech, Dick also began to investigate the geologic causes of numerous problems besetting residential development in the Los Angeles area, and in 1958 his article, "Residential Ills in the Heartbreak Hills of Southern California" (reproduced herein), was published in the Caltech alumni magazine. During the 1950's Dick began to work closely with Frederick Converse, a fellow professor at Caltech and founder of the geotechnical consulting firm that still bears his name. Together Dick and Fred began to integrate geology and soils engineering knowledge to form much of the foundation of today's profession of engineering geology. It was during this period that they met Barney Morris, a major builder of homes in the Los Angeles area. Barney Morris was interested in sound grading practices and the safe development of hillside tracts, and he retained both Dick and Fred to provide solid engineering and geologic input. The relationship was productive to all three parties and they became life-long friends. As an indication of his friendship, before Mr. Morris' passing in 1985, he endowed the Barney and Estelle Morris Chair in Geology at Stanford.

Dick's interest in the origins of granites and pegmatites continued, and having formulated several theories based on field evidence, he decided to test

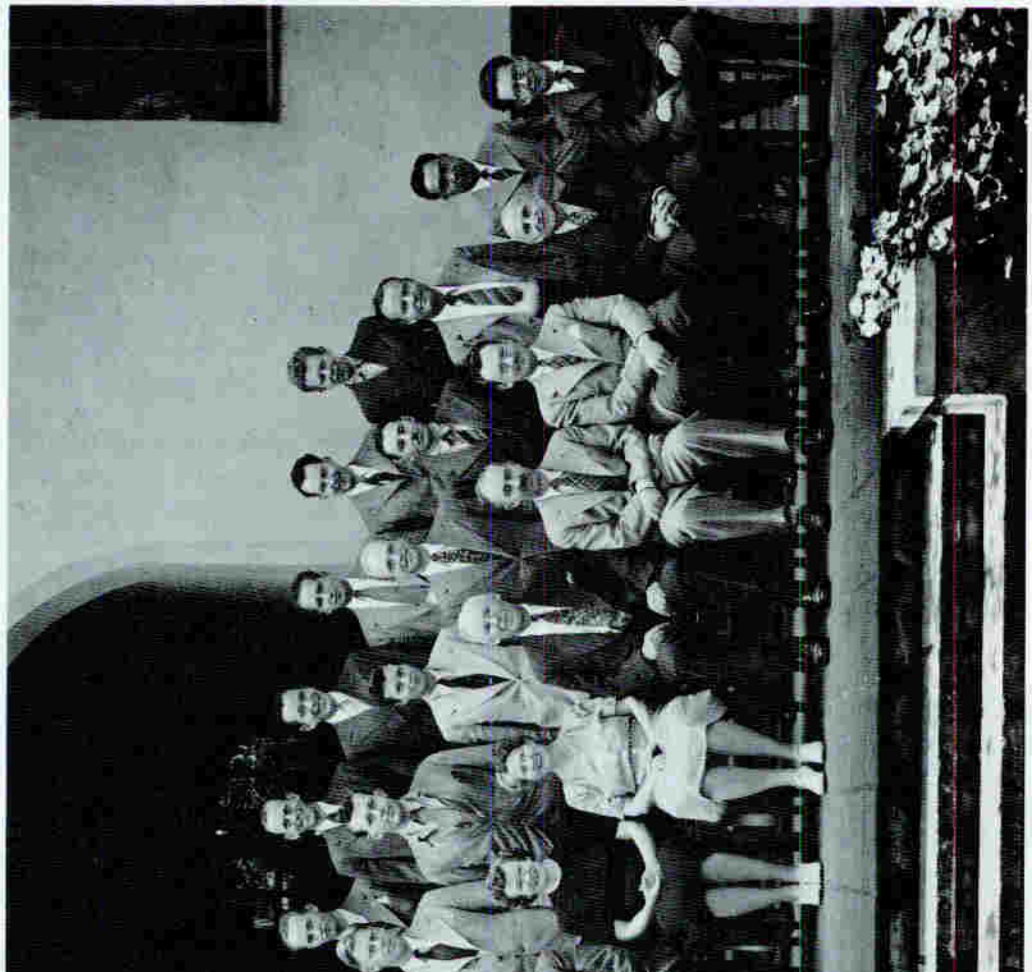

Figure 3. Caltech Geology Department Faculty, circa 1947. Five prominent geologists/seismologists on bottom row, from right to left: Charles Richter, Ben Gutenberg, Richard Jahns, Ian Campbell and John Buwalda. Which three became Honorary Members of AEG?

his theories in the laboratory (Figure 4). In the late 1950's experimental work on high pressure-high temperature silicate systems was being conducted in only a few places. One of these was the Pennsylvania State University (Penn State). In 1960 Dick and Frances packed again, this time to leave Caltech and venture into the wilds of central Pennsylvania. Dick joined the Penn State faculty as Professor of Geology and Chairman of the Division of Earth Sciences in the College of Mineral Industries. He also joined an illustrious group of geologists and geochemists, including C. Wayne Burnham, Arnulf Muan, and O. Frank Tuttle. Soon afterward, Lauren Wright accepted Dick's request to leave California to join the Penn State faculty.

At Penn State, Dick taught geology, conducted experimental petrologic studies, published his findings, and carried out administrative work related to his chairmanship. In 1962 he was elected Dean of the College of Mineral Industries by vote of the faculty.

Figure 4. Dick Jahns at 40 years of age. "Would you buy a gemstone from this man?" (Caltech photo).

His term as Dean was marked by the streamlining of a formerly rigid, hierarchical structure in the College, by the rapid promotion of diligent and effective teachers, and by the construction of a third building for the College of Mineral Industries.

During the time he was at Penn State, Dick remained in close contact with his many friends in California, and in 1965, at the behest of Fred Terman and Wallace Sterling, accepted the position of Dean of the School of Earth Sciences and a professorship in Geology at Stanford University. Once again Dick and Frances packed and departed for California, saying goodbye to the Pennsylvania winters.

Stanford at that time had perhaps the best geology faculty of any college in the United States. Indeed, Dick was to join such luminaries as Konrad Krauskopf, Charles Park, Evan Just, Robert Compton, Ben Page and Chester Longwell. However, Dick observed that the School of Earth Sciences had two problems. He described the first problem as "developing a reputation for the Department that is as good as the faculty actually are," for although the faculty was excellent and the emphasis was on teaching, the Department was essentially introspective and went virtually unnoticed in University affairs. The second problem involved the perenially low enrollment in those Earth Science departments other than Geology, i.e., Mineral Engineering, Petroleum Engineering, and Geophysics.

Dick tackled his new job with enthusiasm, and his 14-year tenure as Dean was marked by a blooming of the School of Earth Sciences. Student enrollment, both at graduate and undergraduate levels, increased significantly. Two of the former "weak sisters" of the School, Geophysics and Petroleum Engineering, grew in terms of both faculty and student enrollment to become outstanding departments on a nationwide level. A new department, Applied Earth Sciences, was created by combining the fields of mineral engineering, engineering geology, economic geology and hydrology. In 1970 another of Dick's goals was achieved when the School of Earth Sciences moved into a new building, the Ruth Wattis Mitchell Building.

Dick taught several geology courses at Stanford, but perhaps the best known was his course in engineering geology. Enrollment for this course consisted of both engineers and geologists. Dick divided the class into teams, in which both disciplines were represented, and then sent these teams into the field to confront real problems. As he told each new class, "You fellows better learn to get along now, because you are going to have to cooperate when you get out in the real world." The seeds of mutual respect and many lasting professional friendships were planted in these classes (Figure 5).

Commensurate with his administrative duties as Dean, Dick continued to teach and lead field trips to such diverse areas as the Pala pegmatite district near San Diego, the Auburn Dam site, the Death Valley-Panamint Range area, and the Mother Lode mineral belt. His academic duties also included acting as adviser for 30 graduate students: 9 MS candidates and 21 PhD candidates. In 1983 he received the Outstanding Teacher Award from Stanford University's School of Earth Sciences. His other professional and academic contributions to geology resulted in his receiving the following honors: Honorary Member, Association of Engineering Geologists, 1983; Ian Campbell Medalist of the American Geological Institute, 1981; Public Service Award, American Association of Petroleum Geologists, 1982; Sigma Xi National Lecturer, 1968; Achievement Award, American Federation of Mineralogical Societies, 1972; Distinguished Alumnus Award, Caltech, 1970; Welton J. and Maud L'Anphere Crook Professor, Stanford University.

Despite the limitations placed on his time by teaching and administrative work, Dick managed to find time to continue several facets of research. These included field and laboratory work on granitic rocks and pegmatites, seismic hazards, and ore deposits. Each summer he spent several weeks doing field mapping in New Mexico. His publication list is formidable (q.v.), and he had materials organized for several additional papers at the time of his death. It is significant to note that Dick was not one to capitalize on the work of his graduate students, but instead chose to publish original work conducted by himself.

Dick's reputation at Stanford brought him to the forefront of the applied geologic profession and as a result he was asked to serve on various geotechnical committees and boards and to act in an advisory capacity for several major projects. He participated in the training of astronauts and implementation of the NASA Apollo Program.

Dick belonged to at least 20 professional societies, which indicated his commitment to professionalism:

American Association for the Advancement of Science; American Association of Petroleum Geologists; American Association of University Professors; American Geophysical Union; American Institute of Mining, Metallurgical, and Petroleum Engineers; American Institute of Professional Geologists (Charter Member, 1963); Association of Engineering Geologists (Honorary Member, 1983); Branner Geology Club of Southern California (President, 1958); California Academy of Science (President, 1978); Earthquake Engineering Research Institute; Geochemical Society; Geological Society of America (President, 1971); Geological Society of Washington; International Association of Engineering Geology (Steering Committee for establishing U.S. National Group, 1980); Mineralogical Society of America; Seismological Society of America; Sigma Xi; and Tau Beta Pi (Figure 6).

Surprisingly, Dick found time to do some consulting work despite his other commitments. He was involved with three California-based consulting firms and worked closely with several independent consultants. His consulting projects included the Diablo Canyon Nuclear Power Plant, the proposed Auburn Dam, the proposed LNG facility at Point Conception, and the Los Angeles Metro Rail Subway.

In 1979 Dick stepped down as Dean of the School of Earth Sciences, but he continued to teach at Stanford. He remained active in his public service and consulting work, and in his fundraising for the University.

During 1982, Dick began to experience serious health problems and in December of that year underwent major heart surgery. During 1983 he underwent two additional operations. Despite these physical adversities, he remained surprisingly active. On the last day of 1983 he passed away while home with his family.

In 1986 Stanford University created the Richard H. Jahns Fellowship in Field Geology. In 1988 the Association of Engineering Geologists and the Engineeering Geology Division of the Geological Society of America jointly created the Richard H. Jahns Distinguished Lectureship, in which funds will be provided to a selected individual to present several lectures annually, aimed at universitites that do not provide programs in engineering geology.

Figure 5. Stanford University Dean Richard H. Jahns was visibly moved when he noticed a giant blow-up of his photograph inserted into the vacant center of a second-story sandstone wreath on the geology corner of the Quad. The photo was a birthday surprise for Dick from some of his students in the Earth Sciences Department.

Figure 6. Dr. and Mrs. Richard H. Jahns (at right) during Geological Society of America Annual Meeting, New Orleans, 1982. Others left to right, Hollis Hedberg, Dr. and Mrs. K. B. Krauskopf, and John Rodgers. (Photo courtesy of GSA)

INSIGHTS FROM COLLEAGUES AND FORMER STUDENTS

How Dick Jahns influenced his students and colleagues, and how they remember him, are recorded by the following comments. More than a few former students have gone on to become successful engineering geologists. These comments include remembrances from his early Caltech student days (1932–35 and 1937–39), from his service with the USGS (1939–45), from his 14 years on the Caltech faculty (1946–60), from his tenure at Penn State (1960–65), and from some of his more recent proteges, co-workers, and fellow consultants while he was at Stanford University the last 18 years. Some comments are humerous, some are serious, some are poignant, but all are recollections that stand out from each friend's personal contact with Dick Jahns.

From *Robert P. Sharp*, Emeritus Chairman of the Division of Geological and Planetary Sciences, California Institute of Technology: Dick and I were in school together in the early 1930's at Caltech, but not in the same class. I graduated in 1934, he in 1935. In his senior year at Caltech, Dick switched majors from Chemistry to Geology. He had a lot of work to make up, and only Dick would have attempted to do so in one year. Instead of putting him in the regular field course, the powers-to-be assigned him to me to help work on my master's thesis, a mapping project in the Soledad Basin.

We went into the field nearly every weekend, camping out one or two nights. At that time, Dick was wooing Frances, subsequently his wife for 48 years. So, Dick would work all day in the field with me, drive all the way back to Alhambra in the evening via Saugus, a long drive in those days, and reappear at camp the next morning for another days' work. This behavior testified to Dick's devotion to

Frances, his ability to do without sleep, and his endurance.

Dick's ability to do without sleep was phenomenal, but on occasions it caught up with him. On our annual spring field trip with John Buwalda, much travel by car was involved. On such trips, Dick was always asleep. we called him "Mylie," short for Mylodon, the Central and South America ground sloth who hung, asleep, upside down on a tree limb. When aroused, he'd take one swipe at his tormentor and go back to sleep before he could make a second pass.

Dick also consumed large quantities of food in those days. So, we always said "Growing boys need lots of sleep and lots to eat."

In the fall of 1935 when Dick was going off to Northwestern on a fine fellowship, I went down to say goodbye to him at his grandfolk's place in Alhambra where he had been living. This was his last night in town. What was he doing? Playing with (prior to packing) his model railroad equipment! Dick Jahns was such an engaging guy in part because he was always a small boy at heart (Figure 7).

One of Dick's favorite stories in which he was caught off-guard involved the late *John P. (JP) Buwalda*, Professor of Geology at Caltech: During his undergraduate days, Dick and JP spent a day in the field in San Pedro and were preparing to return to Pasadena via the Inter-Urban "Red Car" Line in the evening. Upon arriving at the station, they discovered, much to their dismay, that all of the seats on the two-car run were occupied, and they were faced with the probability of having to stand during much of the long trip across the Los Angeles Basin.

Sizing up the situation, JP told Dick, "I think I can get seats for us, if you've got the guts for it." Although not sure of the implication, Dick assured JP that he was with him 100 percent. JP then entered the second car and authoritatively requested everyone to move to the front car, as the second car was going to be uncoupled and left at San Pedro. As both JP and Dick were in field clothes, the passengers apparently thought they were Inter-Urban employees, and with much grumbling, everyone rose and moved into the first car. Dick and JP then sat down in the recently vacated second car and soon were underway for Pasadena.

As the train rolled along, some of the people standing in the front car noticed the second car was still attached, and began to filter back into it. For the most part, the new arrivals fixed JP and Dick with hostile, menacing stares, and some began to whisper to one another. At this point JP leaned over to Dick and murmured "This is where you might need the guts."

Figure 7. Caltech students placed sign on vintage GMC field car: "See the West with Jahns scenic tours."

Clay T. Smith, a fellow student of Dick's at Caltech, writes: As you know, wherever Dick Jahns went, waterbags or water balloons soon followed. To the best of my knowledge, I was the first intended victim of a waterbag at Caltech. During the spring of 1939, after the Department had occupied the new geology buildings, I had been provided an office in the basement of Mudd Hall. Dick appeared in the doorway, and invited me to go with him to Arms Hall. Lamb that I was, being led to the slaughter, I hardly noticed that we went out the first-floor door and crossed the courtyard, instead of taking the second-floor catwalk, which also connected the buildings. To this day, I don't know what caused me to stop (premonition, I guess) just as we were to pass under the catwalk. In the instant that I stopped, a moderate-sized waterbag splashed harmlessly at my feet. I will say for Dick: he carried out the deception to the bitter end, and had I been properly "bagged," he would have certainly gotten wet from the splash. Although he never confessed who his cohort was, I am pretty sure it was Bob Wallace, who, when we arrived panting on the 2nd floor, was busily working in his office, having seen and heard nothing.

Bob Wallace of the USGS writes: Who me–water bag Dick Jahns at Caltech in 1939? What an accomplishment it would have been to have pulled that off! No, the truth probably is that I was on the second level of a triple-crossing, water-bagging venture concocted by Dick Jahns. He would have had a cohort on the top level of the Mudd Building water bagging all below, including me on the catwalk of the second floor.

I first met Dick at Northwestern University where he already was a living legend–the brightest MS candidate ever to be in the Geology Department, it was said. Later at Caltech I was told that Dick had taken all of his undergraduate geology requirements in his senior year, making straight A's, while at the same time serving as president of the student body and captain of the baseball and basketball teams. Incredible, but that was Dick!

Back again at Caltech as a PhD candidate, Dick organized both touch-football and basketball teams in the Division of Geological Science and, if I remember correctly, Geology beat the Caltech varsity basketball team on more than one occasion.

Dick was among many of us who responded to Chester Stock's charisma and, thus, carried out theses in vertebrate paleontology. One generally wouldn't think of vertebrate paleontology as a proper background for a future in minerals, earthquake studies, or engineering geology, but considering the careers of Dick, Paul Henshaw, Art Drescher or Bob Hoy, among others, it seems to have been a perfect choice.

AEG Honorary Member *Richard W. Lemke* writes: I knew Dick as a close friend during approximately the last 40 years of his life. In 1944 and 1945 we worked together in the field in southeastern United States mapping mica-bearing pegmatites at which time he was in general charge of the program for the USGS.

Space does not permit the recounting of the many experiences and anecdotes that occurred during that interesting period. Dick's brilliance in the field and his unusual ability to convey that knowledge to his co-workers, combined with his great personal warmth and rare good humor, placed him in a most special category. At times though, his boundless energy placed severe strain on those who tried to follow literally and figuratively in his footsteps. I well recall the 7 work-day weeks–the mapping on the surface until it was too dark to see, followed then by mapping underground for several more hours, and finally, Dick's look of mock indignation when we groused because he wanted us to spend part of the remaining night writing reports. It should be mentioned here that Dick's plane table sheets and notes were works of art, which required little or no additional work, whereas ours were sloppy and necessitated long periods of purification.

Dick commonly approached things differently than other people. For example, he always wore tennis shoes in the wettest mines when the rest of us were slogging around in rubber boots. Also, some of his gastronomical episodes left not only the natives of the area but his fellow workers awestruck. Who else could down at one sitting an entire quart of ice cream and ask for more? Who else, after meticulousy cleaning the last shred of meat from his lobster, would ask for all our lobster shells so that he also could pick them clean, claiming that we had left 25 percent of the meat behind.

Most of us remember that Dick was a great train buff. He never was more happy than taking pictures of some of the last of the monster steam engines and the long lines of cars they pulled. This almost caused our undoing one day. We were cruising along a country road paralleling a railroad track in North Carolina, when along came a big freight train going in the same direction as we. Dick began gleefully taking pictures, but soon stopped because he had to take them into the sun. Thereupon he commanded me, as the driver of the vehicle, to cross the tracks at the next crossing so that he would be taking the pictures in the opposite direction. So I pressed the accelerator to the floorboards and raced the train to the crossing. It was as close to a tie as I ever want to experience. As I wiped the sweat from my trembling hands on the other side of the tracks, there was Dick, with a look of real rapture, unconcernedly snapping more pictures (Figure 8).

From *William Muehlberger*, University of Texas: As we all know, Dick was a fantastic story teller. Having spent the summers of 1948-1949 with Dick and Frances in New England and parts of the summers of 1947 and 1953 in New Mexico camping and working with Dick, I managed to hear many of his stories more than once. However, he embellished or modified the story so well with any retelling, that it was almost impossible to recognize it until the arrival of the punch line.

I have been asked many times whether I had made Dick a peanut butter sandwich without bread for his field lunch–let me now tell my memory of it.

We spent two weeks camping in the summer of 1953 at an abandoned silver district south of Hillsboro, New Mexico while we completed a geologic map. Dick played a trick on me one day in the field and I decided that there had to be a retaliation someday, somehow.

My chance came remarkably soon. The next day Dick planned to map the Pennsylvanian units that occupy a high, large, dry mountain above camp. As usual, I made our lunches, and he carried his off without bothering to see what I had made for him. His entire lunch was a rectangular slab of peanut butter in the shape of a sandwich. There was nothing else in the bag. To top it off, he didn't carry a canteen that day! He was obviously thirsty all that evening and when I asked him why, I got a growl–"peanut butter sandwich."

Figure 8. Dick Jahns (at right) and burro in Mojave Desert, California, 1960. (Caltech photo)

Dick and Frances are the salt of the earth. Travelling with them in their car across the continent with all our summer needs, plus Babe, a full-size police dog, in itself has a number of interesting tales. The New England summers are among the highlights of my life–ideal for the neophyte geologist–working with a superb geologist and teacher, and living with them and thus benefiting from the super food and care that Frances lavished on us.

Dick and Frances had Sally and me over for dinner before we were married, and gave Sally an evening of marvelous hints about what life would be like as a geologist's wife. we look back on that evening as being a key one in helping keep our marriage intact during the times that field facilities were far from ideal for a wife and small, diapered children, while the husband went off to the field day after day. They are super people!

As with all practical jokers, Dick occasionally found himself a victim of someone else's efforts. One time Dick wrote to a colleague (who prefers to remain anonymous) and asked to borrow a geologic map of his field area. The sinister colleague wrote back to Dick saying he was sending along the only copy of his field map under separate cover, and requesting Dick to be extremely careful with the map, as it represented several field season's work. Dick's correspondent then made up a bogus map soaked it in glue, inserted it into a mailing tube, and let it "set and cure" several days before mailing it. Upon receiving the parcel, Dick, not surprisingly, discovered he could not remove the map from the mailing tube. Distraught with the thought of possibly damaging the results of several months work by a close friend, Dick resigned himself to the laborious task of removing the mailing tube from the map. This effort, as Dick recalled, chuckling, involved several evenings spent literally peeling the mailing tube apart, layer by layer, with an x-acto knife.

Just weeks before his death, Jahns received a book entitled *Legends of Caltech*, published by the Caltech Alumni Association in 1983. Although he had left Caltech in 1960, he was not forgotten, as the following excerpt proves:

"Getting Back at Dick Jahns"

Caltech had (still has) an honor system, governing relationships between members of the Caltech community, including faculty and students. *Arthur A. Chodos*, a member of Caltech's professional staff, reports that students were not the only pranksters in the community. Dick Jahns, then professor of geology, had acquired a reputation as a practical joker early in his Caltech association. In addition he was known to be a skilled water bomber.

On one occasion, Jahns' students, anxious to "get back" at their prof, detained him prior to Geology Club in order to slow him down on his way from the parking lot. During the 10 minutes of delay, the students managed to remove the rear axle from Jahns' four-wheel drive jeep station wagon and place it on the bench in the geology clubroom, where it greeted him upon his arrival. It was rumored that Jahns drove home in front-wheel drive.

On another occasion, Jahns' exhaust pipe was hooked via a hose to a bag of flour on his rear seat, while he sat in front in a blue suit. On yet another occasion, the rear wheel of his jeep was jacked up slightly, and a rope was wound around the wheel so that when he started the jeep a large cardboard box was dragged across the parking lot to impact the front of the jeep.

Chodos says he is certain that there were other such interactions, and that he is sure that Jahns gave as good as he got.

The following tongue-in-cheek tribute to Dick Jahns was written by a Caltech student, or faculty member, under his nom-de-plume. It appeared in *The Fumerole*, the Caltech Geology Club magazine, April 1951:

A Local Phenomenon

by Ali vir Hassoun
Professor or Biographical Geology,
University of Wadi-U-Wahnt, Arabia

A positively challenging phenomenon of transcending importance to even the most casual observer has long existed in the halls of Arms and Mudd. A rare species of being has occasionally been observed, and not one of the myriads of scientifically trained, reasonably alert, growing, young American boys who co-exist in the same halls with this phenomenon has attempted its scientific description and explanation.

This creature gives eloquent testimony to the heights of literary fancy one may go. It's expressions are, no doubt, culled from the ranks of those words in the dictionary of over four syllables, which are combined into a veritable plethora of thought-provoking sayings, designed merely to impress the very whey out of the inept and inexperienced neophyte. Occasionally, however, with deft but judicious motions, it attempts to decisively overwhelm its audience with fragments of colloquial English, which, when translated, may be rendered thus:

AEEV - BIN - HAD,
EEOOR - AHL - THRU,
or
EEOOR - GAHN

It must be realized by now that the subject of investigation is a veritable rainbow of passionate opinion on all topics of even the slightest transcending importance. A bit of practical advice, however, to those contemplating serious work in this field: If this species ever becomes cognizant of your intentions, with catastrophic suddenness and shrewd insight, it will make you the target for a veritable plethora of synapse-stuttering, devilishly ingenious, hatchet-edged remarks; and chuckling with fiendish, hideous glee will lead you to a mental slaughter of a type rarely experienced by ordinary mortals. It can be a somewhat harrowing experience.

It will then, in sardonic voice and leer, crudely attempt to sooth your wounded self-estimation with the statement: "Your story has elements of tragedy, while your idea has elements of merit." It must now be recognized that this species is remarkably characterized by a disposition somewhat akin to a diseased duodenum.

In this unrelenting battle for data, this investigator admits only to a draw with this creature, in spite of ghoulish laughter which is now undoubtedly emanating from deep in the wings. For what chance does an ordinary mortal have against this species, which this investigator has named *Homo sapiens Jahnsi*.

Things remembered about Dick Jahns from *Joseph H. Birman*, former student of Dick's at Caltech, since then a colleague in engineering geology: One of the finest speakers I have ever heard. Stress and timing; perfect enunciation; his phrases were almost visible.

Humble without seeming to be. Respect for and willing to learn from persons of all stations. For him, the expert was as likely to be unlettered as degree-littered. For me, this lesson on perspective has been invaluable.

Love of people and society and giving to them directly of his profession.

Wit and humor. Color. Enthusiasm. Acceptance with wry amusement, and tolerant of life.

Superb teacher. One of the four best in my experience. We will miss him.

Ivo Lucchitta, USGS, Flagstaff, Arizona, was one of Dick's students at Penn State. Ivo penned the following touching tribute which also appeared in GSA's *News and Information*, April 1984:

Eulogies, memorials and tributes will no doubt be written by distinguished and important people regarding Richard Jahns' many splendid achievements. What I would like to say springs from a humbler perspective–that of a student, a perspective that perhaps is sometimes neglected.

That Jahns was a brilliant scientist is unquestioned. That he believed in placing science at the service of society is well known. That he was a remarkable human being is legendary. But for many of us, his former students, he was even more remarkable in another and special way; he was an extraordinary teacher, a true inspiration.

His classes invariably were lively, productive, enjoyable, and different. In the early 1960's, I was his teaching assistant for courses such as Structural Geology and Field Methods. In that capacity, I not only learned a great deal, but also got much feedback from the students, who were uniformly fired up and delighted by Jahns' teaching. On occasion, I also had to stand in for Dick's lectures when he was away, and it was then that I comprehended with stark clarity, just how impossible it was to fill his shoes. Yet, there was a role of his that was even more important than that of teacher, and that is the role of mentor. I shall illustrate from personal experience.

In the mid-and late 1950's, I found myself as an undergraduate at a tough and highly competitive institute. Fresh from Europe, I was unaccustomed to American ways, I was bewildered, I was alone. Needing to support myself, I found the academic competition very heavy sailing indeed. My performance was anything but brilliant. It was Jahns who had the generosity and the compassion to see beyond the machine that performed well or indifferently, as the case might be, to the struggling human being underneath. He encouraged me; he gave me strength and the will to persevere; And I went on. Whether this has been an immense boon to the profession remains to be seen, but Dick did his part: subsequent successes and failures are my doing. This is my personal story, but it can be repeated again and again for other students, many of whom stumbled at the start, were encouraged by Dick, and went on to distinguished careers.

In the early 1960's there was a confraternity of graduate students at Penn State who were shaped and molded by two men: Dick Jahns and Paul Krynine. Krynine taught us to think, to ask why; he gave us perspective. Jahns gave us the tools of the trade, he gave us joy in our work, and he gave us self-confidence. So strong is the imprint, that this now-scattered band of students can be instantly recognized by those in the know. I have no doubt that the other members of the band would join me in recognizing this debt that can never be paid.

Vale, Dick, we shall miss you far more than you, not an arrogant man, would have ever understood or believed possible.

George Cleveland, formerly with the California Division of Mines and Geology, recalls that while Dick and he were mapping in a well-to-do neighborhood along the crest of the Palos Verdes Hills, two women from a nearby house approached them and demanded to know what they were doing. Dick, as usual, was wearing a railroad engineer's cap, and noticing that the two women had recognized the Union Pacific logo on the cap, replied that George and he were putting the finishing touches on a new railroad route that would connect San Pedro to Torrance via the Palos Verdes Hills. The two women became highly agitated when Dick went on to point out how convenient it would be for them to use the new line, as it would pass within 500 ft of their house, which overlooked the Pacific. Dick then introduced George as the party in charge of picking the site for the Palos Verdes Station. George, quick on the uptake, pointed to a site where he said the new two-story station structure would be built (a structure at the indicated site would have completely blocked the existing view of the ocean from the woman's house). At that point one of the women, on the verge of hysteria, blurted out that she was going to telephone her husband "who would see that no train tracks or station will be built near our house ever, ever, EVER!"

Dick, sensing that George and he had caused "the maximum amount of grief in the shortest possible time," admitted that George and he were not with the railroad, but instead were geologists mapping the Palos Verdes Hills. The women's anger was quickly matched by their relief; and Dick and George were allowed to proceed unharmed, but not without a muttering of verbal abuse. As they trudged away from the irate women, George recalls that Dick commented, "how seldom it was that one met people who could adjust to new situations gracefully."

The tempo of Dick's fun-loving escapades increased when he visited the New Mexico Bureau of Mines offices in Socorro. Dick most frequently victimized his former college roommate and closest friend, *Max Willard*. One day Dick arrived in Socorro unbeknownst to Max, and finding Max's office open, but empty, prepared a surprise. He placed a balloon inflated nearly to bursting with water in Max's desk drawer, pinching off the orifice by closing the drawer. To ensure that Max would open the drawer, all of Max's pens, pencils, and matches were hidden. Dick then withdrew, and shortly thereafter Max entered his office, sat down at his desk, and began to look for a match to light his pipe. Max opened the drawer and was immediately drenched by a stream of water. Max sputtered and loudly exclaimed, "Damn you, Dick Jahns!" even though he had not been told Dick was in town.

One of Dick's favorite tricks, called the "pick-me-up," involved waiting until someone was comfortably ensconced on the "throne" in the men's room. Dick then would quietly reach in and turn off the light switch, and roll a lit "cherry bomb" into the darkened room. Max Willard, victimized several times by this ploy, remarked that it was a somewhat harsh but effective cure for constipation.

Dick also was fond of "burglar alarms," a device that could be attached to a car engine, and when the car was started, emitted a loud whistling noise, followed by an explosion and a great cloud of blue smoke. One of Dick's favorite targets was *Bob Bieberman*, an easy-going, friendly geologist for the New Mexico Bureau. After several startling ignitions, Bob caught on, and whenever he heard Dick in the building, would immediately run out to the parking lot and check under the hood of his car. He then would return to the building and keep Dick's whereabouts known until the end of the work day. When Dick became aware of Bieb's tactic, he began recruiting other members of the Bureau staff to "fix Bieb up."

From *Frank E. Kottlowski*, Director, New Mexico Bureau of Mines & Mineral Resources: Dick Jahns was a legend in New Mexico and if one were to set down all the personal anecdotes, it would require many pages. The practical and yet highly scientific geologist, wearing his blue engineer's cap and tennis shoes (even through yucca and cactus) worked in just about every part of New Mexico and influenced most of the geologists that have been in the state.

Dick was a consulting editor for Holt, Rinehart and Winston when they set up a geologic field technique series. This was in the middle 1950's and just about that time field geology went out of style with everybody hurrying to the laboratory to manipulate numbers. Dick worked with me on my book manuscript; the first draft came back with more comments by him than the actual bulk of the draft's text! Some of Dick's comments (and all were deserved) were in the earthy language that is common in the village bar of Cuchillo. One in particular ran something like "I know what you are trying to describe, but even I cannot understand your explanation–rewrite." Needless to say, most of the usefulness of the book was owed to Dick's editing.

One time when Dick was visiting the Bureau office in Socorro, Max Willard was foolish enough to go out in the field in one of the Bureau field vehicles. Max liked foreign cars and at that time had a small but powerful Jaguar which he drove to work to pick up the field vehicle. Some time during the day Dick, along with Bill Muehlberger and other husky geologists, picked up Max's Jaguar and placed it in the flower bed which was rimmed by relatively high curbs making it impossible to drive it out of the flower bed.

And then there are the serious moments. During one of the New Mexico Geological Society field trips in south-central New Mexico, Dick gave a talk on the geology and mineral deposits of the Sierra Cuchillo, another place where he had worked during World War II and in subsequent years. His lucid description of the complex geology and mineralogy was so much appreciated by the field participants, that they broke out in spontaneous applause upon the completion of his talk. Dick was a person whose shoes no one can fill.

Dick Jahns enjoyed a well-deserved reputation as a quick-witted man with a sharp sense of humor. His profuse vocabulary and his mastery of grammatical syntax provided the foundation for his ability to respond to seemingly innocuous comments with clever quips.

The late *Jack McGill* recalled being described by Dick in an after dinner speech at an AEG banquet as "so well adjusted, he drawls." Typical of Dick Jahns on greeting an old friend: "Someone told me that you were a halfwit, but I stood up for you and told him that's not true, you're much more accomplished than that."

While working on a trenching and drilling program in Los Angeles, Dick consistently referred to one of the authors of this article as a "a real trencherman." He felt flattered, as he thought the term referred to his proficiency in logging excavations. Later he looked it up in the dictionary.

Bennie Troxel recalled several incidents that reflect his warmth, humor, and keen insight: At a party at Dick's house for the Los Angeles contingent of the California Division of Mines and Geology, Dick awarded a small specimen of Kunzite (from the Pala District) to my wife, Betty, for being so tolerant of my numerous absences to do field work. This was his subtle way to chide the other wives at the party to be more forgiving to their husbands who were required to do field work.

During some AEC hearings, I whispered a comment to Dick about approaching 50 years of age, and he immediately asked, "From which direction?"

During the same hearing, I made a comment to Dick that I felt humble about giving testimony at the hearing. His reply–"Bennie, you have a lot to be humble about."

Howard "Buzz" Spellman of Converse Consultants, recalls during his 1964 treks with Dick to the Portuguese Bend landslide, Dick unfolded this true story: A homeowner, living in a house just west of the slide margin, faithfully reported slide movement daily to the Los Angeles County officials. One day he told the County "the slide has stopped." It really had not, because unbeknowst to the homeowner, the slide had enlarged westward and his home was now included and moving right along with the slide.

From *Jack T. Eagen*, Moore & Taber, Anaheim, California: My association with Dick goes back to 1968 when we were working together on the Portuguese Bend landslide complex. As a fairly young geologist, I listened when the "master" spoke. Some of the most memorable times were those at lunch break when we would sit out on the rocks at Portuguese Point and tell jokes, even to the point of forgetting that the tide had come in and we were going to get wet. He had a great sense of humor. The final treat of the day, and one I looked forward to with great anticipation, after a long hot day of mapping or down-hole logging of an auger hole, was a trip to the local 7-11 store to indulge in a slurpy. I can remember introducing Dick to this confectionary treat and it became a source of many comments, jokes and lively discussion. Dick's usual greeting to me (after a joke) was "what flavor do they have today?"

Another of the things I remember so much about Dick was his ability to squeeze every bit of geologic information from you to use in the construction of a detailed geologic cross section. It was amazing how many bits and pieces of information were at one's fingertip, but which had been overlooked or shoved aside as not being important. Dick was a master at drawing out the available bits of data and then using them in an analysis.

I remember Dick for his humor, his gentlemanly manner, his helpful and professional attitude. (Author's note: Dick always called Jack Eagen the "Slurpy Kid").

From *David Cummings*, Leighton & Associates, Irvine, California: Dick was quite generous in sharing his time, knowledge, and experience with others. Annually, he would come to Los Angeles from Stanford University to give a one-hour lecture on "The Future of Environmental Geology" to a class of undergraduate, non-science majors at a small liberal arts college. These lectures were given at a time when environmental geology was in its embryonic stage. He used his personal set of 4x5-in. glass-mounted lantern slides. Some of the slides had the tape unravelling at the corners; other slides had one or two sides bare where the tape had fallen off. Trying to find a projector to show these slides was almost impossible. I think he used these slides purposely so that he could watch my frustration with impish joy in 1) searching for a projector, and 2) having located a projector, wrestling with the slides in the wooden holder as he would bark "next."

His breadth of knowledge, skills in communication and ever-present sense of humor were used effectively with sophisticated and innovative geologists at simulations of lunar landings during the early Apollo program with the USGS. Dick was keenly perceptive and able to quickly identify areas for improving communications between the astronaut and "Mission Control."

Dick was present when and where new applications of geology emerged–whether engineering geology, environmental geology or astrogeology. Requests for his participation attest to his mastery of geologic principles. He always had equal respect for the wide range of people he met, whether they were undergraduate non-science students or professional and seasoned geologists.

As *Richard Proctor* recalls: I first got to really know Dick Jahns in 1960 when I visited his office at Caltech. I went there to ask him to serve on a three-member Board of Geotechnical Consultants for the Metropolitan Water District of Southern California (MWD). The MWD, where I worked at the time, had just begun plans to build 52 mi of tunnels to distribute surplus northern California water into southern California urban areas. The MWD Consulting Board consisted of Dick Jahns, Thomas F. Thompson and Vladimir P. "Walley" Pentegoff (Figure 9). All three are now deceased. (For memorial to Vladimir P. Pentegoff, see August, 1982, *Association of Engineering Geologists Bulletin*).

During the period 1965–72, nine geotechnical reports for proposed tunnels were prepared by those three expert geologists. Their reports were then given out with the Specifications to all major tunnel contractors during the bidding period. The reports are masterpieces of clear writing and are some of the first geotechnical reports to boldly give opinions of anticipated conditions as well as present the factual data. (Example report included herein).

Dick had a nickname for many people. I was not spared, and became known as the "Burrito Kid." It came about as follows: The MWD had a field office in East Los Angeles where many of the Board meetings were held between Dick, Tommy, Walley, and two or three staff geologists and engineers. At 9:30 a.m. a horn would interrupt our meeting, signifying that the lunch truck ("garbage scow") was outside to provide coffee-break refreshments for workers in the general area. Dick would invariably choose a gooey sweet roll, but my favorite was a chile relleno burrito. (This is a large green chile stuffed with jack cheese, dipped in egg batter, fried, then rolled in a flour tortilla–yum yum!)

Being an excellent and ardent field mapper, Dick loved to get out into the field to really see things for himself. Dick had been in good health most of his life, but in the 1970's he had an ailment that took several years to diagnose as a heart problem. The symptoms were tiredness, weakness and occasional shortness of breath. In December 1982 he underwent double bypass surgery. The operation was apparently successful, as through most of 1983 Dick reported feeling better. Thus it was a shock that he

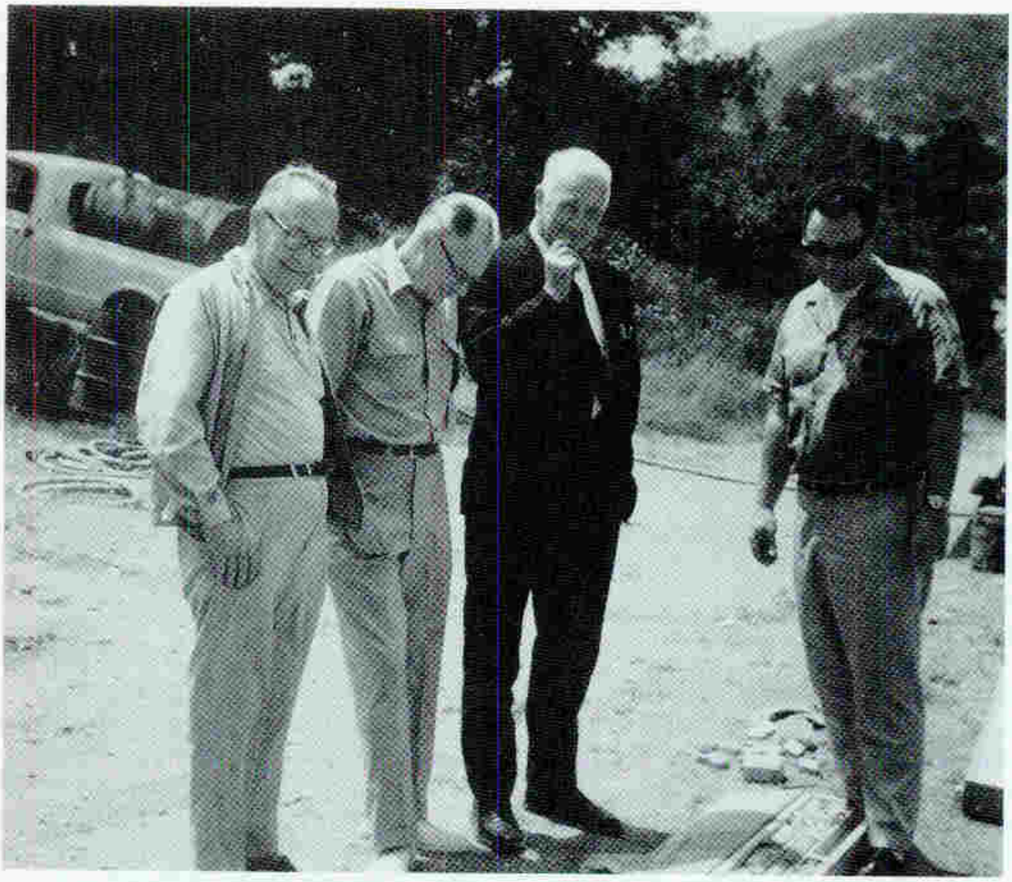

Figure 9. V. P. Pentegoff, R. H. Jahns, T. F. Thompson and R. J. Proctor viewing core. (MWD Foothill Feeder Tunnel Project, 1970).

suddenly collapsed and died while watching a football game at home with his family on New Years eve, 1983.

A glance at Dick's bibliography will show he was a prolific writer, even when in poor health during his last several years. Our profession will miss the future contributions that he surely would have made. John Keats' words are apropos to the untimely passing of Richard Jahns:

When I have fears that I may cease to be
Before my pen has gleaned my teaming brain.

Allan V. Cox, who succeeded Dick as Dean of the School of Earth Sciences at Stanford University, gave a eulogy at a memorial service on January 4, 1984 at St. Denis Church, Palo Alto, California. His eulogy appeared in *Geotimes*, April 1984. From the *Stanford Observer*, October 1984, Allan recalled a formal function for Dean Jahns: "When I was a new faculty member at Stanford, the first official function I attended was the Dean's Tea, as it is euphemistically called. When a water bag dropped on the assembling group, my reaction was one of surprise that so little respect was shown to the dean. It turned out, of course, that Dick was the water bagger–not the water baggee."

From *Karl Vonder Linden*: As the editing and proofing of this Biography draw to a close, I pause to reflect on Dick Jahns. Since his death, I've thought quite a bit about him. Yet, to describe the essence of the man in writing is like trying to engrave the Encyclopedia Britannica on the head of a pin; there just isn't room.

Dick's professional accomplishments, as attested to in these pages alone, are legion. Teacher, scientist, administrator, counselor–all hats he wore with distinction. Yet, a few things remain, so far, unsaid.

Dick was a man devoted to his family. Frances and he shared 47 years as husband and wife; their devotion to each other needs no further elucidation for those who knew them. Their children are both now grown; Alfred is an attorney and Jeanette is a homemaker and mother of three. Yet, when I think of Al and Jeanette, I see the two of them sitting on the floor with Dick, who is explaining how to fix a broken toy or is "helping" them run an electric train.

Dick also was a man who had no hesitation to help someone in an emergency. While I was a graduate student at Stanford, my father died suddenly. As Carol and I were hurriedly packing and getting our two small children ready for the trip to Pennsylvania, Dick (Dean Jahns to us then) arrived at our apartment. He helped entertain Gary and Joan while Carol and I finished packing and then offered to drive us to the airport. As we were leaving, he handed me a sizeable personal check and said, "Here, just in case you need it."

I think all in all, the quality that made Dick unique was this unselfish willingness to help other people; not for personal gain or for some altruistic ideal, but instead, because he genuinely liked people and cared about them.

Memorial to Richard H. Jahns

By Richard Meehan and Douglas Hamilton
Earth Sciences Associates, Palo Alto, California

(Reprinted with permission from: *Bulletin of the Seismological Society of America*, Vol. 74, No. 5, pp. 2057-2058, October 1984. The following photo, Figure 10, is courtesy of Doug Hamilton.)

A few days after Christmas of 1982, Dick Jahns lay in a Stanford University Hospital bed recovering from a major coronary overhaul. Various tubes and wires stuck out of his body; and Dick, having emerged from anesthesia only hours before, was presumably as uncomfortable as a man could possibly be. His friends and students, who usually sought Dick's company to obtain advice on matters of faculty politics, nuclear safety, pegmatites, and the behavior of their wives and colleagues, dropped by the hospital to visit their mentor. It would be nice to tell Dick a joke, cheer him up a little.

"These guys are real pros," Jahns explained cheerfully to this revolving crowd of visitors. First, they split you open from here to here," he went on, sweeping his hand from collarbone to abdomen, explaining the complicated surgical procedure. Dick admired the practical arts. It amazed him that he had been unconscious for the last twenty-four hours. According to his doctors, he had discoursed eloquently on a variety of subjects. This tickled Jahns; he couldn't remember a thing. No one was surprised to hear this, for Jahns was a master of rhetoric under any circumstances.

Soon enough, the subject changed from surgery to his vistors' problems and concerns. Dick listened, nodded, questioned, encouraged, and endorsed. The phone rang. Visitors stacked-up outside the door. Dick Jahns was back in action.

Dick established himself as a first rate scientist soon after his graduation from Caltech in 1935. Affiliated with the USGS during the late 1930's and early 1940's, he worked on a variety of geological subjects, including the New England Quaternary and various ore deposits in the Southwest. During the war, he developed an interest in pegmatites, and as a professor at Caltech in the post-war years, went on to establish himself as the world's leading scientist in this subject. Dick was able to combine sound, scientific work with good teaching at Caltech, later at Penn State, and finally at Stanford, where he served as Dean of the School of Earth Sciences from 1965 to 1979. Dick enjoyed the politics and style of science as much as its logic and esthetics, and was in his later career President of the Geological Society of America and Chairman of California's State Seismic Safety Commission. A remarkably broad collection of people sought Dick's leadership–less for his authoritative direction, for he dispensed little of that–but because he was able to show them how to accomplish things and enjoy life at the same time. He was a generous and fatherly man who stood apart from the "me-ness" of modern times. He found refuge from the extraordinary demands on his time in places like the pegmatite gem mines of San Diego County, where he savored both the unfolding verification of his petrologic theories and the companionship of old friends among the mine owners, or in his basement, where he built himself a tiny world of model railroads.

Dick spent much of his life on California college campuses, and he was an alert observer and interpreter of fashion, intellectual and otherwise. His view of the esthetics and purposes of science were unabashedly and perhaps even pointedly old fashioned. His lectures were full of Victorian elegance and thunder and reminded his listeners how and why geology had been invented in the first place.

Dick's funeral filled a church on a sunny January morning. It was a fine, traditional and honorable occasion. No one would have enjoyed it more than Dick.

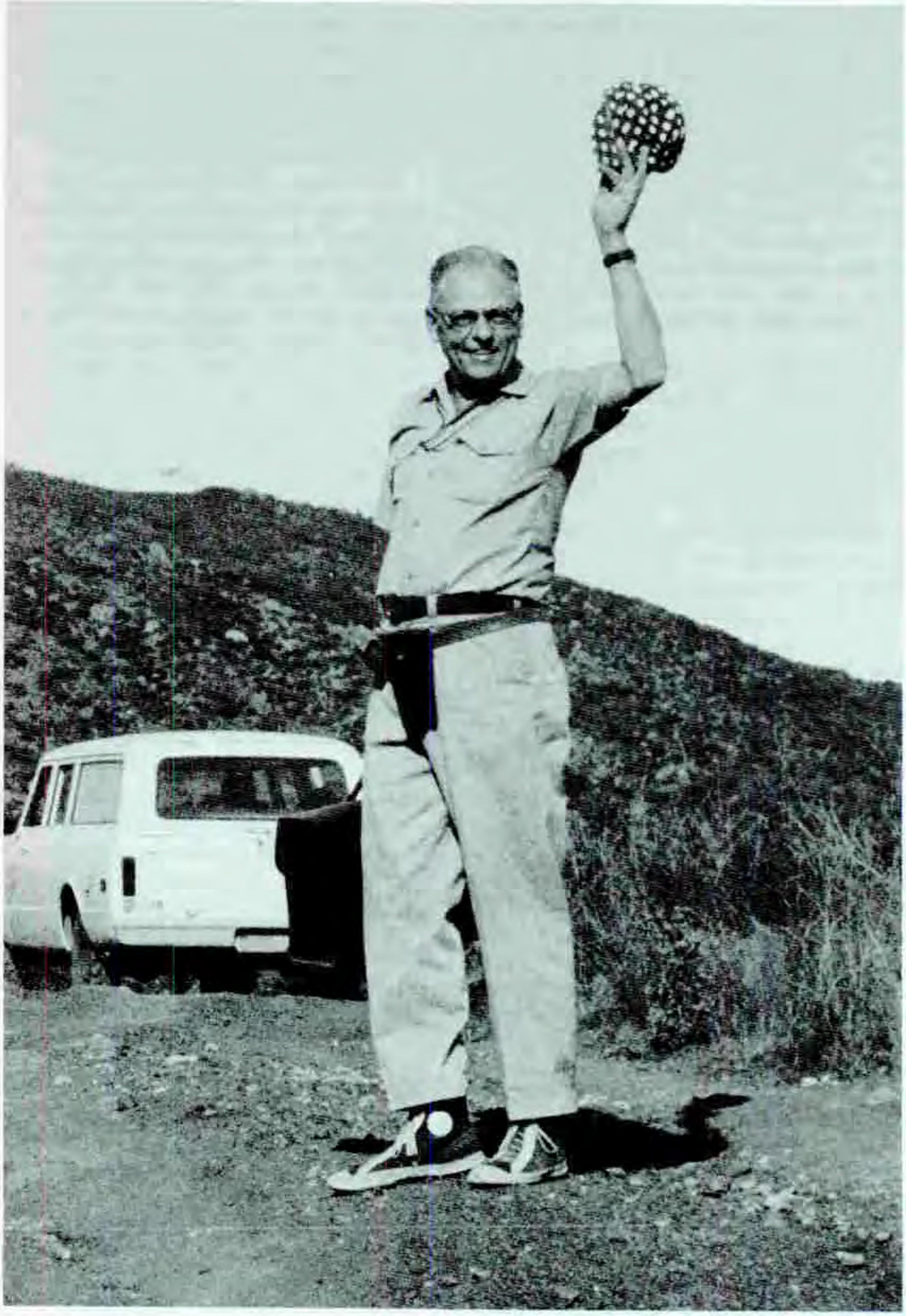

Figure 10. Richard H. Jahns

R. H. JAHNS' ENGINEERING GEOLOGY LAB PROBLEMS

AUTHOR'S NOTE

Dick Jahns was an imaginative teacher who felt that although college courses, of necessity, had to tax the brain, there was no reason that some humor should not be thrown in. Perhaps this philosophy was most apparent in a series of geologic problems and maps he originated for his classes at Caltech, Penn State, and Stanford.

Both authors were exposed to these materials: Vonder Linden as a student at Penn State and Stanford, and Proctor as an Adjunct Professor at Caltech. knowing of Jahns' reputation for devising clever and interesting lab problems, Proctor asked Jahns if he would mail him copies of several problems to help out a novice instructor. The following is part of Jahns' reply, dated September 21, 1975:

Dear Richard,

Here's a miscellaneous bag for you, representing what I have been able to dredge up in the way of engineering geology problems, etc. The ones marked * were for a course in which there are many non-major undergraduates.

Enclosed also are some puzzle maps used for various geology classes, but you'll note that the same old meanness runs throughout as a continuous thread!

Lotsa luck!
/s/ Dick

The following geologic problems and maps exemplify Dick's talent for presenting real world problems in a humorous manner. Some problems require an essay answer (usually limited to two type-written pages) while others require the completion of an incomplete geologic map. We include these problems here to preserve them for posterity, to expose other academicians to Dick's style of teaching, and to enjoy, because they are just plain fun to work.

PROBLEM OF THE HILLEN HILL RESERVOIR (Figure 11)

The Occidental City Municipal Utilities District (OCMUD) is confronted by an extraordinarily difficult situation. The soundness and safety of the mighty Hillen Hill Reservoir has been questioned by the State Overseers' Board (SOB), and the seriousness of these questions has been underlined by public urging for a thorough investigation by a consortium of organizations including the Committee on Land and Water (CLAW), General Landslide Underwriters' Board (GLUB), Committee for Regional Adjusting and Zoning of the Environment (CRAZE), Conservation Office for the Undying Golden Hills (COUGH), and Committee on Regional Architectural Planning (CRAP).

Hillen Hill is an elongate ridge that lies immediately west of the broad alluvial plain occupied by the sprawling (and rapidly growing) metroplis of Occidental City. Recognizing the urgent need for increased capacity in the water distributing system, the Utilities District built a new reservoir at what appeared to be the most logical location. This reservoir, countersunk into the crestal part of Hillen Hill, provides a good distributive head for the domestic water system. Tied in with the huge system of the State Natural Aqueous Facilities, Unlimited (SNAFU), the reservoir has been in service for two years without any evidence of special problems.

Unfortunately, this project was completed without close consideration of geologic factors. Indeed, attention to the natural environment was confined to the surveying of topographic features and the testing of materials encountered in the reservoir excavation. All, however, is not lost, for the Chief Engineer of OCMUD, Roscoe "Cappy" Sitty, has succeeded in obtaining some useful geologic information.

Tied in with the huge system of the State Natural Aqueous Facilities, Unlimited (SNAFU), the reservoir has been in service for two years without any evidence of special problems. But now has come a spectrum of suggestions that the reservoir lies astride a fault that may be active (or might be in the future), that the facility could be endangered by large-scale landsliding, and that possible future leakage from the containment could cause difficulties in various downslope areas. Statements and rumors to these and other effects have become so widespread that the public is understandably concerned over a structure and body of water that in effect loom almost directly over them.

In the library files of a nearby institution of higher learning, the Occidental City College of Utilities, Letters, and Technology (OCCULT), he has uncovered a Master's Degree thesis by R. O. Tate entitled, *Petrography, Petrology, and Petrogeny of the Hillen Hill Gabbro.*

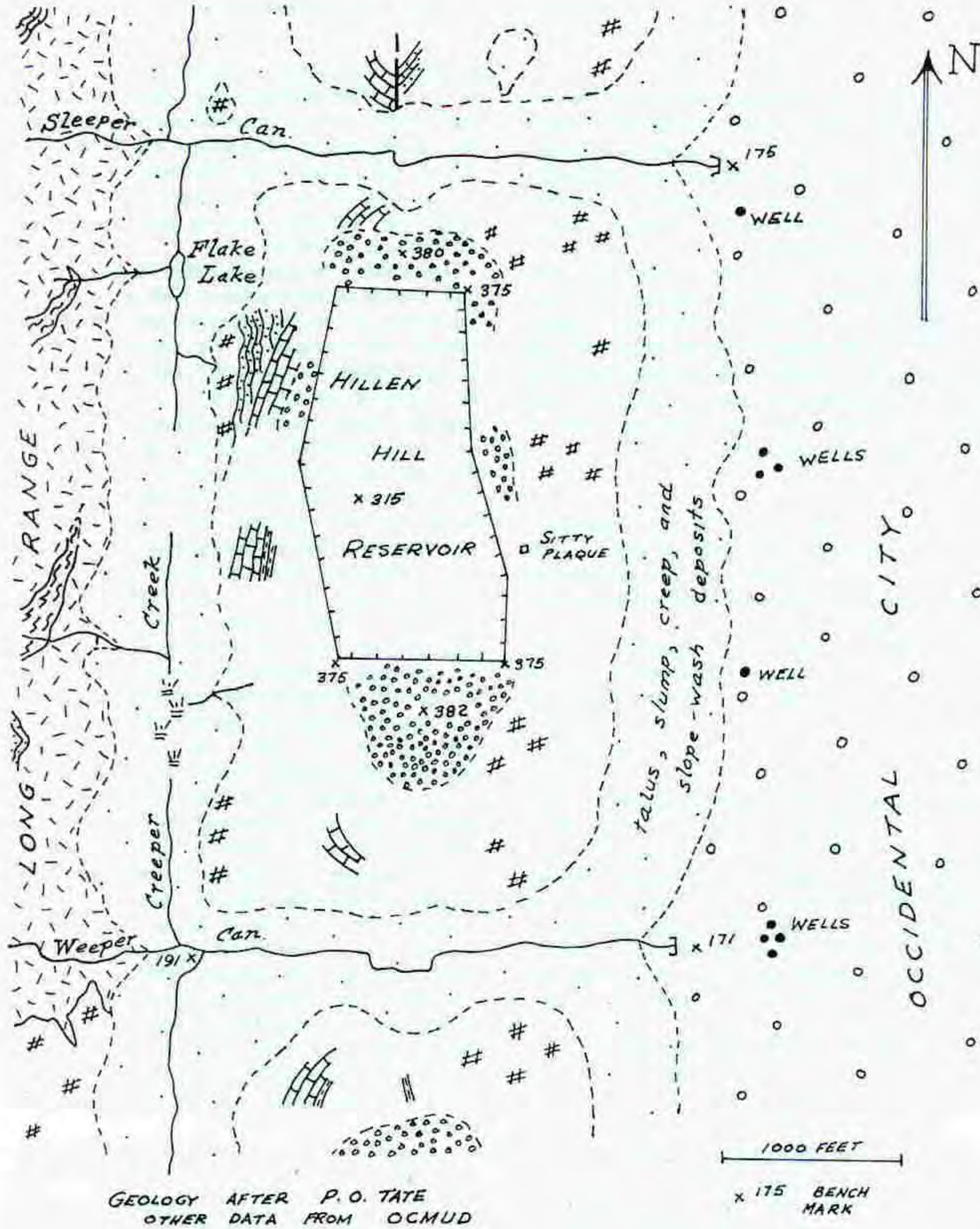

Figure 11. Hillen Hill Reservoir.

Attempts are made to locate Dick Tate for direct consultation, but it is discovered that he has joined the Peace Corps and is now in Ghana. The pressure of time, therefore, makes it necessary to rely solely upon his map and upon those of his thesis descriptions that are pertinent to the current problem. Among other things, he has noted that the gabbro (# pattern on map) is a hard but much fractured rock, that Occidental City lies on a piedmont of alluvial-fan detritus, and that Hillen Hill is (or was, in pre-reservoir times) capped by gravels from which a Pleistocene horse tooth was once recovered.

You are now called upon for useful analysis, conclusions, and advice. What can you contribute toward solution of the problem through the interpretation of Tate's geologic map? The reservoir can be drained for your inspection if you wish, but none of the natural materials would be thereby exposed for your view. The original excavation was lined with 6 in. of clayey silt, over which a 3-in. coating of asphaltic concrete was placed as a protective skin. A layer of sand 8 in. thick was placed over the reservoir floor before the clayey lining was installed.

What are the geologic problems, if any? Is the reservoir safe as designed and built? If not, what might be done to insure reasonable safety? Or would it be more proper either to tear out the existing structure and begin anew, or to convert it into sunken tennis courts?

Your analysis and conclusions, based upon the usual geologic-engineering team approach, will be much appreciated by all concerned.

Howe-Jahns-Blewett, Consultants

DAMSITE IN THE CORONARY CANYON AREA (Figure 12)

The Northeast Division of the mighty Bayshore Tissue and Towel Company has opted for the construction of an enormous new plant on Lorna Dune Beach, in Alkaloid County. A port facility will be constructed for shipping via the A. B. Sea, and good rail transportation is already available on the Tidewater Branch of the Occidental Outbound. Vast quantities of fresh water will be required for the plant, but this appears to be no problem because two substantial streams are present in the area.

Yet a water problem does exist, for it will be necessary to establish a large reservoir reasonably near the plant in order to ensure a continuingly reliable supply. Approximately 10,000 acre-ft is the estimate minimum capacity. Where should the dam be built, and what should be its general design?

These questions have become somewhat pressing, as word of the Company's plans has been getting around. Already the Society for Preservation of Animals and Men (SPAM) and the Society of Prevention of Acts, Schemes and Thoughts Inimical or Contrary to Safety (SPASTICS) have expressed interest in what Bayshore intends to do to the local scene. Granting that the entire project will be appropriately monitored by the State Civil Advisory Board (SCAB), often referred to as the "Board of Old Men" (BOOM), and by the State Water and Air Pollution Engineering Management (SWAPEM), it would be well to have sound answers to questions of design, safety, and pollution before such questions are raised by other groups! Too, there is promise of pressure from the Committee for Repulsion of Urban Development (CRUD), and of counter-pressure, from the Anti Conservationists Union Union (aCUu). Altogether, this is a disagreeable prospect for confusion and cross-currents unless plans are matured at an early date.

The area is characterized by marked local topographic contrasts, and it is underlain by a thick section of sedimentary rocks that have been considerably deformed. Various kinds of surficial deposits also are present. Following a reconnaissance of the ground, the engineering staff of the Tissue and Towel Company have recommended five localities for special consideration as damsites, four of them in Coronary Canyon (Table 1). They were accompanied on their tour of inspection by Rob N. Scoldem (AB in practical science, Weybeloe Normal; MS in geology, Pismo Tech), who prepared a preliminary geologic map.

According to Scoldem's notes, Locality A is characterized by sandstone, conglomerate, shale, and talus; Locality C by sandstone, conglomerate, shale, and talus; Locality D by a carbonate rock and talus; and Locality E, where the canyon is highly asymmetric in cross-profile, by conglomerate and much talus; further notes are not available, except that sinkholes are abundant in the westerly part of the Ah Wilderness Refuge Area and that jasper of gem quality occurs in conglomerate at Pratt Falls and Snarling Rapids.

Unfortunately Geologist Scoldem is no longer available for consultation, as he was buried by a large landslide while examining the terrain immediately east of the Sabriskie zeolite diggings. His field

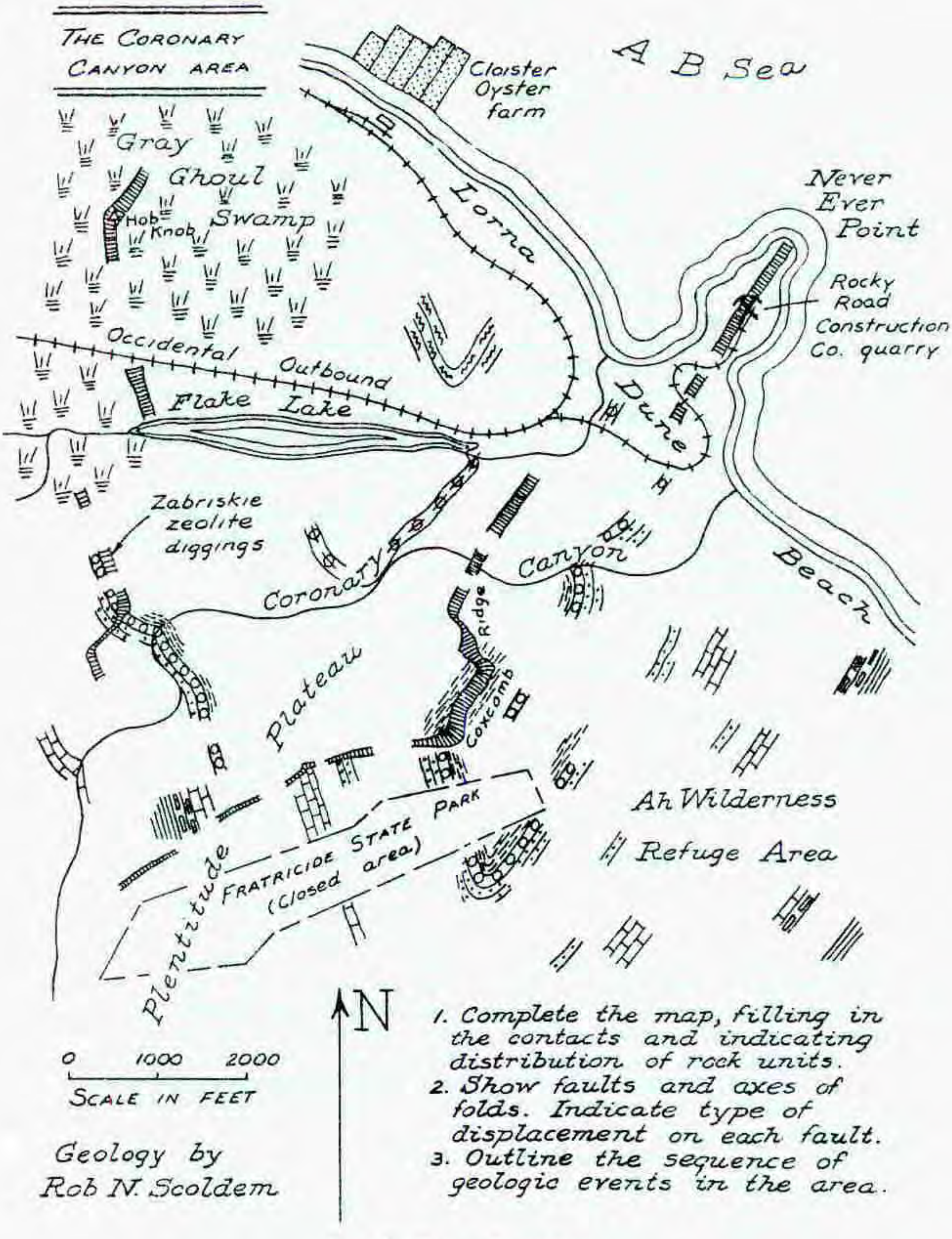

Figure 12. Coronary Canyon Area.

Table 1. *Damsite localities.*

Locality	Elevation at Stream (ft)	Depth of Canyon (ft)
A. Coronary Canyon, approximately 2,000 ft upstream from Lorna Dune Beach.	193	318
B. Coronary Canyon at Pratt Falls, 1,250 ft south of east end of Flake Lake (where stream cuts through Coxcomb Ridge).	246	215
C. Coronary Canyon at Snarling Rapids, 2,250 ft south of west end of Flake Lake.	504	145
D. Coronary Canyon at Coiling west of northwest corner of Fratricide State Park.	590	52
E. East end of Flake Lake.	49	138

map and some of his notes were recovered, but he has not yet been found, poor beggar!

And so, you see, we must make do under the pressure of time. We must rough out the geologic relationships in the area, and combine them with engineering interpretations toward the selection of a suitable damsite and design of a dam. Any assumptions are acceptable, so long as they are compatible with information already at hand.

By the way, would you recommend that the new plant be constructed northwest or southeast of Never Ever Point? Why?

THE RADIATING RESERVOIRS AREA (Figure 13)

Vapid Valley is a lush and broad, nearly flat-floored depression that is surrounded, horse-shoe-like, by very high ground. It is in part underlain at considerable depths by a great thickness of saline deposits, as determined from wells drilled in search of irrigation water. The valley floor requires much irrigation for the vast plantings of the Purity Pit, Peel, Pulp, and Puree Company (known widely as "5P"), as the region is semi-arid; but the necessary water is derived from surface runoff stored in reservoirs that essentially ring the valley. Other major activities in the region include the epsomite operations of the Cathartic Crystals Corporation at Salt Cake Lake, northwest of Vapid Valley, and the enormous quarrying and processing complex of "Big G," the Giant Granite, Grit, Grout, Grus, Gravel, and Granule Corporation at the southeast corner of the valley.

Big G and 5P have agreed to form a holding company for purposes of further developing the local resources in a more effective and integrated manner. Whether such development emphasizes surface or subsurface activities will depend heavily upon available water, and the key question is whether the present surface storage capacity can be approximately doubled. An early judgment of feasibility is required, as the preliminary planning must be soon cleared with the Council for Land and Water (CLAW), the Committee for Rural and Urban Management (CRUM), the State Commission for Atmospheric Balance (SCAB), and the Western Agriculture Regional Tribunal (WART). Analysis by RETCH, Reviewers for Energy, Travel, and Commercial Hazards, comes later on.

You are approached on this problem, with questions that include:

1. Assuming an adequate overall supply of surface runoff in the region, can surface storage capacity for such runoff be at least doubled?
2. How might this best be done, and at what site or sites?
3. What kind or kinds of designs would you regard as feasible?

The objectives are fairly clear, but obviously there is a basic need for technical guidance. And the time frame is so pressing that field studies at this stage are out of the question. The only available input, aside from company data on land ownership and production, is a partially completed geologic map prepared by Rollin Stone and Seymour Sparks on the basis of numerous hiking trips in the area.

Stone and Sparks are two bright, energetic young men with strong interests in spelunking and mineral collecting. Their formal training in geology has been thus far limited to one course at Weybeloe Normal, whence they recently transferred to Big Red College. Unfortunately they are now taking courses at Stanford-in-Iran and hence cannot be effectively contacted for this phase of the investigation. So you are on your own here on the local scene. Lotsa luck!

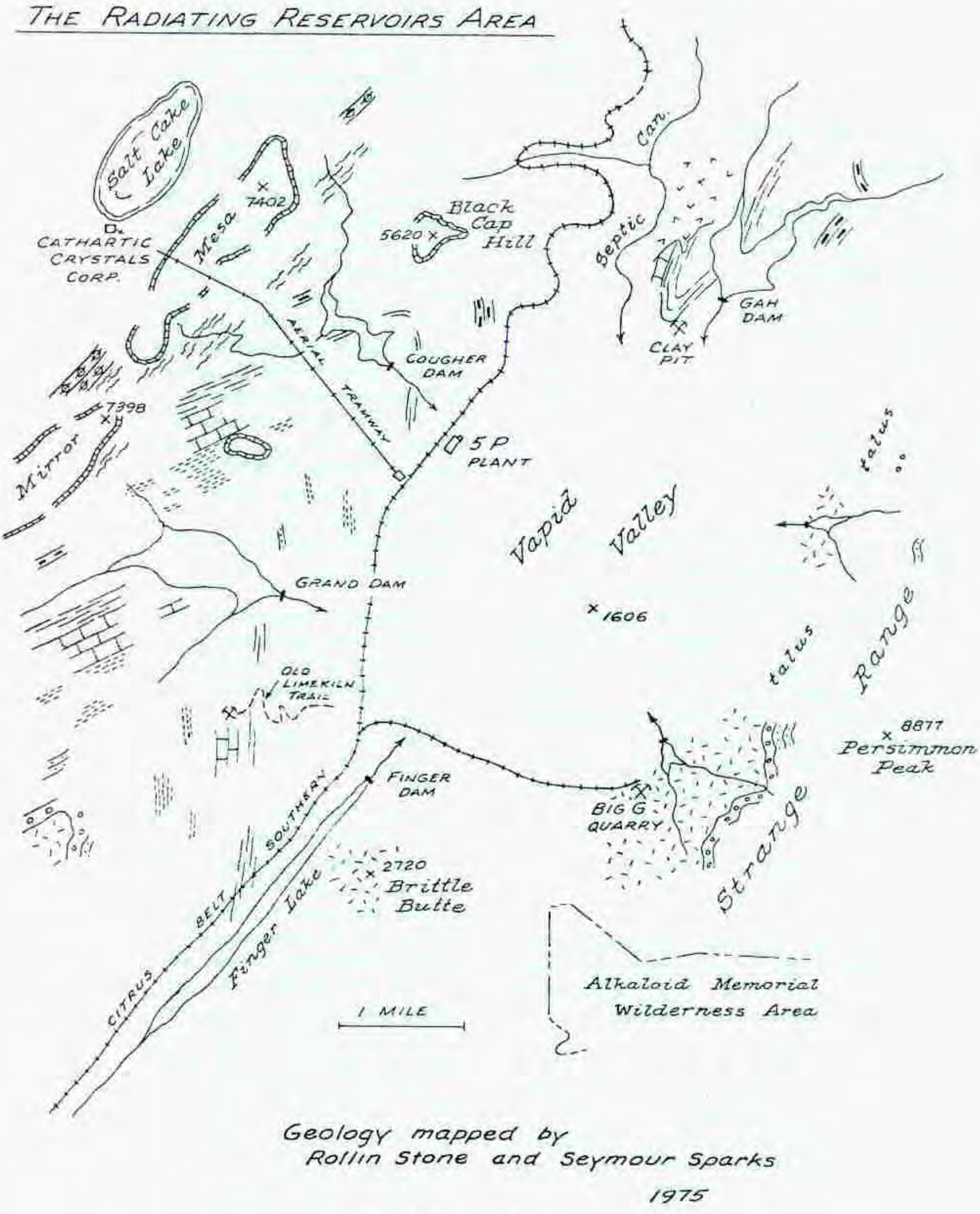

Figure 13. Radiating Reservoirs Area.

POWER PLANT SITING AT MULTIPLE MESA
(Figure 14)

Population explosion in the Greater Prismville area has elicited worldwide attention as an extraordinarily challenging lesson in demography. Growth from a sleepy little village on the Occidental Outbound Railroad to a small megalopolis has taken but half a century, but in retrospect this was an inevitable result of three essentially simultaneous discoveries–the almost unique qualities of Bitter River water as a constituent of certain bottled goods with high commercial value, vast deposits of zanadrium phosphate on the eastern part of the extensive Migraine Plain, and an equable climate very attractive for crowded suburban living. So people came in an ever-increasing stream; the Prismville Chamber of Commerce (PCC) long since has learned to relax, whereas the City College (PCCx) and Citizens' Council (PCCo) have had their hands increasingly full, so to speak.

Now a power crises looms. Hydroelectric capacity in the region has been fully developed for three decades, and air pollution from fossil-fuel plants has reached maximum tolerable levels. A nuclear power plant seems to be the most feasible route toward resolution of the demand problem, and the AEC has agreed to cooperate in such a project. But a suitable site must be chosen for the plant, probably in the Multiple Mesa area some miles west of the population center. The Prismville Heat, Electricity, and Water Company (PHEW) has selected three prime possibilities, designated A, B, and C on the accompanying map. This map, taken from company files represents the reconnaissance work of Y. Knott Testit, an able geologist who was trained in the Inner Institute of the State Technological Miniversity. Unfortunately Testit is not available for consultation, as he disappeared forty years ago in a blast at the Boozer Brothers Basalt quarry.

Can you give PHEW and the AEC a hand at this time of crisis? Very careful geologic and engineering studies will be made before a plant is built at any site, but in the meantime there is need for tentative selection of one site (presumably A, B, or C) so that preliminary design of many project elements can be considered. Please complete Testit's map, interpret the geology of the area, and indicate your choice of site. Reasons for this choice should be indicated.

THE ROLLICKING ROCKS AREA
(Figure 15)

Mr. Ariel Travers, Superintendent of the Long Division of the busy Orofino Eastern Railway, is an outdoors-type man whose chief hobby is cartography. A competent engineer and an excellent observer, he has made maps of the entire region served by the railway for which he works. He once participated in a geology course at the Leland Stanford Junior University, and this brief contact with the earth sciences left him with an almost incandescent enthusiasm for adding all sorts of geologic data to his maps. Rarely does he understand the full meaning of the rocks, faults, and other natural features that he sees, but he does delineate them carefully and well.

This remarkable man has been fascinated by the geologic complexities of the Rollicking Rocks area, so called by railway trainmen because of rapid movement of coarse granules and rock fragments across the tracks during violent windstorms that originate in the lofty Abscess Range, about 60 mi east of Salt Cake Lake. During the year 1952, Mr. Travers prepared the map that is reproduced for you on a separate page. He did an outstanding job of gathering and plotting data, but you probably will agree that most of these data need interpretation that he was unable to furnish.

The Travers map has now become a highly significant document, for the Pacific Institute for Management of Population, Land, and Ecology (PIMPLE) is pushing hard for legislation that would set aside, as a wilderness area, all property outside the railroad right of way. This pressure is strongly opposed by the Mining Operations, Resources, Business, and Industrial Development Sector (MORBIDS), and by the Board for Research and Action on Tunnels, Waterways, Urban Residential Sites, and Traffic (BRATWURST).

Plimpton B. ("Hurry") Kane, Chairman of the Governor's Rural and Urban Management Program (GRUMP), has wisely suggested that firm action on the matter should be deferred until the area can be appraised in terms of its geology, physical situation, and natural resources. To fortify his position, he has noted that the area is receiving attention on the following fronts:

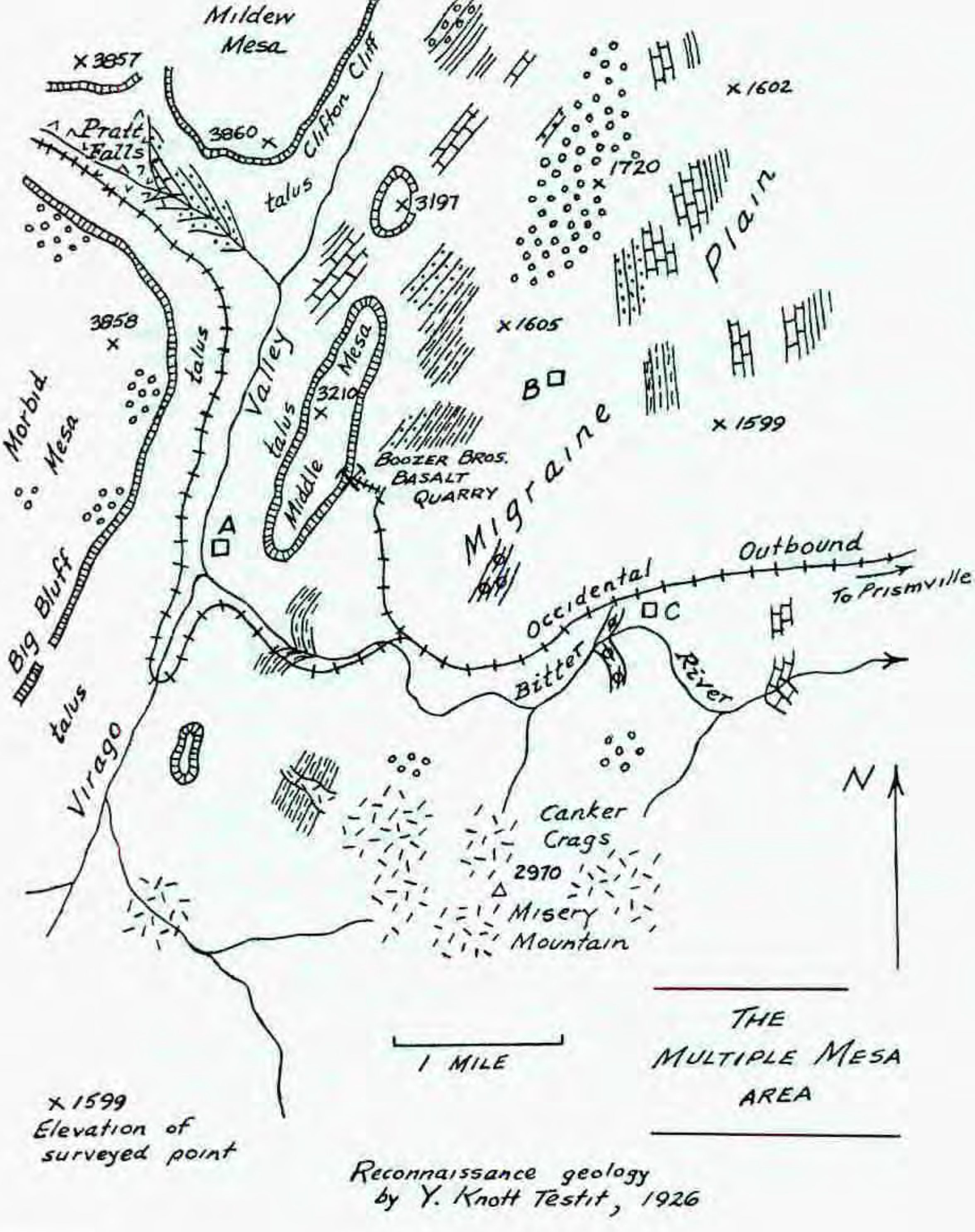

Figure 14. Multiple Mesa Area.

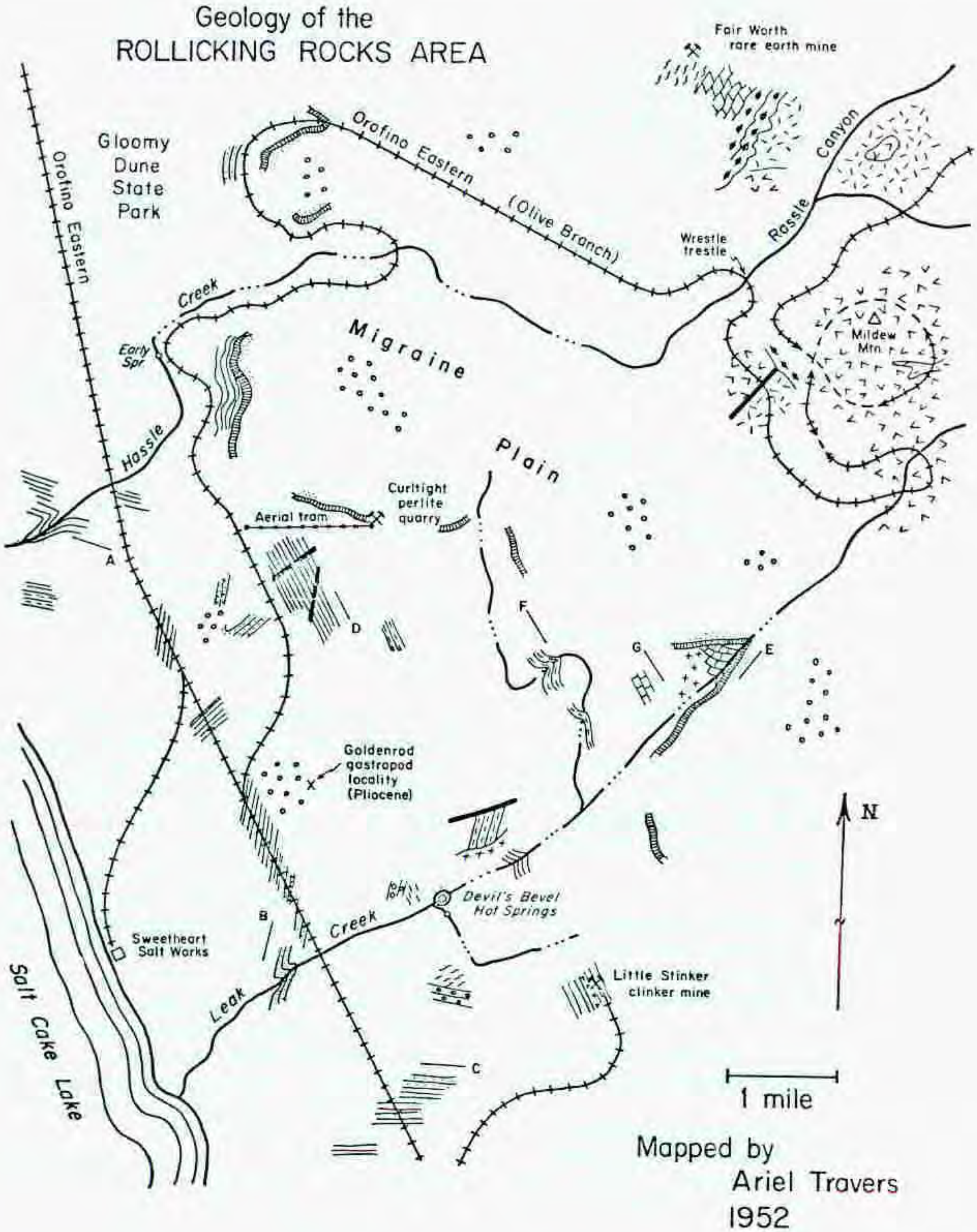

Figure 15. Rollicking Rocks Area.

1. The Garg Oil Company has completed seismic exploration of Migraine Plain and the area to the southwest, and is now preparing to drill two exploratory wells.
2. The Little Stinker Corporation is planning a major extension of its present mining operations southeast of Devil's Bevel Hot Springs, in order to meet increased demands for its product in the metropolitan area of East Toxic, about 50 mi to the south.
3. The Homestead Electric Power Company (HEPCO) intends to site and construct a nuclear power plant somewhere in the area within the coming decade.

You and the Travers map are now brought together for preliminary consultation. For geologic openers:

1. Please translate Mr. Travers' cartographic product into a more truly geologic map, adding contacts, faults, and fold axes where necessary.
2. Prepare a simplified columnar section for the area, showing the various rock units and all unconformities in their respective temporal positions.
3. Outline the sequence of events implied on the map and in your geologic column.
4. Kindly add direction and approximate degree of dip to the strike symbols at localities A, B, C, D, E, F, and G.
5. Where is the major fault in the area? Has its movement been mainly dip slip or strike slip? Give reasons, please, for your judgements.
6. What, probably, is the source of the sand in Gloomy Dune State Park?

Responses to these and other pertinent items of interest should be incorporated into a brief but reasonably complete geologic-engineering report that is addressed primarily to the following questions:

1. Where could the two exploratory wells best be drilled? What kind of geologic section would each penetrate?
2. What kind of mining operation would best serve the needs of the Little Stinker Corporation?
3. Would it be practical to develop a recreational facility at the margin of Salt Cake Lake? For what purpose or purposes?
4. Can you identify one or more feasible sites for nuclear power generation? If so, where?
5. Assuming a need for substantial volumes of water (e.g., for power plant cooling), where might dam-reservoir facilities be installed? What general kind (or kinds) of dam would you recomend, and why?

THE MORDANT MOUNTAIN AREA
(Figure 16)

The doughty little Cloudburst and Western Railroad was originally conceived in 1895 as a sightseeing line. As such, it was constructed southward from Toxy City, a thriving community in the Verdant Virago Valley, to reach Saul's Falls, a spectacular cascade of the Raging Mad River over a resistant section of Devonian jasperoidal quartzite. In 1899 a short extension permitted the opening of a quarry by the Blackbird Blackboard Company, and the railroad further thrived after metalliferous deposits were discovered on Kitchen and Mordant Mountains in the lofty Mildew Range. Access to the subsequently developed mines from railhead in lower Raging Mad Canyon was established by means of burro trails and aerial tramways.

The year of decision for the short-line carrier was 1907, when its role was fundamentally changed. It was pushed southeastward across across the Mildew Range and the rugged country beyond to connect with the mighty Ten Central Railway at Megaville, a move designed for lucrative bridge traffic in merchandise and perishables. Unfavorable topography made the new construction an awesome and terribly expensive task, but Chief Engineer MacAdam Rhodes and the consulting firm of Battle, Wynn, and Crowe were equal to the challenge. Special difficulties were overcome in excavating for bridge footings in the main canyon, and the boring of Tunnel No. 12 through thick-bedded dolomitic marble was repeatedly interrupted by the fall of large blocks. Fortunately, Tunnel No.11 penetrated a section of finely crystalline limestone that was more easily handled. Heavy blasting was required for cuts through a well-cemented pebble conglomerate in contact with this limestone, but phosphatic shale in Goodnight Gulch was readily removed by means of the crude power equipment then available.

Construction of Devil's Funnel tunnel through the backbone of Mordant Mountain was a saga in itself. The west portal cut, at the head of Funnel Gulch, was excavated in loose talus comprising blocks of granodiorite and boulder conglomerate containing beautifully preserved Devonian corals, and the work was temporarily halted by militant paleontologists who wished to make suitable collections for museums before the locality was despoiled. When this problem was resolved so that underground work could be started, other problems soon took its place. Although the hard-rock excavation went reasonably well, numerous large inflows of water were extremely troublesome. Moreover, it soon became evident that the advancing bore was draining a considerable body of overlying ground, as many springs and seeps on the mountain began to dry up. This prompted an injunction on behalf of Ryder, Roper, Tye, Knott, and Brandt, a large corporation with extensive sheep-grazing rights in the area (and incidentally a contributor to the railroad's traffic!). After a costly settlement was negotiated, it required nearly three years to hole the tunnel through at the east portal, as the last 1,360 ft was driven through severely heavy, broken, and caving ground. This part of the bore was lined with redwood timber, later replaced by reinforced concrete.

The subsequent chapters of the little railroad's history tell a mixed story. Traffic has had its ups and downs, but the overall density has been reasonably good. Operating headaches, however, have been repeatedly encountered, and at times in over-lapping fashion. Mountain country with grades of 3.1 to as much as 4.9 percent translates into high levels of expense in getting trains over the road. In addition, both maintenance and contingency funds have been blotted up again and again by the effects of floods, slides, and rockfalls. And, most vexing of all, the rails and other steel in Devil's Funnel tunnel have corroded at almost unbelievable rates. Replacement has been necessary at intervals of only a few years.

In 1967 the Cloudburst and Western assigned Seymour Slopes and Cutter Close, two promising young men from the Engineering Department, to an investigation of the corrosion problem. Having both taken courses in chemistry, metallurgy, and engineering geology at Weybeloe Normal, they were better qualified than any of their colleagues for this task. And they came through with some exciting results. With characteristic engineering accuracy, they made a reconnaissance geologic map of the Mordant Mountain area, pain-stakingly plotting the distribution and attitude of contrasting rock types. They did not understand the geologic significance of everything they saw, but they were careful and accurate observers. More than this, they recognized that the corrosion in the big tunnel was due to acid waters derived from disseminated sulfides in the overlying rocks. Indeed, their field notes included the suggestion that these sulfides might well constitute a vast low-grade copper deposit!

The railroad management has since followed up on the economically-oriented suggestion made by Slopes and Close, and has engaged the services of Dr. Gabriel Grabenhorst to appraise the possibilities of a large-scale commercial operation. Armed with the reconnaissance geologic map, the good doctor has made preliminary studies and already has reached a conclusion that the copper deposit can be worked by in-place leaching, an efficient method that would involve little environmental aggression. Here is an attractive opportunity for the railroad to diversify, to prosper, and to solve one of its long-term maintenance problems! A feasibility study is dictated by the information at hand, but unfortunately this must be conducted in the absence of Slopes, Close, and Grabenhorst, who only yesterday were involved in a tragic collision between their track speeder and the afternoon downbound manifest freight train in Tunnel No. 11.

One essential for a sound leaching operation is a reliable supply of water. This is judged to involve surface capacity in the form of one or more reservoirs, preferably in the Mordant Mountain area. The desired capacity is at least 10,000 acre-ft. Can you lend a hand with this problem? Is there a suitable site for a dam and reservoir in the area? Or perhaps more than one? Would you please serve the Cloudburst and Western (and your instructor) by submitting a succinct preliminary report that includes:

1. Selection of the most feasible site(s), or rejection of all possible sites.
2. Evaluation of the site(s), and perhaps alternative ones, in terms of major geologic and engineering conditions and factors.
3. Recommendations for further exploration.
4. General recommendations for design of the dam or dams.
5. Brief comments on means for transferring the water from reservoir's storage to the leaching sites, and for collection of the leach waters.

Planning Section
Cloudburst and Western Railroad, and
Howe-Jahns Blewett, Consultants

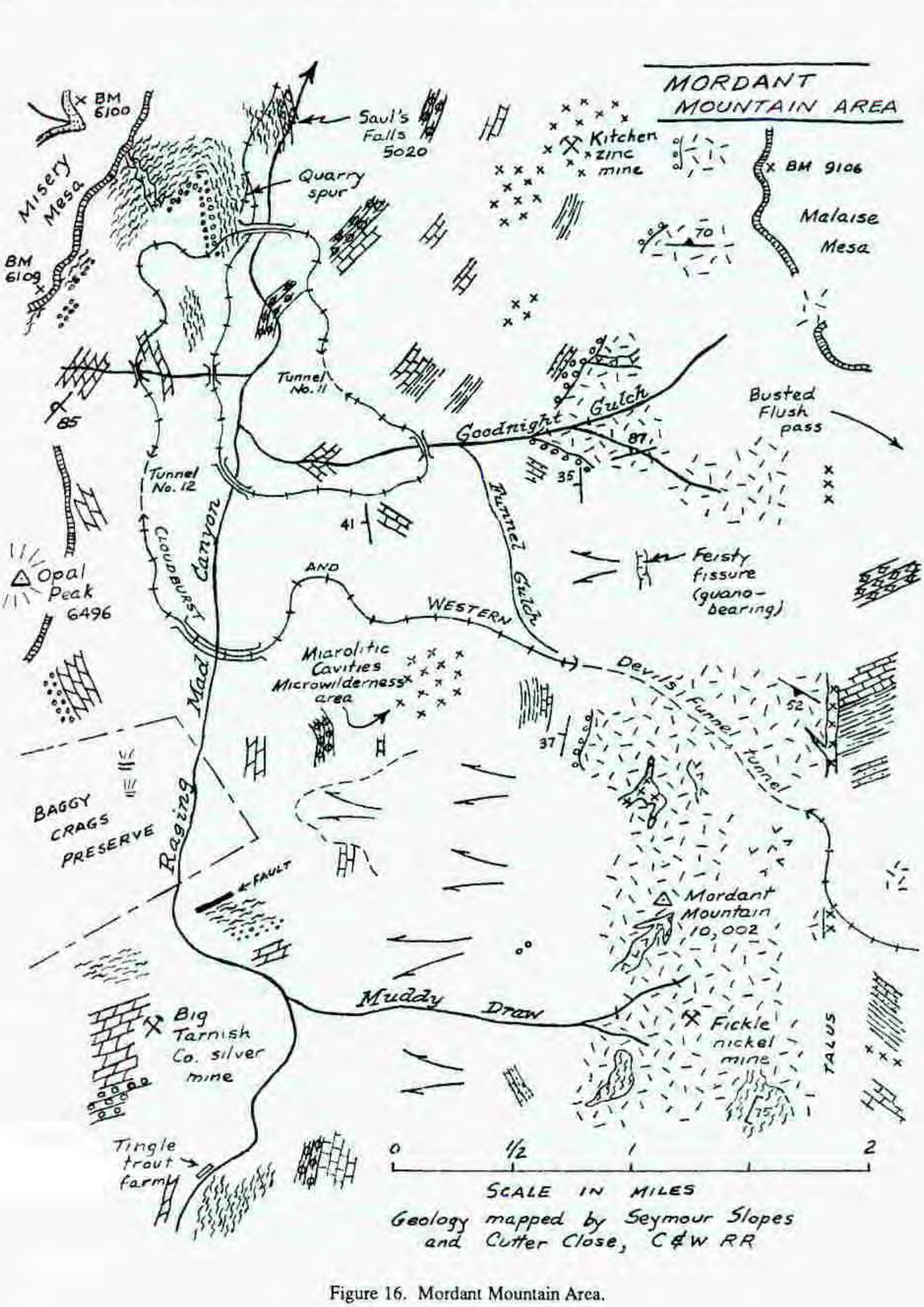

Figure 16. Mordant Mountain Area.

HEARTBREAK HOUSE
(Figure 17)

A certain five-bedroom home in the San Francisco Bay region is under extreme structural distress, and a reasonable projection of its four-year history would seem to indicate ultimate self-destruction. The unhappy owners, Stead E. and Lotta Noyes, report that a few small and relatively inconsequential "construction cracks" appeared soon after the family moved into their new abode, and that these cracks were limited to the usual locations, i.e., interior and exterior walls at and near the corners of doors and/or window openings. Mr. Noyes quickly arranged for cosmetic repairs through the cooperation of Royal Schafft, general manager for the original builders, the Yuletide Engineering, Contracting, Construction, and Home-building people (YECCH), and the annoyance seemed to have been eliminated. But more than mere annoyance lay ahead.

Two years ago, during the end stages of an unusually wet winter season, near-vertical cracks began to appear along the lower parts of longitudinal walls adjacent to one end of the house. Transverse walls were essentially unaffected, but within a nine-month period additional cracks were progressively developed in the longitudinal walls until approximately one-half of the total structure was thus affected. During the past year or so, the weather has been exceptionally dry, and few new cracks have appeared; instead, each of the existing cracks has propagated upward to ceiling levels, in general with an irregularly curving trend as shown diagrammatically on the accompanying sketch. Most of the cracks now open progressively upward, and in their upper reaches some form 1/2– to 1-in. gaps in the wall surfaces. The distraught owners report that, for the past two years, their house has been extremely noisy, with numerous dull thumps and sharp pops from walls, floors, and ceilings. These repeated audio expressions of structural movements have interrupted family activities, including conversation and sleep, and they have contributed to elevated levels of personal uneasiness.

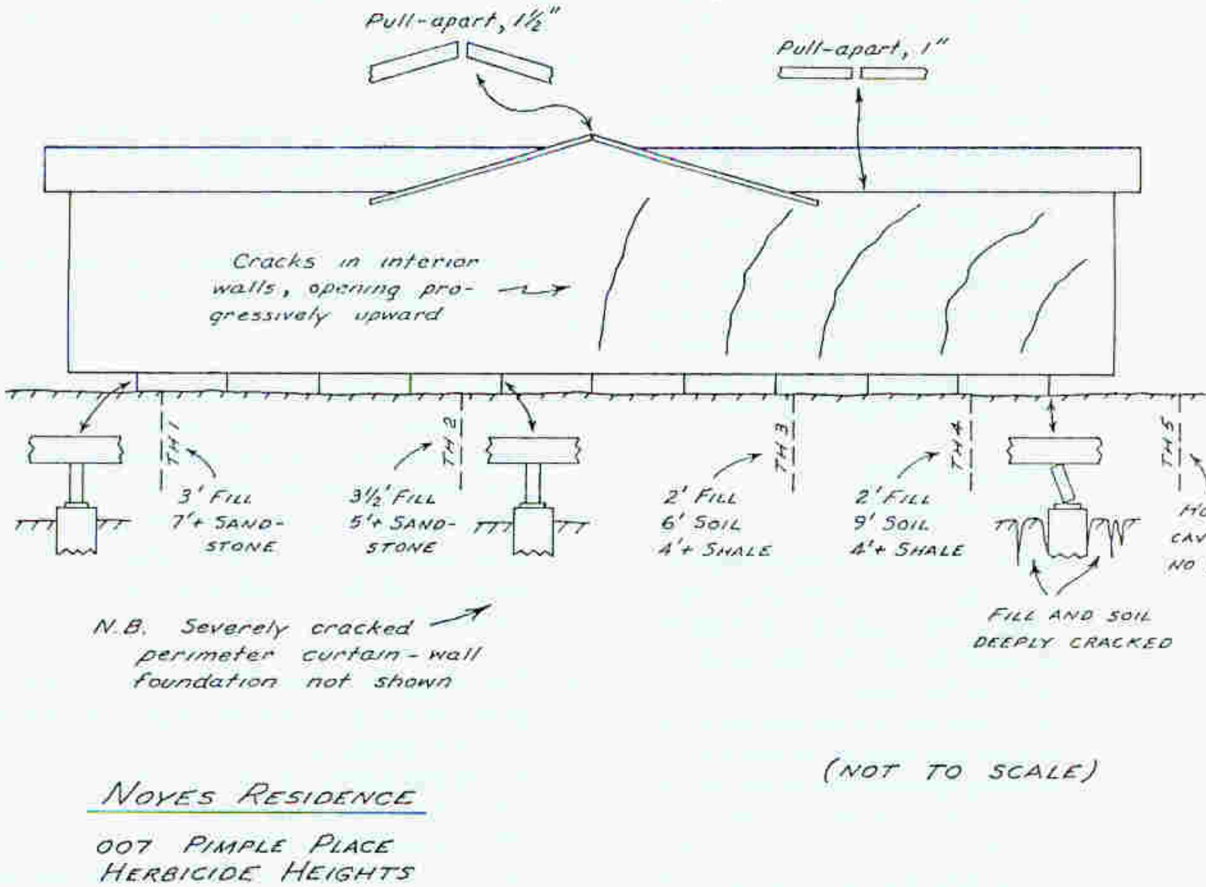

Figure 17. Heartbreak House.

Months ago, when Mr. Noyes discovered that many windows in the house could not be opened and closed, and when he found that several doors required shortening and rehanging to remain functional, he appealed for advice and help from the City Engineer and the local branch of the Joint Emergency Response Commission (JERC). The City Engineer was not available for comment, as he was on leave while appraising a large active landslide on which his own home had been built, but JERC referred Mr. Noyes to several soils engineering firms for technical assistance. Such assistance subsequently was provided by Penultimate Eclecteric Soil Testing Service (PESTS) in the form of a foundation study that included the boring of five test holes along one side of the house. Two months and several thousand dollars later, Mr. and Mrs. Noyes were informed that 1) their house is resting on expansive soils, 2) its foundation structure is inadequate for purposes of stability, and 3) it should be razed and rebuilt on new foundations if the site is to be suitable for future residential use.

Now poor Mr. Noyes appeals to you. We can agree that he has been had, but how, why, and by what or whom? To what circumstances can his difficulties be attributed? What actually has been happening? The foundation structure comprises a perimeter curtain wall of reinforced concrete extending 20 in. below grade, and interior supports, on 8–ft centers, of short 4 by 4 fir members resting vertically on concrete caissons that extend 30 in. below grade. Is this combination adequate, and if not, why not? Finally, what options are open to him, assuming that his house is not yet so severely deformed that it cannot be restored to satisfactory levels of appearance and utility even if fundamental problems are resolved?

PROBLEM MAPS
(Figures 18 and 19)

The problem maps are artificial geologic maps designed to teach and to reinforce some of the principles of field geology. They are intermediate between actual field mapping on the one hand and published map study on the other.

They are like field mapping in that you are given outcrops and other field data and are required to fill in the contacts and other symbols and to deduce the geologic history. They differ from it in that they present no problems of identification or correlation of units: the same map pattern always represents the same rock unit wherever it occurs on the map. The patterns are the standard lithologic symbols used in columnar sections, or obvious variants of them. These maps are like actual field mapping in another important respect: they are commonly open to more than one possible interpretation. This means you will often, as in real life, have to be flexible and to rely on geological probabilities.

The best procedure is first to reconnoiter the map, getting an idea of the topography (from clues such as geographic features, place names, railroad alignments, and the law of V's of inclined strata), filling in contacts in easy areas, looking for evidence (such as unconformities) bearing on them stratigraphic sequence, and starting to build up pieces of the geologic column and history. Then proceed to the harder areas, trying to form a picture of the structure and to connect up the stratigraphy and history. Finally, decide on the pros and cons of the alternative hypotheses for the problem areas, and complete the history, giving the evidence and alternatives and your preferred choice in the tricky parts.

Each finished map, and its associated schematic columnar section and geologic history, and answers to any specific questions are due at the end of the hour in which they are discussed in class.

HYDROLOGY LAB PROBLEMS
Geologic Map of New Jersey
(Ask Librarian for Copy)

Locate the Raritan (or Magothy-Raritan Formation) of the Coastal Plain of New Jersey (Cretaceous Age).

I. 1. Which functioning equation would you use if you wanted to determine the ultimate or long range response to a new well supply from this formation in the city of Camden?
   2. Which functioning equation would you use to determine the short-range response to a well supply from this formation in the city of Camden?

II.1. The Magothy-Raritan Formation has some good sands in it. Assume typical values are $K=1,000$ gal/day ft^2
   $T=150,000$ gal/day ft at a given locale.
   2. How thick would the aquifer be?
   3. What formation underlies it?
      a) Would this be an aquifer or aquiclude as compared with the Magothy Raritan?

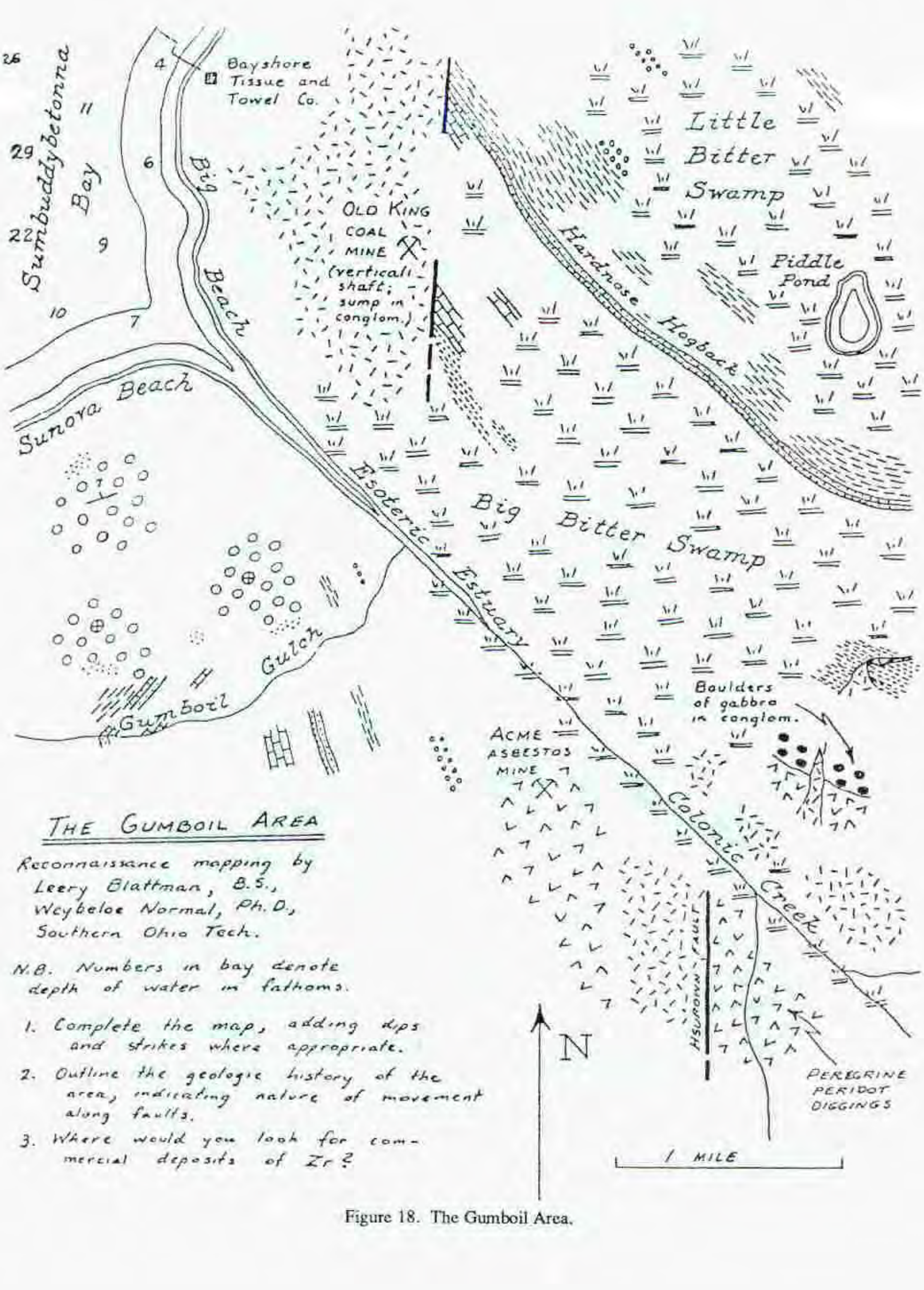

Figure 18. The Gumboil Area.

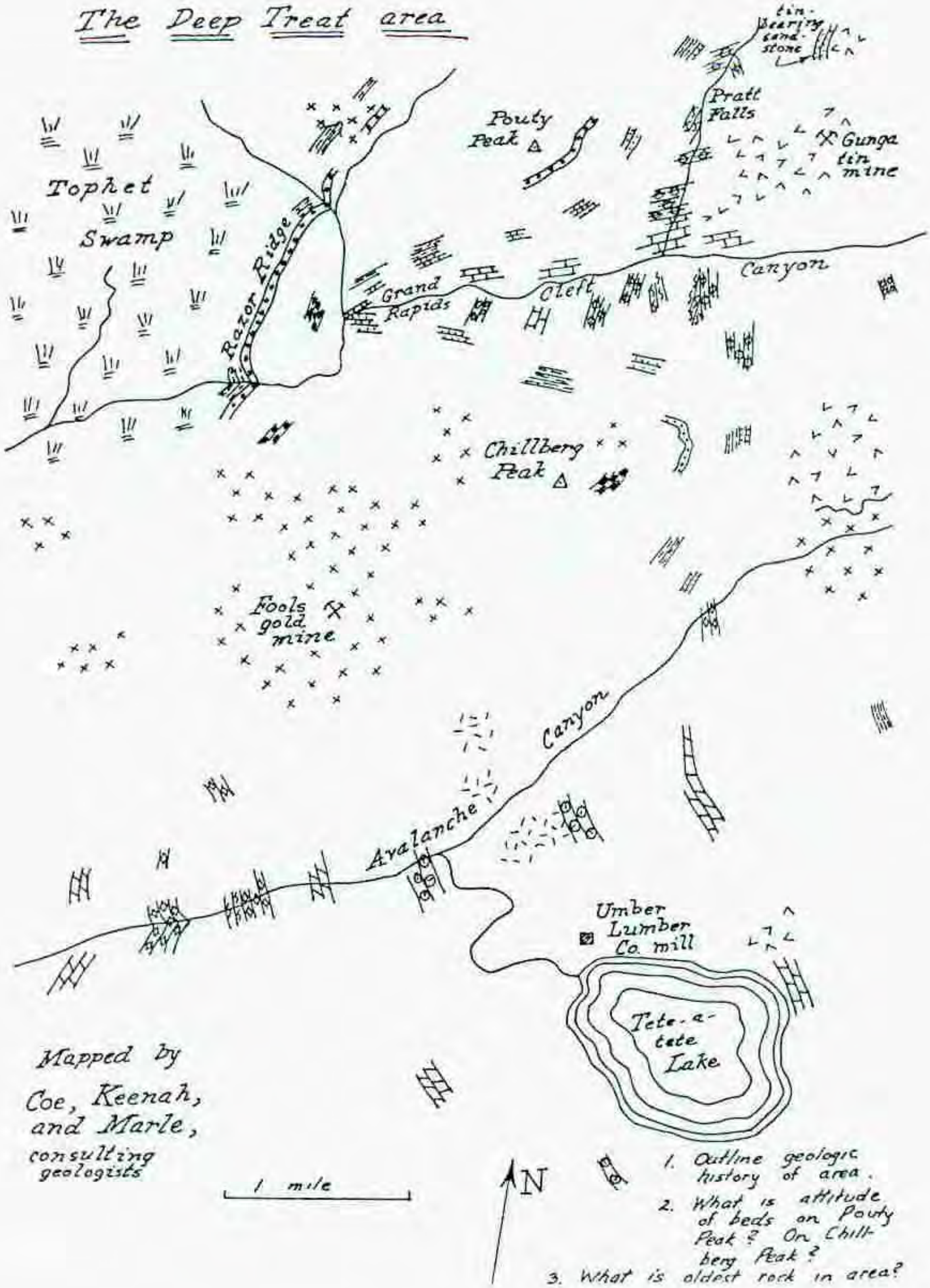

Figure 19. The Deep Treat Area.

b) What would you guess its storage and transmission properties might be?
c) Take a stab at a coefficient of storage and a T. Why?

4. What formation overlies the Magothy-Raritan?
a) Would this be an aquifer or aquiclude?
b) Take a stab at a K and a T. Why?

III.1. In modeling the aquifer, what geometry would you use?
2. Is the aquifer artesian or unconfined at
a) Camden?
b) Haddonfield or Moorestown?
c) How would these affect T and the solution of the equation?
3. What sort of S would you expect from a pumping test at
a) Camden?
b) Haddonfield or Moorestown?
c) Why?

IV. What boundary conditions would you place on this aquifer?
a) In the outcrop area?
b) At Raritan and Delaware Bays?
c) Down Dip?
d) At the top and bottom of the aquifer?

V. 1. Why would salt-water intrusion be a problem in this area?
2. A well mear Delaware Bay in the vicinity of Salem pumps 1.5 mgd. The salinity of the water is rising. What remedies would you propose?
3. Wells down dip near Hammonton are perhaps salinity problem although they are inland. What might be the source of this saline water?

LECTURE NOTES ON AGE DATING OF QUATERNARY FEATURES AND MATERIALS
(March 1970)

The following notes relate to several of the methods that have been used for determining "absolute" ages. Whether radiometric or not, all have their respective limitations. Yet they have proved to be powerful tools, especially when applied to materials that can be correlated with established physical or biological sequences.

Direct Counting Methods

These methods generally involve the counting of layers in naturally-occurring materials whose genetic environments are reasonably well understood. The layering must reflect some kind or temporal cycling (e.g., annual) that can be firmly identified. Examples:

1. *Tree rings*–Reliable when counted and interpreted by experts. Best results from long-lived conifers. Chronology back to 2,000 yr or more before present in many areas, and to an extreme of about 9,000 y.b.p. for bristlecone pine (living + dead trees) in White Mountains of California-Nevada. Of very limited direct usefulness for geologic dating, but extremely valuable for calibrating the radiocarbon method of dating.

2. *Varved sediment*–Best results from undisturbed sections of annually layered deposits laid down in Pleistocene glacial lakes, hence use is much restricted geographically. Requires a combination of favorable exposures and careful, painstaking work. Yields numbers representing spans of time in some regions amounting to as much as 4,000 yr. Does not yield specific ages, but can be valuable when coordinated with other methods.

Radiometric Methods

These methods are based upon growth or decay rates of certain isotopes, most of them members of the uranium decay series. For the time span of the Quaternary period, some are applicable to carbonaceous materials, some to carbonates of organic or inorganic origin, some to deep-sea sediments, and a very important one to terrestrial volcanic rocks. All of the methods require careful analytical work, and all are liable to serious errors if conditions essential to the respective chemical models have been violated during the respective histories of the analyzed materials.

Carbon-14 method–organic matter, and organic matter with calcium carbonate. Age range 0 to about 40,000 y.b.p., but up to 70,000 y.b.p. with special techniques and suitable materials for dating. Results are generally good. Errors are due mainly to contamination by younger carbon. Initial concentrations of C^{14} can be low in materials where the carbon was formed from terrestrial waters. Can be cross-checked with tree-ring and archaeological data, and very useful for cross-checking with other kinds of radiometric dating. Has been applied to dating of pollen sequences, archaeological sequences, many kinds of sedimentary sections, etc.

Ionium-deficiency (Th^{230} growth) method–calcium carbonates. Age range 0 to 250,000 y. b.p. Requires some initial uranium, no initial Th^{230}, and unrecrystallized material (for fossils, typically aragonite with little or no calcite). Unreliable results with mollusks but some good results with corals; incorrect ages ordinarily are too low. Chief sources of error are secondary addition of uranium and non-radiogenic Th^{230} to fossil materials.

Ionium-excess (Th^{230}/Th^{232}) method–deep-sea sediments. Age range 5,000 to 400,000 y.b.p. Recent adaptation of earlier method found to be unreliable. Some good results, but age dates commonly too high.

Protoactinium-ionium method–deep-sea sediments. Age range 5,000 to 120,000 y.b.p. Based on decreasing ratio of Pa^{231}/ Th^{230} with time. Results range from good to poor: erroneous ages generally high. Reasons for discrepant ages are not yet fully understood.

Protoactinium method–deep-sea sediments. Age range 5,000 to 175,000 y.b.p. Based on assumption of constant rate of Pa^{231} accumulation. Has yielded some good results, even on materials with anomalously high ionium excess protoactinium-ionium ages.

Uranium-234 method–calcium carbonates. Age range 50,000 to 1,000,000 y.b.p. A decay method based on more rapid escape of U^{234} than parent U^{238} from material. Requires reliable estimate of original U^{234} in sample, which is difficult to achieve. Results can be good for marine corals, but are poor for marine mollusks and fresh-water materials.

Helium-4 growth method–calcium carbonates. Theoretically no age limit. Based on time-dependent He^4 accumulation in sample. Total He and U must be known, along with U^{234}/U^{238} ratio. Variable results, with major errors (low ages) attributable mainly to later introduction of uranium and to loss of helium. Some successful use with mollusks and corals.

Potassium-argon method–volcanic rocks. Has proved to be suitable for Quaternary dating where rocks initially contained no Ar^{40}, and in which all the Ar^{40} formed from potassium decay has been retained and can be distinguished from Ar^{40} introduced from external sources. For fresh samples, uncontaminated by older material, results can be very good. Method has been used to calibrate the paleomagnetic scale.

Other methods–the chlorine-36, beryllium-10, and other radiometric methods that have been suggested are untested, impractical, or in disrepute at the present time.

Paleomagnetism

The present, or normal, magnetic field of the earth has existed essentially as such during the past 0.7 million years. From 0.7 to 2.4 m.y.b.p. the field was reversed, from 2.4 to 3.4 m.y.b.p., it was normal, and for a substantial period of time before that it was reversed. Brief periods of normal polarity occurred about 0.9 and 1.9 m.y. ago, and a brief period of reversed polarity about 3.0 m.y. ago. The chronology of polarity shifts has been well calibrated by means of K-Ar age dating on a very large number of terrestrial volcanic rocks whose remanent magnetism also has been determined, and thus it provides excellent temporal check points for the Quaternary period.

Of great importance is the rather recent discovery that the remanent magnetism of deep-sea sediments is sufficiently strong and stable to provide an independent method of dating by polarity reversals. Thus continuous cores can be dated, both magnetically and radiometrically, with ages thereby assigned to their contained fossils.

The Fossil Record

Chronological interpretations from the fossil record, when made in the classical sense, yield relative rather than absolute ages. Moreover, paleontologists can testify to the difficulties encountered in properly dealing with faunal populations, ecological conditions, and other factors pertinent to decisions on relative ages of the containing sediments or rocks.

But fossils can be used for dating in other ways, and some of these uses have become highly productive. Most directly, fossils can provide the material for radiometric age determinations, such as C^{14} dating of ancient pollen or wood. Of even wider application are their "bridging" functions when coordinated with radiometric and/or paleomagnetic age dating, and with regional or world-wide geologic events. As one example, many datable deep-sea sediments contain the remains of temperature-sensitive species of foraminifera and other organisms, thereby providing a means for dating major episodes of Pleistocene glaciation. A calibrated chronology of glacial and interglacial episodes is of great value in dating many materials and landforms in onshore areas.

Application of Dating Methods

The methods of age dating briefly noted above can be applied singly or in various combinations, with results ranging from definitive to wholly unreliable. The best age determinations derive, directly or indirectly, from careful analysis or uncontaminated materials in methods that have proved trustworthy for the respective materials, and accordant results from two or more methods are a desirable goal. In many situations, however, a qualified age value is the best that can be obtained. This most commonly takes the form of a maximum or minimum, rather than a definite value.

The following hypothetical examples illustrate some of the situations that have yielded useful determinations of age:

1. Fossil pollen or other carbonaceous material occurs at one horizon in a freshly-exposed section of ancient lake beds. C^{14} dates on three samples are reported as 14,500, 15,000, and 14,800 y.b.p. accompanying mollusk shells are dated by the Th^{230} growth method at about 8,000 y.b.p. The Th^{230} age should be regarded as a minimal value, and the correct age for the horizon probably is near 14,800 y.b.p.

2. Fossil mollusks and some carbonaceous matter occur in marine sand and rubble immediately above the wave-cut bench of a broad coastal terrace. The bench is 110 ft above present sea level. Age of the fossils, as indicated by the C^{14} method, is greater than 35,000 yr, by the Th^{230} growth method 65,000 yr, and by the He^4 growth method 50,000 yr. The two higher values are questionable as absolutes, but 65,000 yr could well be a reasonable minimum.

Consider, now, the present elevation of the wave-cut bench. When could this bench have been formed? Certainly not during the 10,000 yr or less of Holocene time, when sea level was progressively rising to its present position, nor during latest Pleistocene (Wisconsin) time, when sea level was hundreds of feet lower than its present stand. Even with allowances for considerable crustal uplift in the area, the latest period when the bench could have been cut by marine erosion was during the high sea stands that occurred during a part of early Wisconsin time and during the preceding Sangamon interglacial interval. This places the age at least 100,000 y.b.p., on the basis of accordant Pa^{231}, Pa^{231}/Th^{230}. and Th^{230}/Th^{232} chronologies for deep-sea sedments in which glacial-interglacial boundaries can be distinguished via the remains of temperature-senstive organisms. Thus the minimum age of the wave-cut bench, the fossil mollusks, and their containing sediments actually is about 100,000 yr; the true age could well be greater by a factor of at least two.

3. Marine deposits form discontinuous veneers on a step-like series of coastal terraces, and fossil mollusks are recovered from the sedimentary veneer on the eighth terrace, at an elevation of about 900 ft above present sea level. Several carefully selected samples of these fossils, composed almost wholly of aragonite, are dated by the Th^{230} growth method. Resulting values range from 100,000 to 250,000 y.b.p. The position of the terrace in the geomorphic sequence indicates a pre-Sangamon Pleistocene age, but more specific correlation with the glacial-interglacial chronology would require detailed geologic analysis of the entire sequence. Without such analysis, however, it could be concluded that the indicated range of radiometric ages is almost certainly minimal, and that the actual age of the fossils probably is much greater.

4. A section of terrestrial sediments contains a thick layer of andesitic tuff breccia. Juvenile breccia fragments in this layer are found to show normal remanent magnetism, but an age of more than 700,000 yr is strongly suggested by folding of the rocks and two angular unconformities higher in the section. Dating of two fragments by the K-Ar method yields values of 1.85 and 1.92 m.y.b.p. An age or about 1.9 m.y. is compatible with a known brief episode of normal magnetic polarity during the period of reversed polarity that existed from 0.7 to 2.4 m.y. ago, and it probably is close to the correct age.

LECTURE NOTES ON DATING OF QUATERNARY MOVEMENTS ALONG FAULTS (March 1970)

Reliable criteria for applying geological ages to fault activity can be essentially correlated with two basic generalizations:

1. At least some movement on a given fault postated the youngest rocks or features displaced by the fault.

2. The most recent movement on a given fault antedated the oldest undisplaced features that were formed across the trace of the fault, or the oldest undisplaced rocks that a) lie unconformbly above or against the fault and its host rocks, or b) were emplaced along or across the fault.

The first relationship is readily appraised wherever the fault is exposed or can be reasonably well inferred, and where the pertinent rocks or features can be dated. The second is much more difficult to evaluate, as it requires rather special geologic situations, good exposures, and firm identification of critical genetic features. If these conditions are satisfied, and if the ages of the post-fault rocks or features can be determined, a minimum age for the latest fault movement can be indicated with confidence.

Despite its difficulties, assignment of a minimal age to the most recent episode of movement along the trace of a prehistoric fault is simple and straightforward as compared with distinguishing and dating two or more episodes or events in the fault's most recent history. Here the problem is twofold:

1. Distinction of episodes or events ordinarily requires recognition of different amounts of offset in rocks or features of contrasting ages, as well as appropriate age dating of these rocks or features.
2. Even under the unusual conditions that permit such recognition and age dating, it generally is quite impossible to determine whether a given amount of offset represents one, two, or several individual events of movement along the fault.

The most promising situation for appraising multiple fault movements during Quaternary time include the following:

1. Naturally or artificially exposed sections of Quaternary fluviatile deposits that can be dated.
2. Successive sections of coastal terrace deposits, preferably of contrasting ages.
3. Artificially exposed sections of Quaternary lake deposits, including sag-pond deposits, in which pollen can be dated by the C^{14} method.
4. Successive datable shorelines of shrunken or extinct Pleistocene lakes that are sufficiently well preserved for measurement of contrasting fault offsets.
5. Series of gullies and streams that have been progressively offset by horizontal fault movements.

It should be emphasized that, although these and other situations might yield useful information relating to repeated fault activity, they cannot be expected to provide the kinds of data needed firmly to identify and date individual events of prehistoric movement. It would be much more realistic to aim toward the recognition and dating of more general episodes of movement, acknowledging that each episode could have included one or more individual events.

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R. H. JAHNS REPRINTS FROM LESS AVAILABLE SOURCES

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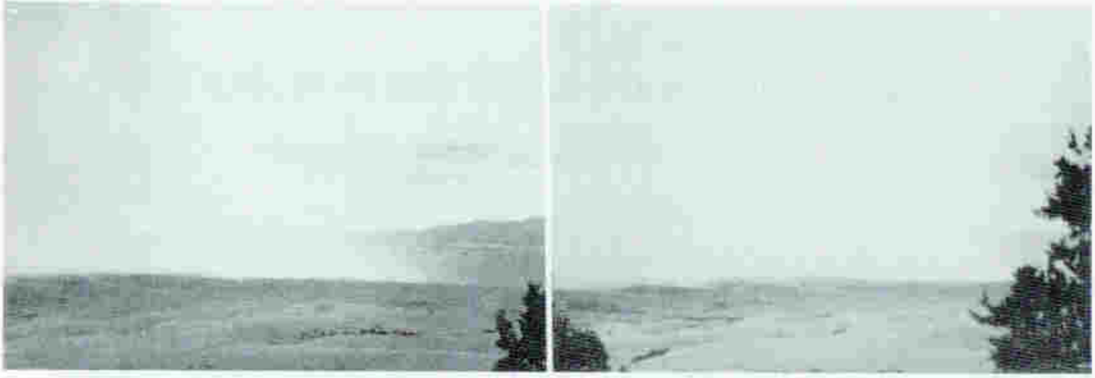

Typical summer storm starts in high-desert country; three minutes later creeks begin to flow.

by RICHARD H. JAHNS

Desert floods

Not many people see them—

but those who do never forget them

"IT WAS a 15-foot wall of water, moving toward us about as fast as a man could run. We had crossed the wash only a few minutes before, when already we could hear the roar of the flood not far upstream. It passed us with a rush, making such a commotion that you couldn't hear a man yelling right into your ear. It was about midnight and too dark to see much in detail, but the front of the water was nearly vertical, and huge granite boulders and chunks of trees kept dropping over its edge. This edge was much higher in the center than along the sides of the wash, and it didn't seem possible that water could have such a slope. The whole business moved on down the channel, giving us the feeling that nothing could stop it this side of Glendale."

As he spoke of the great débris wave that poured from Blanchard Canyon during southern California's New Year's flood of 1934, this resident of La Canada Valley seemed scarcely disposed to believe what he had actually seen.

Anyone who happened to be out of doors in this area on that particular New Year's Eve, had a rare opportunity to observe one of the principal features of the desert flood—the débris wave—and to see that previous reports of such things as "vertical walls of water," "thunderous roaring," and "irresistible force" were not just the dubious products of overactive imaginations. Such eye witnesses often are later troubled with doubts, and the nightmarish qualities of such floods may well cause them to question the intrinsic reliability of their own observations.

Few persons *do* see such things, it is true, and yet spectacular floods are quite characteristic of arid and semiarid country. They are even responsible for many familiar features in the desert landscape. The infrequency of such floods, their most common occurrence in sparsely populated areas, and the unpleasantness of the weather generally associated with them cause many to pass unobserved. Few have been described in detail, and rarely do conditions permit their inclusion in the photographic record.

The word "desert" is used here in its most general sense—which of course is contrary to that preferred by organizations like the Los Angeles Chamber of Commerce and the New Mexico Boosters. Much of the southwestern United States is arid or semiarid country, and ranges from such true deserts as the Colorado, Papago, Gila, and Mojave to areas of intense cultivation and considerable settlement. Development of the latter generally is founded upon the introduction of water from nearby mountain areas or from more distant rivers. Much of the desert country is characterized by profound contrasts of landscape and climate. Ranges in altitude are great, and commonly occur within short distances. Deep, precipitous canyons drain rough, mountainous country in some places, and high, rolling tableland in others; in turn they debouch onto relatively flat-floored valleys. Bold mountain scarps that rise to heights of 4,000 feet or more are by no means rare.

Temperatures are high, in both winter and summer, and daily and longer-term temperature ranges are great. Strong winds are common during certain seasons. Annual precipitation and humidity are low except in the highest mountains and near the southern California coast. On the other hand, heavy rainfall in the most arid regions results from single storms in some years. Much of the country is so dry that all streams are intermittent, and indeed rarely flow, but elsewhere the desert areas are traversed by large rivers fed from distant sources. Nearer the coast are mountain masses that capture enough moisture from the air to supply small perennial streams of their own.

Whether wet or dry, the stream courses are everchanging in their appearance, and it even seems that the longer the periods of their inactivity, the more catastrophic are the changes wrought by the following floods that traverse them. Even the permanent streams vary considerably in their behavior from one season to another. In his *Southern Sierras of California*, Charles Francis Saunders speaks feelingly of the changing moods of

Six minutes later storms begins to move off; 15 minutes later storm has passed, sun is shining.

the Big Tujunga, in the San Gabriel Mountains of southern California:

> During storms, and for days afterward, it goes thundering and gnawing at its banks, ripping out trees, undermining rocks and cracking them together till the sparks fly, rolling great boulders around like marbles. The stream may then be a hundred feet across and twenty deep, and the sound of its fury may be plainly heard a mile away; but with the passing of the rainy season its passion is forgotten, and in July, following its tortuous course for miles, I found it in tenderest and most lovable mood. Now it would be rippling past gravelly beaches open to the sun, now idling in the still shadows of cottonwood and willow; now, slipping round a corner, it would widen out and sparkle through a setting of sedgy mead under perpendicular white cliffs, suggesting a miniature Yosemite and returning echoes to my call; again dropping musically by proper little cascades from rocky shelf to shelf, it would gather comfortably in drowsy lins of restfulness.

He also points out, however, that most of the streams "prove on inspection to be, during eight or nine months of the year, little more than floods of sand littered with cobbles, where lizards bask and snap up flies and top-knotted quail toe about dry-shod."

Desert floods typify a land of contrast. In most areas they are rarities as measured by human standards. Geologically, however, they are common and recurrent features, and represent the chief mechanism for the erosion of the mountain ranges and deposition of sediment in the lowland areas. These floods usually result from torrential downpours of the cloudburst type, which develop either from cyclonic storms or, more commonly, from thunderstorms. The cloudbursts ordinarily are irregular in distribution, affect rather small areas, and involve short-time precipitation of exceptionally high intensities. A downpour at Opid's Camp, in the western San Gabriel Mountains, seems to hold the all-time record of slightly more than one inch of precipitation in a period of 60 seconds during the early morning of April 4, 1926. Reports of half an inch in five to ten minutes are by no means rare, and doubtless cloudbursts of even greater intensity have gone unrecorded in more remote regions.

The distribution and duration of a typical summer thunderstorm in the "high-desert" country of southwestern New Mexico are shown in the pictures above. This small storm generated a cloudburst of the type known as a "saddle-blanket shower," in tongue-in-cheek testimony of the oft repeated statement that such a blanket would cover the wetted area. Thunder clouds gathered over a period of about 35 minutes during the early afternoon of an August day in 1942, and suddenly precipitation began over a well defined area of not more than four square miles. The storm shifted in a rather irregular path, but in general travelled slowly from northwest to southeast. Within a few minutes of the original downpour, water began to course down several of the dry creek beds. Within 15 minutes the storm had passed, but some of the creeks continued to flow for as long as half an hour.

In many regions where there is some cover of vegetation and where stream gradients are not very steep, cloudbursts of moderate intensity result in rather quiet, "orderly" floods. In one such flood the waters of a creek, which "came down" as a result of a thunder shower in the Black Range of southwestern New Mexico, were nearly free of debris, and did not disturb the coarse gravels or even the low bushes in the stream bed.

In some contrast was the flow of a larger stream a few miles to the north. The waters, derived in greater abundance from the same storm, formed a débris-laden front that traveled down the valley at a rate of about five miles per hour. As shown on page 12, they coursed down a channel whose bottom was marked by sun-cracked and hoof-printed mud, only partly dry. The front of the wave was distinctly higher and steeper on one side of the channel than on the other, apparently because the water there was more heavily freighted with stones, fragments of vegetation, and other detritus. As more and more solid matter was picked up from the bottom and from caving banks of the wash, the forward progress of the water in contact with the bottom was slowed distinctly. Relatively clear water, traveling faster at positions higher in the wave, constantly flowed over the débris-rich portion as a sort of waterfall, only to be in turn slowed by additional débris picked up from the dry stream bed. In this way an essentially vertical wall of water was maintained to a height of about eight inches. Some of the relatively clear water at the surface of the flow reached the front of the wave as series of low, relatively fast-traveling ripples, most of which were 50 feet to more than 200 feet apart.

As the water approached the observation point, a separate lobe began to develop, and to travel more

In torrent of silt-choked waters well-defined waves gnaw at bank of this arroyo near Santa Fe, N.M.

rapidly than the remainder of the front (right below). This lobe was marked by a distinctly lower frontal wall, evidently a reflection of a relatively lower content of solid matter. This in turn may well be ascribable to the course of this lobe over mud and gravel of the stream bed that was still wet from a previous flood, and that hence contained relatively little loose material. Upstream from the front of the flood waters, the surface of the flow rose gently for a distance of at least 150 feet, where the water had an average depth of about four feet. The general flood crest fell rather rapidly, however, and within an hour the water was only three inches deep and fairly free from solid matter.

Damaging Flood Waves

Though fascinating to watch, neither of the floods noted above was particularly unusual, as neither overtopped the banks of the arroyo in which it flowed. On other occasions both of these streams have developed damaging flood waves in response to much more severe storms. Their banks were overtopped, meadow and pasture lands were gutted and rilled, some boulders were strewn on their surfaces, dwellings and other buildings were broken into by the flood waters and partly banked with débris, and there was some loss of life.

A rather energetic series of flood waves was observed in June 1948, north of Santa Fe, New Mexico, where a large arroyo drains an area underlain by soft, fine-grained rocks. The flood waters hence contained no boulders, but instead formed a reddish-brown, mud-choked torrent. The soft banks of the arroyo were vigorously attacked, and from time to time great masses of the bank material dropped into the rapidly moving waters. Large and distinct waves marked the flood. These were spaced 25 feet to more than 100 feet apart, and in general were three inches to two feet high. Most appeared to travel by the same rolling mechanism as that described above for a less tumultuous flood. In the last stages of the flow, individual waves were travelling over moist ground with very little surface water.

Of somewhat different aspect are the rare floods of the most arid, desert parts of the Southwest. These generally stem from sudden and violent storms on steep, rough slopes with little vegetation, and the waters rush down dry canyons in which all sorts of detritus may have accumulated for years. Thus an abundant supply of boulders, rubble, and other débris usually is incorporated with the flowing water to form flood waves that may contain as much as 90 percent solid matter. These are known as mudflows or débris flows. They behave as viscous liquids, and hence travel much more slowly than clear water. Some mudflows contain more solid matter than others, the ratio of liquid to solids depending largely upon such local conditions as topography, stormwater supply, and type of rock.

I was fortunate enough to witness a rather spectacular mudflow in the extremely dry country about 30 miles northeast of Parker, Arizona, in January 1943. A cloudburst of unusual magnitude was indicated by a formidable display of lightning and thunder in a very heavy overcast that enveloped a part of the nearby mountain range. No rain fell at the mine I was visiting, but within an hour there was a great roar in an adjacent steep-walled canyon, which emptied onto a valley flat at the base of the range. At first dull and punctuated only now and then by booming sounds, this roar became almost deafening even before the flood appeared.

The flood was an awesome sight. A dark reddish-brown mass of water-lubricated débris moved—very slowly, it seemed—down the last tortuous part of the canyon. It formed a curving, but extremely steep wall, which must have been about 35 feet high at the point where it burst from the narrow mouth of the canyon. Masses of rock more than 30 feet in maximum dimension cascaded down this front and quickly disappeared from view beneath its base. The entire mass moved much like wet concrete, and its tremendous bulk and leisurely pace gave it an appearance of almost irresistible force.

Flood waters course down bed of New Mexico creek; one lobe advances more rapidly than rest of front.

A feature of peculiar fascination was a series of dust clouds that rose from the sides of the flow, where dry soil and rocks of the canyon walls were sheared off by the moving mass. It was not unlike puffs of dust rising from the hopper of a rock crusher.

Patches of soil, mats of brush, branches and even trunks of cottonwood trees, and boulders of many sizes floated along the upper surface of the flow, and in the more turbulent places they bobbed up and down or even were briefly tossed into the air. Evidently these masses were very buoyant in the heavy, sludge-like "liquid" of water and ill-sorted débris, and were held up also by the almost solid mosaic of rock fragments between them and the bed of the wash. Waves more than eight feet high traveled slightly faster than the front of the débris flow itself, and succeeded one another at intervals of 50 to 100 feet.

After the initial wall of the flow had passed, the roaring noise diminished perceptibly in volume, but by no means was it less than a roar. The part of the flow that succeeded the front became progressively richer in water, and behaved more and more like an ordinary stream. Each succeeding wave, however, obviously was more heavily freighted with solid fragments.

It was impossible to follow the initial flow as it spread out along the valley floor, but inspection a short time later indicated that it had come to a halt about a mile from the canyon mouth. Evidently it had fanned out somewhat and had stopped when enough water had soaked into the dry sand and gravel of the valley floor to reduce internal lubrication materially. In this, its final position, the front was very steep and about 15 feet in average height. The top of the flow, which dried within a matter of a few hours, was studded with boulders, most of them several feet in diameter. It was also marked by large wrinkles, generally six inches to more than two feet high, that lay essentially parallel to the margin of the flow.

The steep front of the original flow had been breached in several places by later flows of more liquid material, and each of these had in turn been "dried up" and hence halted a short distance beyond. Perhaps each of these successive flows was represented by one of the huge, débris-laden waves that had been seen in the canyon proper. It was interesting to note that nowhere was any stream of water issuing from beneath the halted mudflow, nor was there evidence of free water at any other point examined. Digging beneath the outer margin of the principal flow disclosed patches of essentially dry sand and gravel that evidently had been incorporated into the flow from the surface over which it traveled.

In desert floods there appear to be all gradations between the mudflow, with a maximum proportion of solid particles lubricated by some water, to relatively clear water with much greater velocity and tremendous cutting power. The latter is much more common along the lower courses of large, well defined lines of drainage, especially those with perennial streams. It also occurs in conjunction with mudflows—either preceding or succeeding them, or both. The timing of the two are easily evaluated.

The mudflow deposits are characteristically poorly sorted and stratified, consisting as they do of a jumbled mass of sub-angular fragments. In contrast, the deposits of more ordinary flood waters are sharply bedded, and are composed of rather well sorted particles of sand, silt, and gravel. Where desert-flood sediments are exposed in cross section, they commonly comprise interlayered deposits of the two general types.

The desert landscape is constantly being modified and adjusted by floods of varying degrees of intensity. Complex, generally steep-walled canyons are carved into the bold mountain masses, and broad, fan-like accumulations of rock waste are built outward from their mouths where the streams spread onto the flatter valley floors. The alluvial fans that fringe the southern margin of the San Gabriel Mountains are excellent examples of these accumulations, and many others border the mountain ranges of the Mojave Desert and areas far to the north and east. These fans are characteristically cone-like in form, with slopes that gradually steepen upward toward the mouths of the canyons from which they were built.

The fan materials are coarsest nearest the canyon mouths, and become progressively finer-grained as traced away toward the central parts of the valleys. The fans themselves generally coalesce along mountain fronts to form an apron-like deposit of coarse detritus. As time goes on, their surfaces are continually modified by flood waters, and they show abundantly the effects of this trimming, rilling, and incising. Ordinarily, for example, a mudflow is never reactivated, once it has come to a stop; instead, subsequent flood waters gradually form trenches and channels in it, and at later times their own mudflows course through these channels before coming to a halt farther down the slope.

The surfaces of some alluvial fans are marked by

This jumbled mass of granite boulders is a typical mudflow deposit in the alluvial fan near Pala, Calif.

Sand flows duplicate mudflows in all but violence.

Avawatz Mountains — typical desert mountain range.

perennial streams, whereas others are not wetted by flowing water for periods of months or years. Few real changes are made in the general appearance of any of the fans, however, except during times of extraordinary floods. It is then that large mudflows debouch from the canyon mouths, or tumultuous streams with relatively little solids cut actively into the surfaces of the fans. The amount of material transported during a single flood can be very great. During the New Year's flood of 1934, for example, the waters of Pickens Creek, with a drainage basin of only 1.6 square miles, probably laid down at least 70,000 cubic yards of detritus in La Canada Valley. This is sufficient material to cover the Caltech campus to a depth of about 18 inches.

Similar rapid deposition takes place on much larger scales, too. The great mudflow fan from Agua Tibia Creek, in northern San Diego County, California, was once built so rapidly across the valley of the San Luis Rey River that it formed an effective dam. A lake was developed on its upstream side, and remained there until the river could cut headward through the lower part of the fan and drain the valley once again. The fan is shown in the photograph below, right; the mouth of Agua Tibia Creek appears just beyond the reservoir near the upper right-hand corner. The San Luis Rey River flows from the center foreground away from the observer and out of the picture near the upper left-hand corner. The steep-walled canyon cut by this river is clearly shown near the center of the photograph.

Playa Lakes

In some desert regions the drainage is internal, and flood waters from mountain ranges flow into lakes, rather than ultimately into the ocean. These playa lakes, most of which ordinarily are dry, are particularly numerous in the Mojave Desert region of southeastern California. They are underlain by thinly bedded silt and clay, but here and there are layers of coarse detritus that represent particularly energetic and long-lived mudflows derived from adjacent mountain masses. Indeed, at least one geologist has shown that individual boulders probably can be skated across the wetted surfaces of playa lakes by unusually brisk winds.

The flooded playas typically have only a few inches of water, even after heavy rains, but some storms are so severe, so widespread, or so long lasting that they introduce extraordinary quantities of water into desert drainage systems. Such a series of storms in 1938 contributed more than eight feet of water to Soda Lake and Silver Lake, in San Bernardino County, California. During this storm, mudflows were rather widespread through much of the Mojave region, but in addition the waters of some rivers contained so little débris that they were able to cut energetically into canyon walls and damage highways, railroads, and buildings.

It is fortunate that most vigorous desert floods occur in regions of little or no settlement. Others, however, constitute unwelcome visitations to populous areas, where they inflict great damage and even loss of life. The relation of floods to human activities in such areas is a difficult and complex problem, but suffice it to say here that such floods will course down the surfaces of alluvial fans and valley plains in the future, just as they have in the past; they will appear on the thickly settled fans that fringe the San Gabriel Mountains and Peninsular Ranges of southern California, just as they will occur in the more arid regions farther east. There is nothing in the records to suggest that future floods will become more frequent or less frequent, as viewed over a long period of time. Their effects, however, will become more and more troublesome as human settlement of any given desert or semi-desert area is continued.

As laconically expressed by the Mississippi Valley Committee, "The ideal river, which would have a uniform flow, does not exist in nature." Departure from this ideal reaches its maximum in arid country. The floods may be less frequent, but many spell an awful finality for those works of man that lie in their path.

A resident of a flood-ravaged valley may not be compellingly interested in knowing whether the wreckage of his home was accomplished by a mudflow that filled it with débris or carried it bodily for a few city blocks, or by a torrential stream that undermined it or simply chewed it to bits; yet these possibilities might well have been considered before he chose a location for his dwelling. He might have studied it with respect to the channels on the surface of the fan, the positions of large boulders and other deposits of previous mudflows, and the general topography and amount of vegetative cover in the nearby mountains. Much of the fan surface may have been modified by the effects of settlement, to be sure, but critical scrutiny from a high place, or even a study of aerial photographs generally will disclose the details of the natural drainage pattern. After all, it is a grand experience to witness a débris flow—but not in your own back yard!

Mudflow fan in San Diego County, near Pala, Calif.

THE MOUNT LOWE RAILWAY (CONSTRUCTION OF THE LINE FROM ALTADENA TO ECHO MOUNTAIN)

By R. H. Jahns

(From *The Fumerole:* Caltech Geology Club magazine, March 1957, Vol. X, No. 4).

(Caltech Editor's note: This is the first of three supplements to an earlier article, "To the Clouds by Trolley," written by the same author and published in *The Fumerole* last spring. We print this material through unpopular demand by faithful readers for more technical details on the construction, operation, maintenance, and equipment of this interesting mountain railway. Comments on the earlier article have been received from several Geology Department alumni and other oddballs, including a retired motorman from the Watts line of the old Pacific Electric Railway.)

It was 70 years ago when Professor Thaddeus S. C. Lowe, one of Pasadena's most distinguished early citizens, first envisioned a scenic railway to the summit of the San Gabriel Mountains. A man of imagination, enterprise, and considerable personal wealth, Lowe was singularly well equipped to translate his daring idea into reality. He lost no time in obtaining preliminary surveys of several possible routes for ascending the south-facing scarp of the range, and he personally scouted most of this rugged country on foot in a search for attractive resort sites.

A cog railway to Mount Wilson was first projected, and the Pasadena and Mount Wilson Railway was duly incorporated in June 1891. When it became impossible to develop a working agreement with other interests that already controlled much of the summit area on Mount Wilson, Lowe and his associates changed their objective, and aimed farther west toward the top of Oak Mountain (later renamed Mount Lowe). A splendid hotel was to be built in a wooded glen on the south flank of the mountain, where there was an abundance of excellent water. This spot, known as Crystal Spring, lies at an altitude of about 4,400 ft and is 6-1/4 airline mi north-northeast of the present Caltech campus.

Construction of the railway was started late in 1891 from a connection with the los Angeles Terminal Railway at Lake Avenue and Calaveras Street in Altadena. At that time the Terminal line was a narrow-gage steam-operated route, but it later was electrified. Much of it's original right-of-way is now occupied by the Pasadena Branch of the Union Pacific Railway. Laying his light-weight rails to a 3-1/2-ft gage, Lowe extended a single-track line northward up Lake Avenue for a distance of nearly a mile, and thence turned northeastward to angle his way up the steepest part of the broad alluvial fan toward the mouth of Rubio Canyon (see Mt. Lowe Quadrangle of the U.S. Geological Survey). Beyond the apex of the fan the track was placed along the north-west wall of the canyon, where several short timber trestles were erected and thousands of feet of bench were cut in hard rock, some of the cliffwere so steep that members of the drilling and blasting crews had to be suspended at the working faces by means of cables. The ruling grade of the line was held to 7 percent, and the terminus, known as Rubio (later as Rubio Canyon), lay deep within the canyon at a point 1.8 mi from Altadena.

Horse-drawn cars were used during construction of the Altadena-Rubio line, but these gave way to open single-truck electric cars, operating on 500 volts d.c., by the time passenger service was begun in May 1893. Each car seated 35 persons, and there were many riders at 50 cents for a round trip. In the meantime work was being pushed ahead on the next, and most spectacular, segment of the railway. This was the Great Incline, which ascended a bold spur on the north side of the canyon. With a minimum grade of 48 percent and a maximum of 62 percent, it gained 1,280 ft of altitude in its length of about 2,700 ft between Rubio and Echo Mountain. To establish a satisfactory grade along a straight line, one very deep cut and several smaller ones were excavated in the granitic rock of the ridge, and a considerable aggregate length of timber trestles was built across low points in the route. The final grade was broadly convex upward, a desirable feature for obvious reasons.

Equipment and supplies were hauled by rail to Rubio, and thence were wrestled up the incline by block and tackle, by burro train, and by back-packing on the part of the workers themselves. By the end of 1892 a heavy construction cable had been snaked up the incline, and thereafter the work became much less difficult. Heavy timbers, poles, ties, and rails first were pulled into place on rollers, and later, as an increasing length of tract was installed, they were hauled upward on wheeled sleds. Still later, machinery for the powerhouse was pulled to the top of the incline. Water was hauled by burros and mules from the stream in Rubio Canyon during early stages of the construction, and subsequently was brought down from Crystal Spring by a pack train of 36 burros.

After 18 months of hard work, the incline was opened for regular service with considerable ceremony on July 4, 1893. The tracks consisted of three rails, each weighing 20 lb to the yard. The center rail was used jointly for uphill and downhill traffic, but gave way to two separated rails at an automatic turnout halfway up the incline. All rails rested on longitudinal stringers that were framed into the ties to prevent creeping. Two little "opera seat" cars, the Echo and the Rubio, were permanently attached to the endless pulling cable, which was 1-1/2 in. in diameter and was tested for 100 tons in tension. The load of cars, passengers, baggage, and equipment reportedly was never greater than 5 tons. As a safety measure, a heavier stationary cable ran through automatic clutches underneath the cars, an arrangement designed to hold the cars at any given spot in case of an accident involving the pulling cable or its mechanism.

The powerhouse at Echo Mountain really was something for those days. To quote from one published account, "The machinery consisted of a 100 horse-power motor capable of standing an overload of 25 percent and which made 500 revolutions per minute. This speed was reduced by a series of gears and pinions, so that when it reached the grip sheaves through which the endless cable ran, it was reduced to 13 revolutions per minute. This huge wheel was 9 ft in diameter, and attached to it were 72 automatic grips, so arranged that 45 of them were gripping at the same time. By this means the wearing of the cable was reduced to a minimum. It was not strained or chafed by the constant operation of a grip as on the San Francisco cables. The cable was controlled by one of the most powerful friction brakes manufactured. Other automatic devices were attached to the machinery, one being the speed regulator, which stopped a car automatically should the car run above a certain set speed or should the engineer fail to stop the car at the proper place. The engineer on top of Echo Mountain had a miniature railway in front of him so that he could tell the exact location of the cars and the grade they might be on. These, together with the extra safety cable, were among the reasons why no accidents occurred on this section of the 'Mount Lowe Line'."

The motor for the cable railway operated on 500 volts d.c. Electricity first was generated in Altadena by means of gasoline-powered engines, and shortly thereafter it was obtained from two small hydroelectric installations in Rubio Canyon. Later on, gas was piped all the way to Echo Mountain (Professor Lowe just happened to own a gas works in Pasadena), where it was used in part to generate power for the electric motor at the head of the incline.

Here was an amazing accomplishment, but more was to come. Three hotels were completed or under construction by the time the incline was put in service, and the Alpine division was yet to be built from Echo Mountain to Crystal Spring. A long series of almost unbelievable physical disasters was still in the future. As for Professor Lowe himself, he sailed suavely through the financial panic of 1893 and soon was hailed as southern California's outstanding citizen–yet he was to lose control of his remarkable railway only 3 years later.

Unwanted Ads (sic!)

Available! To lecture on geology from Pliny the Elder to Hussod! Artistic rates. Will perform cigaret tricks during lecture at no extra cost. Apply–Jerry Iceberg, 268 Arms Hall.

For sale! 2000 Haband specials. Slighly used. Many damaged by water-bombs. Reasonable! Apply–Dick Jahns, 210 Mudd Hall.

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RESIDENTIAL ILLS

in the Heartbreak Hills of Southern California

by Richard H. Jahns
Professor of Geology

The house shuddered slightly to the tune of creaking joists and a low background rumble that Earnest Winner, half-rising from his comfortable pillow, fuzzily identified with a modest earthquake. A mumbled comment to his wife, a few muscular twitches after reassuming a horizontal position, and he was again asleep. Presumably his rest was a pleasant and untroubled one, for Mr. Winner was yet unaware that he had become a serious loser.

Early the next morning, his young son burst excitedly into the bedroom, shrilling, "Daddy, Daddy, the garage is gone!" And this disquieting message proved to be quite accurate, as the almost-new garage and its contents, including the family automobile, two bicycles, and a beloved assemblage of power tools, had indeed vanished from sight of the house—along with the rearward one-third of the entire lot.

What had appeared the previous afternoon as an irregular "settling crack" that traversed the back lawn and garden was now the ragged edge of a sheer drop-off, at which the remaining segment of the driveway terminated absurdly. One can imagine Mr. Winner's emotions when he looked over the edge and saw that he had lost a substantial part of his property to the deep canyon lying behind it. The missing part of his backyard now formed an uneven bench part way down the canyon wall. There, tilted at crazy angles about 50 feet below him, rested the dislocated elements of his garage. One headlight of his car seemed to peer inquiringly at him through the wreckage.

The unhappy Winner didn't know that his contribution to the canyon was merely the latest of many in this small part of the Pacific Palisades district, not a few of the slides having occurred during the years since settlement of the Greater Los Angeles area began to expand in this direction. He was soon to find out, though, that some of his neighbors had been suffering even more serious losses from successive slides nibbling away at their properties. He also was to discover that several lots, *including his own*, had been occupied by houses at least once before! Fissuring, settling, and gross migration of the ground had damaged these structures and had withdrawn so much support from beneath them that they had been condemned as unsafe for further occupancy. All had been removed, down to the last shingle and stud, then the lots had been regraded and sold to the next persons desiring a fine view of the Pacific Ocean. These transactions, of course, were unaccompanied by pertinent comments on recent geologic history.

This is where Mr. Winner had come in. Now, as he contemplates his personal disaster, he wonders why he wasn't made aware of what he tardily recognizes as obvious. Possibly he also is thinking in terms of whom he can sue, for what, and on what grounds.

Meanwhile, Mr. and Mrs. Purdy Gesser have just reached an agonizing decision as to the disposition of their modern home in the Portuguese Bend area of the Palos Verdes Hills. They reflect, as they look through their enormous picture window across moonlit waters towards the dark silhouette of Catalina Island, that this is their "dream house," built to their own plans at a lovely spot of their own choosing. They recall how they had "thought of everything"—an area with mild climate and relative freedom from smog, a quiet, pleasant neighborhood within easy driving distance of schools, church, shopping centers, and Purdy's office, a large view lot with all utilities available, and a fine home that they could afford through careful management of their resources. But now, after less than three years, the picture window is badly cracked, the walls and floors are buckled, the patio and adjacent ground are warped and ruptured, and the kitchen and living room are held six feet above the sagging foundation by enormous jacks. The house is a split-level structure, though it wasn't built that way!

Two years ago the Gessers, along with many neighboring families, had begun to realize that something was terribly wrong. Doors that had been sticking no longer could be closed, tiny cracks in the walls had become inch-wide gaps, the roof had developed a dozen unaccountable leaks, and water and gas pipes had been broken several times, generally at points of minimal accessibility. Soon the word was out—the Gesser home was one of many built on an enormous landslide mass, a mass that, somehow reactivated, was now moving slowly toward the nearby sea. It didn't help to learn that geologists had long ago recognized and described the area as one of ancient landsliding, and that this particular slide was discussed in several public reports readily available to the public.

"When will the movement stop? Will it stop in time for us to save our home?" These questions were asked again and again by the Gessers as they clung to living in a wracked house that was disintegrating a bit more each day. Having gone completely through the emotional wringer, they finally supply their own answer: "Not soon enough." They will salvage what furniture, fixtures, and materials they can, and will make a fresh start somewhere else. However, any start on a new home must be deferred, perhaps for many years. The financial loss must be recouped, as insurance barely will cover the costs of moving, demolition, and storage of possessions, and the intrinsic value of the ground itself is understandably limited.

The location of Heartbreak Hills

The Winners and the Gessers are just two families among thousands who have taken up residence in the Heartbreak Hills of southern California, and their personal tragedies constitute a small sample of what has happened or is likely to happen to those others who have not given appropriate thought to the ground on which they live. But what and where are the Heartbreak Hills? This figurative name can be given to those areas of irregular terrain in which problems of stability confront the developer of building sites; such problems include elements of surface erosion and deposition, undesirable settling, and mass movements of material, acting either singly or in some combination, slowly or rapidly, and on a small or large scale. It should be added that flat ground itself is no guarantee of complete stability, as the foundation engineer can testify.

Heartbreak Hills are present in most areas of the world, and numerous situations justifying such identification could be cited for nearly every major urban locale. However, the name can be properly applied only to specific parts of these areas, and such geologically unfavorable parts generally are small. Thus unsafe foundation conditions begat of landsliding are restricted to local portions of the Pacific Palisades area, just as most of the Palos Verdes Hills and even some of the Portuguese Bend area itself are geologically safe for the homesite development. On the other hand, these are only two of many areas in southern California where significant geological hazards have been recognized.

The fundamental problem

The fundamental problem is one of distinguishing the naturally safe from the naturally unsafe locality, and of identifying the naturally safe locality that can be made unsafe through the actions of man. Often the problem is easily solved, but at times it involves the interpretation of complex geological relationships that challenge the most competent investigator. The general situation in southern California has been outlined by one geologist as follows: "The highly varied topography and climate of the region, together with the complexity of its rocks and their structure, form a background of physical factors that cannot be ignored in the development of this region by man. Some of these factors are related directly to floods, earthquakes, mass movement of ground, and other recurring events over which man has little fundamental control, and others are developed by some of man's own activities. Failure to anticipate or properly to evaluate these factors during past development of the region has led to unfortunate, and at times disastrous, consequences . . . Only during recent years has there been widespread recognition of the need for careful geologic appraisal of engineering problems in southern California. Normal study of the positive factors in location and design of buildings, dams, aqueducts, and other structures, for example, is now being supplemented by consideration of the nature and movement of solid and liquid materials in the subsurface, the position and behavior of active faults in the area, the movement of surface water in the area during previous centuries, and other features that are likely to have significant long-term effects."

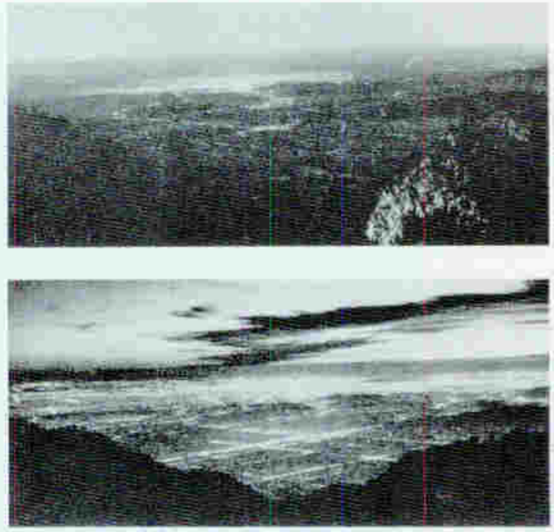
The burgeoning population of southern California, especially during the past two decades, has revealed in various painful ways the locations of more and more Heartbreak Hills. Nearly six million persons now reside in the Greater Los Angeles area alone, and current predictions are focusing upon ten million persons by 1980. As settlement has spread for many square miles across the basin and valley areas (see p. 15), increasing numbers of people almost literally have been driven into the intervening and surrounding hills. Hillside living has real advantages, too. The higher areas offer the last available residential sites within reasonable distances of major employment centers, and they make it possible for families to live away from the congestion, noises, odors, and other objectionable features of metropolitan districts. They also provide excellent views for the home owners, and the topographic irregularities broaden the possibilities for architectural expression in the homes themselves.

For decades southern Californians, while making jokes about their well-known dry rivers and arroyos, have built many of their homes across and within these obvious lines of drainage, evidently on the naive assumption that surface waters nevermore would put in an appearance. That this approach lacks certain elements of wisdom has been demonstrated in forceful ways by several floods. The extraordinary New Year's Day flood of 1934, for example, ravished the valley occupied by La Cañada, La Crescenta, Montrose, and Tujunga, smashing or undercutting some homes and filling many others with coarse debris. Even more impressive was the havoc wrought by the great flood of March 1938, especially in the San Fernando Valley area. Here extensive settlement during the 20's and 30's had superimposed entire communities upon the natural pattern of drainage, and numerous channels had been modified or even eliminated by artificial fills without adequate provision for future runoff. Flood waters spread widely across the valley floor, scouring deep gullies in streets and yards, destroying many structures, and depositing thick accumulations of gravelly muck over large areas.

Flood-control installations

Some storms in southern California bring several inches of rain within periods of an hour or less, and twenty inches in twenty-four hours has been recorded more than once in the mountain areas. Most of these storms occur during the winter months, when the ground already is saturated or nearly so, and the problems of runoff are complicated in the lowland areas by a steadily expanding blanket of pavement, buildings, and other impervious works of man. Fortunately, many of these areas in the coastal region are now protected by flood-control installations of various kinds, but it may be several decades before such works are widely introduced elsewhere in southern California, especially in communities where more realistic homesite and grading regulations are needed.

Man has been surprisingly sluggish in extending the lessons of lowland drainage to the hillside areas, where topography accentuates the potential dangers to residential structures. During the period since World War II, heavy earth-moving equipment has been widely used in reshaping the landscape for development of residential sites in the Santa Monica Mountains, the foothill fringe of the San Gabriel Mountains, the Puente and San Jose Hills, and many



Population growth in Greater Los Angeles. Top, a moonlight view of Pasadena and Los Angeles in 1908. Bottom, essentially the same area in 1950.

other parts of the Greater Los Angeles area. Ridges and slopes have been notched with little regard for the nature of the materials removed or newly exposed in the cuts, and canyon bottoms have been filled to provide additional sites for homes and other structures. Disaster has been inevitable.

The heavy rains of January and March 1952 sent tremendous volumes of water down the bare surfaces of raw cuts and fills, gullying them deeply and moving huge quantities of muck and debris around and into homes and streets, so that many recently opened hillside tracts appeared as "seas of mud." What man had done to modify the terrain was vigorously extended by nature. In many places, temporary remedial measures merely aggravated the situation, as damaging runoff from subsequent storms was diverted to other vulnerable targets. Even those canyon dwellers who had relaxed in the assumed protection of debris-collecting basins that had been developed up-drainage from them found that their safety was transitory. Many of the basins were quickly filled to capacity with solid matter, which eliminated their protective function.

Uncontrolled flow of water does far more than scour the surface in one place and deposit objectionable debris in another. When it enters the subsurface, especially in and near fresh cuts and loose masses of fill, it can contribute forcefully to gross instability of the ground. Not only does it add weight and pressure as a pore-filling fluid, but it can seriously weaken the ground through lubrication of potential slippage surfaces and the scouring away of interstitial fine-grained matter. Its effects upon the volume, plasticity, and other characteristics of clay minerals can be disagreeably significant. Thus it has been a major factor in

Settlement of coastal terraces in the Pacific Palisades area, 1946. Large landslide masses (X) face the ocean, and a steep-walled cut (C) exposes old slide debris.

most types of ground failure. The exact subsurface paths of water circulation often are difficult to establish, but it generally is possible to predict the gross effects of artificial cutting or filling.

Many homes have been damaged by essentially local settling of the foundation materials, in amounts ranging from an inch to several feet. Often this is attributable to the placing of fill on natural slopes from which neither existing vegetation nor soft soils were removed; these natural unconsolidated materials tend to promote settling and slippage beneath the fill. The excavation of some cuts has exposed avenues of natural groundwater drainage, so that seeps have appeared in the cut faces. Not only do such seeps have undesirable effects upon lawns, gardens, and the foundations of structures, but the water commonly migrates downward beneath the structures and lubricates potential surfaces of slip in the underlying bedrock. All too often, one effect triggers off another.

Homes in some hillside areas have been erected upon soft, unconsolidated materials that are quite unable to bear the additional load. Downslope migration is the inevitable result. Although southern Californians have learned to live with earthquakes and have made admirable progress in the construction of earthquake-resistant buildings, they have given little thought to the intrinsic stability of the soft ground upon which many of them have built their homes. Nor, in general, have they considered the possible triggering effects of earthquakes upon subsidence and lateral movements of such ground.

By far the most spectacular examples of mass movement in southern California are landslides that involve large bodies of bedrock. Although specific conditions vary from one occurrence to another, all these slides can be ascribed to an unfavorable relationship between steepness of slope and inherent strength of the rocks beneath the slope. On this score, the most troublesome rocks in the Greater Los Angeles area are siltstones and sandstones whose shaly structure permits slippage along their surfaces of stratification. Many other kinds of rocks also are liable to sliding where they are soft or are weakened by the presence of numerous bedding planes, fractures, faults, or other structural discontinuities.

On October 28, 1937, surface cracks were observed on the hillside above Riverside Drive, not far from the Los Angeles Civic Center, and soon it became apparent that a huge section of the hill was slowly moving downward toward the nearby Los Angeles River. On November 26 more than a million tons of soil and rock suddenly moved downward, covering Riverside Drive and seriously damaging buildings and utility lines. About half a million dollars was expended in removing the slide material and in making major repairs. The event made interesting news, but to most persons it was only a temporary nuisance that soon was forgotten.

Some years ago the old highway between El Monte and Pomona was covered by a slide mass on Kellogg Hill. Study of this mass showed that its removal probably would do little more than make room for additional material poised higher on the slope, so highway engineers relocated the road around the toe of the slide.

The Pacific Palisades area recently has become well known for its large slides, although geological evidence indicates that sliding has occurred again and again in this locality for thousands of years. As shown above, human settlement has extended over a broad,

Landslide mass covering U.S. Highway 101 in the Pacific Palisades area, March 1958. Note that somewhat earlier sliding has concealed the cut (C) shown on the page opposite.

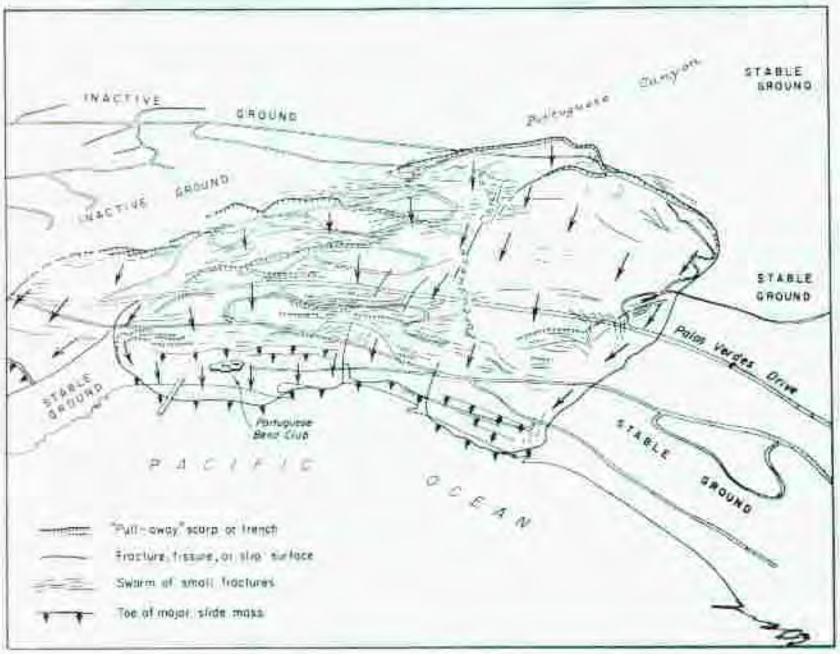
terrace-like area that is gashed by several deep, steep-walled canyons and is bounded on one side by a high sea cliff. This surface is underlain by sands and gravels whose stratification is essentially horizontal. These materials are relatively stable, and in the eastern part of the area, where they are very thick and form the entire sea cliff, little major landsliding has taken place during the past century. In the western (or left-hand) part of the area shown on page 16, the sands and gravels form a rather thin veneer over older and weaker shaly rocks. These rocks have been tilted and folded, and along much of the ocean front, where their bedding planes dip at moderate angles toward the beach, slippage has been promoted by water introduced through the overlying pervious sands and gravels, and also by wave erosion that has removed support from the base of the sea cliff. The natural erosion by wave action has been largely eliminated through the development of beaches and the construction of embankments along U.S. Highway 101, but man has increased the contributions of water to the structurally weak shaly rocks, chiefly through the irrigation of his lawns and gardens.

Sliding has occurred at points along the ocean front and along the sides of tributary canyons wherever the structure of the bedrock is unfavorably oriented. The crescentic expression of one large slide can be seen on page 16; this mass is traversed by the loops of road extending from the edge of the cliff downward to Highway 101. Mass movements have occurred repeatedly during recent years, the latest episode following heavy winter rains in 1958. The position of this slide and its effect in trimming back the edge of the sea cliff are shown above. To the left of this mass are several other, slightly older slides.

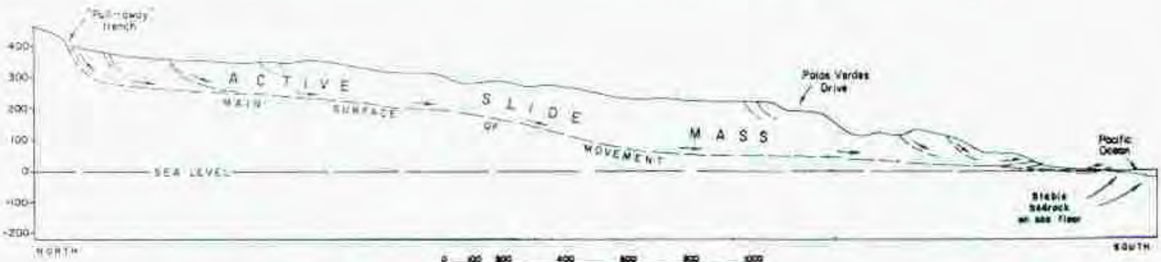
Failure in seaward-dipping shaly rocks also has been responsible for landsliding at Point Fermin, in the Palos Verdes Hills. Movement of an enormous mass was first recognized in 1929, and sliding toward the ocean reached major proportions a little more than a decade later. The migrating mass is about 1,000 feet long and 50 to 400 feet wide, and its upper surface, originally about 100 feet above sea level, is now depressed 10 to 40 feet beneath the level of the adjacent ground to which it formerly was attached. Fortunately, the early movements were sufficiently slow to permit evacuation of the area without serious injury or loss of life. All buildings on the slid block have been removed, and the fissured surface is now a weed-grown "no man's land."

The most spectacular and damaging of southern California's recent slides is that in the Portuguese Bend area. Here a broad, platter-like mass of deformed soft shaly rocks has been sliding intermittently toward the ocean for a long period of time, probably measured in thousands of years. The latest episode of movements, which began in July 1956 and is continuing today, involves only the eastern part of this ancient slide mass. The moving ground occupies an area of nearly 200 acres, on which more than 150 homes rest in various stages of destruction. The currently active mass, 100 to 200 feet thick, is easing itself seaward over a gently undulating surface of major slippage. It is no accident that this surface conforms in a general way to the attitude of stratification in the underlying rocks, and corresponds in general position to the occurrence of a lubricating layer of altered volcanic ash. This ash consists largely of clay minerals. It is soft and slippery when wet, and has been encountered in numerous test holes bored through the slide.

The Portuguese Bend area in the Palos Verdes Hills, looking north-northwest, 1955. Most of the homes in the central foreground and middle distance are now abandoned.



General features of the active slide mass within the area shown above. Arrows indicate major directions of slide movement.



Generalized section through the Portuguese Bend area in the vicinity of Portuguese Canyon, showing the undulatory surface of principal slippage beneath the active slide mass. The toe of the mass curls slightly upward over stable bedrock along the ocean shore.

The principal features of the slide mass are shown on the page opposite. Its curving upper margin is characterized by a series of fresh scarps and "pull-away" trenches. Preserved along the walls of these trenches are grooves and striations that indicate the downward movement of the migrating ground (see below). The lateral margins of the active slide mass are marked by zones of profound shearing. The eastern part of the mass, which has moved farther than the other parts, is separated from the remainder of the slide by a shear zone in the vicinity of Portuguese Canyon (see p. 18). Maximum horizontal movement has amounted to nearly 30 feet. The entire mass is thoroughly fissured and fractured, like the ice in a glacier that is flowing over a very uneven bedrock surface, and it is marked by many structural complications. The snout of the slide appears along the sea coast, in most places as a low ridge of crushed and broken material in the zone of wave action. It is being thrust upward along stable bedrock that forms the sea floor (shown at the bottom of page 18) where it is being attacked by the marine waters.

Damage to structures in the Portuguese Bend community has been so extensive that many of them have been condemned for further occupancy. All have been wracked to some degree, and several have been almost literally torn apart by differential movements of the ground beneath them. An interesting type of failure has occurred near the shoreward end of the pier at the Portuguese Bend Club. The outer part of this pier rests upon stable ground, the inner part on the snout of the slide mass; the resulting compression has caused the buckling shown in the photo above. A large swimming pool near this pier was so severely fissured by the ground movements that it was replaced by a new concrete pool with a plastic liner; despite subsequent movements of the concrete shell, amounting to several feet locally, the plastic liner held water satisfactorily until the whole installation was recently abandoned.

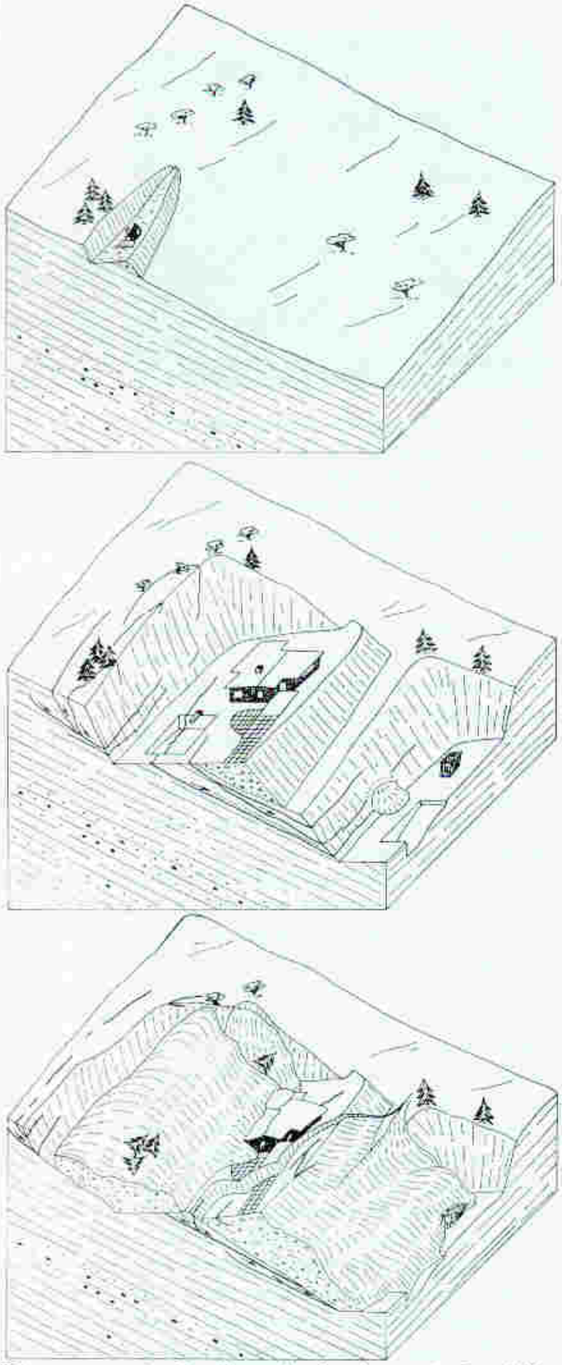
Exposed part of the main slip surface at the head of the Portuguese Bend slide mass. Note the steeply-inclined grooves on this otherwise smooth surface.

Coastwise view of the Portuguese Bend area, December 1956, showing the slide mass in left foreground. The snout of the mass emerges on the ocean bottom along the surf zone between the pier in the foreground and the white breakers in the right distance. Buckling of the pier can be seen near its shoreward end.

The entire Portuguese Bend settlement is rapidly becoming a ghost community. A supplemental tragedy is the effect of the landsliding upon the newly developed tract immediately to the east, which appears within the area of curving streets in the middle distance above. Although these new homes rest upon stable ground, their proximity to the slide has had unfortunate effects on current estimates of their value by the general public.

The basic factors responsible for the present sliding in the Portuguese Bend area probably are little different from those prompting similar movements at this locality during the geologic past, but it is possible that man may have triggered-off the latest movements in any of several ways. Introduction of water to the subsurface, as from irrigation and septic tanks, is particularly suspect. No one can predict with confidence when the movement will cease, but it is almost certain that, once having ceased, it will begin again at some future time. An interesting effort to stop the sliding was made by the County of Los Angeles during 1957, when fifteen caissons of reinforced concrete, each about 4 feet in diameter and 20 feet long, were set in vertical holes bored through the main surface of slippage from points near the toe of the mass. It was hoped that these gigantic pins would have a holding effect akin to that of toothpicks in a Denver sandwich. But this project failed, owing largely to the weakness of the slide materials, which flowed around the pins and tilted some of them in the process.

Man's remarkable capacity for troubling himself has been nowhere more clearly shown than on numerous "dip-slope" hillsides, where the stratification in the underlying rocks is essentially parallel to the ground surface. Evacuation of cuts at such localities has caused much damage, particularly in the Santa Monica Mountains and on some of the hills rising



Three stages in the dynamic development of a "dip slope" hillside. Top, a bulldozer cut is made. Middle, two benches have been completed, and the upper one is already occupied by a house and pool. Slippage within the bedrock is beginning to occur, and cracks are appearing on the ground surface. Water, leaking from the upper swimming pool, is soaking into the bedrock and promoting further sliding. Bottom, sliding has occurred on a large scale as nature tries to reestablish a relatively stable dip slope.

above the broad Los Angeles Plain. At the left is a typical story in the form of three episodes. Lot pads are graded in a dip slope, and homes are built on them. Within a short time, generally less than five years, the beds begin to move past one another, much like the slippage within a tilted deck of cards that is unsupported along its lower edge. As shown in the middle and lower diagrams, cracks and fissures are the surface expressions of slip zones at depth, and the total movement ultimately results in transfer of ground from some parts of the properties and encroachment of enormous slide masses onto other parts. Hundreds of major failures in the Greater Los Angeles area can be attributed to this general situation. It seems plain that cuts should not be developed in hillsides underlain by rocks liable to bedding-slippage, and where the geometric relationships between surface slope and rock structure are essentially as shown in the upper diagram.

It seems obvious that man cannot take for granted the ground he lives on, and that responsibility for troubles stemming from a careless attitude rarely can be fixed upon someone else, legally or otherwise. The geologist has long been aware of stability problems, although not all geologists have enjoyed uniformly pleasant experiences with their own properties! Geologic relationships in the Heartbreak Hills are now receiving fuller attention from the engineer, who recognizes that it is more satisfactory to prevent or avoid conditions of instability than to deal with their unfortunate results after they have occurred. The responsible public official, having learned that wise development of hillside land can be insured only by regulation, is continuing to press for grading requirements that are realistic and broadly applicable. He has had strong opposition from many quarters, but fortunately has been able to take advantage of public reaction to several disasters. Thus Gilbert E. Morris, who heads the Department of Building and Safety of the City of Los Angeles, was able to put through a forceful and effective grading ordinance as a result of the 1952 floods, and thousands of persons already have been protected through denial of building permits for sites where hazardous conditions exist or would have been created through proposed development.

The public itself must become more aware of the general problem and more sympathetic toward existing and future regulatory measures, lest the disastrous effects of instability continue their alarming increases of the past decades. One may well be sincerely sorry for the individual victims—for all the Winners and all the Gessers—but it also is well to note that everyone ultimately pays the piper in numerous indirect forms, including increased tax, insurance, and utility rates, and, in many instances, lowered property values. All of us, therefore, will have to give more attention to the matter of keeping our property where it belongs if we are to enjoy what amounts to peaceful coexistence with southern California's geology.

THE SHOLUBILTY OF EHYLY ALCOHOL IN GRANITIC MAGMAS

By LONG JAHNS

(1960, from *The Fumerole*: Caltech Geology Club Magazine, February 1960)

Caltech Editor's note: The following fragment, written in longhand, appeared in our office mysteriously. Since it apparently deals with scholarly research of a high degree of competence, we are reproducing the deciphered portion exactly.

The following research was undertaken as part of a long-range program on The Effects of Geologically Improbable Liquids on The Behavior of Magmas and Other Imponderables, carried out jointly by Caltech, Penn State, M.I.T., the Geophysical Lab, and Alcoholics Anonymous. A variety of scientific techniques were employed, including hydrothermal syntheses, mass spectrometry, and consumption by undergraduates.

Thish paper deals with the inveshtigation of a relatively ~~shim~~ simple system, C_2H_5OH-granite. It is an outgrowth of a larger program of inveshtigation on the system C_2H_5OH-vermouth-grenadine-granite. Preliminary studies have been carried out on the joins C_2H_5OH-vermouth (Gray and Flannel, 1954), vermouth-grenadine (Snarf, 1954), and C_2H_5OH-grenadine (T. Totall, 1956). A larger study of the system C_2H_5OH-vermouth-grenadine has been started, but work on the C_2H_5OH-rich end-members is proceeding slowly, due to inshibilities in the apparatus, chiefly the experimenters.

The apparatush used in these exshperiments hash been described previoushly (Jahnsh 1954, 1956, 1957, 1958). The Weshterley granite ~~wash~~ was used as a natural material. The ethyl alcohol was procured originally from Abner Yokel of Hog Wallow, West Virginia, as a byproduct of his inveshtigation of the system C_2H_5OH-people. After 1956 this source became unavailable (U.S. vs. Yokel, 1956 Supreme Court Reviews, State of West Virginia) and other equivalent material was shubshtituted. No shignificant changes in reshults were noted as a reshult of thish change.

It is ~~sheen~~ seen from the phase diagram that firsht melting in the C_2H_5OH-rich end-members produshes liquids at relatively low temperatures, in the neighborhood of 250° K. Shince liquid of thish composition have never been obsherved ash productsh of ~~differnshia~~ ~~difrntiysh~~ cryshtal shettling, it ish concluded that magmatic prosheshes do not take place at this ~~tempersh~~ ~~temprashr~~ COLDNESSH. Formashun of a vpur phs wash noted at ~~temprsh~~ points, whish may have as much as 4 percent granite in soloshun. This casd exspermental difficultys shince ~~inlashun~~ ~~inhulshun~~ breathing this vapr phs cause silicosis of the liver.

Shampling of the phses wash done by oral teshting, undergraduates beeing prticularllly shensitiv to varyashuns in compocishun....aszha mattterafack, we hah shum rel blashtsh in thet ~~lb~~ lab...I remmber the time I was ding feldwrk in NeWenGlnD and I had thish aahshishtant on the alydad and he wash working on SunDaY and along cme...

Caltech Editor's note: At this point, the manuscript degenerates into an illegible scrawl. Submission of the succeeding fifteen pages to various experts in Cyrillic, Greek, Sanskrit, Etruscan, and Cretan Linear B have produced no further information beyond the fact that the general style bears a vague resemblence to certain records of Bacchnalia and Dionysian revels. Considering the nature of the subject matter in the early (legible) part of the article, we feel this resemblence is probably coincidental. We will print further translations and inferences as they are produced, although, since no ~~Roshetta~~ Rosetta Stone for the style exists, this is apt to be a slow process. A diagram, capable of interpretation as a phase diagram, was submitted on the back of someone's edited propositions. However, it was loaned to the Metropolitan Musuem of Modern Art as part of the Caltech Culture Carnival and was not available for publication. We doubt that it would have helped much anyway.

GEOLOGIC JEOPARDY

By Richard H. Jahns

(Reprinted with permission for *Texas Quarterly*, 1968, Vol. XI, No. 2, pp. 69–79).

Not long ago, man was often inclined to reflect with unqualified satisfaction upon his growing record of accomplishment in competing with nature. But as he has continued to reshape the terrain, to modify much of its drainage, to extract useful materials from the subsurface, and to control various elements of his environment on larger and larger scales, it has become less and less clear that so pleasant a view is justified by the record. Today man is being more widely recognized as the kind of schizoid competitor he really is–imaginative, ingenious, resourceful, and remarkably courageous, but with distressing capacities for vastly increasing his own numbers, for enveloping himself with wastes of many kinds, and for making serious mistakes in dealing with his natural surroundings.

As human population has burgeoned and clustered during recent decades unpleasant confrontations with geologic reality have become more frequent and more challenging. Among the so-called geologic hazards, or risks, those most commonly encountered are related to floods, earthquakes, and various kinds of unstable ground, and as such they are normal and widespread manifestations of natural processes operating upon and within the earth's crust. From time to time some of the risks are translated into disasters, either unavoidably or through the active cooperation of man; the nature, location, and even the magnitude of such disasters often can be predicted well in advance of their occurrence, but the advance dating of these occurrences is another matter. Intervals between successive natural catastrophes of the same kind ordinarily are so great that studies of the geologic and historic records rarely lead to forecasts sharply enough focused to be useful without supplementary information of other kinds.

A brief sampling of well-documented geologic risks and disasters from the state of California may provide some notion of the diversity of problems that have been recognized. By no means does California have a corner on such problems, but its great variety of geologic materials and features, combined with major concentrations of population, establishes it as an excellent testing ground for the basic wisdom of its occupants. And in few other places are large numbers of residents confronted by such stimulating assemblages of natural hazards as those in the Los Angeles and San Francisco regions, where contrasts in topography, climate, and geology are especially prominent.

From California's subsurface come those recurring violent actions known as earthquakes, several of which have dealt rather harshly with man and his works during the period of historic record. These shocks have originated along faults, or breaks in the earth's crust, that represent repeated slippage over very long spans of time. Thousands of faults are known within the state, and many of them can be classed as large in terms of their total displacements. Many of them also are geologically active in the sense of having moved within the past 10,000 yr, and more than a few have been active in historic time.

The release of energy in the form of a large earthquake can be assumed to begin with sudden fault movement initiated at some depth in the earth's crust, and to continue as this slippage is rapidly propagated in all directions along the fault. Under appropriate conditions, the displacement may reach the earth's surface and appear as horizontal, vertical, or oblique offsets along the trace of the fault. Such surface faulting also may accompany a relatively small earthquake if the focus, or point of original rupture, is sufficiently shallow.

During the San Francisco earthquake of 1906, predominantly horizontal surface displacement occurred along perhaps as much as two hundred and seventy miles of the San Andreas fault, California's widely known master break. Maximum observed offset of reference features such as roads and fences was nearly twenty feet. Displacements of similar magnitude may well have occurred farther south along the same fault during the great Fort Tejon earthquake of 1857. Among earthquakes originating in California and nearby parts of Nevada during the past century, at least twenty are known to have been attended by measurable surface faulting. The largest offsets observed in relatively recent years were nineteen feet (horizontal) with the Imperial Valley earthquake of 1940, and twelve feet (horizontal component) and fourteen feet (vertical component) with the Fairview Peak, Nevada, earthquake of 1954.

Although surface rupture is neither common nor widespread over periods of human generations, there is obvious risk in erecting homes or other structures athwart the most recent traces of past movements along active faults. Yet this is precisely what has been done especially along the San Andreas fault southward from San Francisco and along the San Andreas and San Jacinto faults in the San Bernardino area of southern California. Moreover, this kind of "gamble-in-residence" is being taken more and more often, and in areas where the positions of active faults are well known; it is particularly distressing to note the number of schools represented among installations that some day might serve as reference features for large-scale shear. The gamble might seem safe enough in terms of the odds against losing, but any loss in this ill-advised game could be a major disaster. Fortunately, the nature of such risk is being increasingly noted and appraised for aqueducts, dams, and other special engineering works, if not for housing developments.

A more immediate threat to some installations that extend across fault traces is the slow creep, or progressive slippage in the apparent absence of earthquakes, that is being recognized as currently characteristic of several major breaks in California. These include the Hayward fault on the east side of San Francisco Bay, the Calaveras fault in the vicinity of Hollister, and parts of the San Andreas fault for a distance of about two hundred miles southeastward from San Francisco. Tunnels, railroad tracks, roads, fences, culverts, and buildings are being deformed and displaced where they straddle the narrow strands of creep, with cumulative offsets generally measured in inches over periods of years or decades. At the Almaden-Cienega winery southeast of Hollister, horizontal slippage along the San Andreas fault averages more than half an inch per year; the main building, which evidently lies astride the active fault trace, has been aptly described as experiencing "obvious structural distress."

Returning now to large earthquakes, it should be emphasized that by far their most widespread effects upon man are results of severe ground shaking that accompanies the sudden rupturing along faults. For a given moment of energy released, the severity of shaking can vary greatly from one locality to another according to the interplay of many factors. Perhaps most important among these is the nature of the rocks or other foundation materials at the site in question, as demonstrated by marked variations in the distribution of damage from individual historic shocks. In general, shaking is least intense in hard, firm rocks like granite and gneiss, and most intense where the energy is coupled into relatively soft and loose materials like alluvial silts, sands, and gravels, swamp and lake deposits, and hydraulic fill. The oft-used analogy of a block of jello on a vibrating platter is grossly simplified but nonetheless reasonable, and assuredly a structure that in effect is built upon the jello must be designed to accommodate greater dynamic stresses if it is to survive the shaking as effectively as a comparable structure built upon the platter.

This focuses principally upon California's metropolitan areas, large parts of which are underlain by relatively soft and poorly consolidated materials, and it further points up the need for prudent design of buildings to be erected on reclaimed marsh land or filled portions of lakes and bays. Much of value has been learned during recent decades in the important field of earthquake-resistant design for structures, and a great deal of this knowledge has been wisely applied in actual construction. Unhappily, however, it rarely is possible to offer more than broad generalizations concerning the nature of ground motion to be expected beneath these structures during future earthquakes. Relations between the release of energy at its source and the attendant ground response at a given surface locality are incompletely understood, and pertinent empirical data are still sketchy at best; thus the engineer with capability for earthquake-resistant design cannot be readily supplied wits precise design criteria.

A considerahbe sum of recorded observations indicates that strong shaking during past California earthquakes has found expression in many different ways. In addition to its widely known effects upon man-made features, it has led to cracking, fissuring, warping, lurching, and local elevation or depression of the ground, to triggering of slumps, landslides, avalanches, and debris flows, to shifting of surface drainage and ground-water circulation, and to broad-scale sloshing of lakes and other water bodies. Various combinations or these and other abrupt changes in the normal scene doubtless will accompany future earthquakes that are certain to occur; indeed, the notion that the state is now "overdue" for another great earthquake is not without some foundation.

It seems obvious that man cannot take for granted the ground he occupies, and that responsibility for troubles stemming from a careless attitude cannot be easily fixed upon someone else, legally or otherwise. Nor can a defeatist attitude survive under the growing pressure or population increase, with corollary expansion or settlement into areas where questions of ground stability must be faced and answered. Here some real progress already has been made, especially in the San Francisco and Los Angeles regions, as more geologists, engineers, land developers, and public officials appear to be asking themselves:

> Will posterity participate
> In chaos we create,
> Or will our heirs commemorate
> Mistakes we didn't make?

Granting man's limitations in controlling certain important elements of his geologic environment, in California and elsewhere, at least he is learning that when he imposes improperly upon nature, nature is likely to respond by imposing more seriously upon him. He has been modifying his approach by seeking better to understand natural processes and more effectively to apply this understanding in the primary struggle, which really lies more with himself than with nature. Nature now can be identified less as the antagonist than as the arena in which ever-increasing numbers of people are competing with one another for food, for air and water, for energy, and for space—there is no other readily available arena, hence this one needs a bit more respect and care.

Toward environmental understanding and improvement, geological scientists and engineers are vigorously investigating many kinds of so-called natural hazards. Active and potentially active faults are now being precisely mapped over large areas, and their respective styles of behavior during the geologic past are being deciphered via a remarkable variety of approaches. New data on creep along faults, the accumulating strain in ground adjacent to faults, and the behavior of the ground during recent earthquakes are revealing some instructive and unexpected relationships. Engineering seismology has fully emerged as a highly significant field of study, with major efforts now being devoted to determining the response of bedrock terranes and surficial deposits to earthquake shaking, the behavior of buildings and other structures during earthquakes, and the most satisfactory types of seismic design for many kinds of structures.

Prediction of earthquakes no longer seems to be an objective for some future century; indeed, at least one important break-through in this area can be expected within the coming decade. Soon perhaps we shall have warning of a few minutes to as much as an hour in advance of strong shocks along two or three of this country's most prominent active faults, a contribution of incalculable value to people if not to their property. In the meantime, increasing coordination of empirical and basic data and of observation, experiment, and theoretical analysis can be expected further to improve our dealings with floods, landslides, ground subsidence, and other kinds of natural hazards. May we look forward to the days when all kinds of ground failure can be forestalled or reduced in impact, when existing landslides can be made safe for useful development, when our buildings and utilities can survive the severest earthquake, and when sound programs for disaster insurance can be predicted upon knowledge not yet available.

The human side of these dealings is even more complex than the problems posed by nature. The general public and numerous stewards at all levels of government have been rapidly awakening to the existence and scope of geologic jeopardy in its numerous forms, with reactions ranging from apathy to panic, but tending properly to consolidate into deep concern. The growing record of damage and death, especially in some thickly populated areas, has become so compelling that direct responses are now extending beyond temporary reactions to individual disasters. Homeowners and public officials, scientists and engineers, universities and utilities, conservation groups and industrial organizations, government agencies and legislatures, and increasingly large numbers of individual citizens are discovering that they have a common stake in learning how better to live with their physical environment, regardless of their other interests. As more and more of them come to recognize the game we all have been playing in nature's arena for so many centuries, more and more of them will want to know what the score is. Geoscientists and engineers must be continuingly ready with the answer, however constrained or unpalatable it might be at any given place or time.

California's Ground-Moving Weather

We have often heard the expression "earthquake weather," and ordinarily have discounted its implications in favor of alternative factors more fundamentally related to shaking of the ground. But other kinds of ground movement that also are important to California's residents have led to more realistic expressions of unhappy implication, among which are "flood weather" and "landslide weather." Barely benign in their behavior or effects, these recurring elements of normal geologic activity are figurative mud in the public eye, and they have been especially troublesome in areas of concentrated population.

The climatic norm in California implies a pleasantness that is consonant with reality for much of the time; yet large departures from this norm are not infrequent. In terms of rainfall, for example, the long-time average of about 15 inches per year for several populous areas represents ranges of 30 inches or more between annual extremes. Much of this precipitation results from individual storms that occur chiefly during the period December through March, or from series of storms that tend to be scattered irregularly through this wintertime wet season. The heaviest rainfall also is irregularly distributed in a geographic sense, owing mainly to variations in storm tracks and to marked contrasts in topography. The effects of topography can be very important, as reflected by large local differences in precipitation during numerous regional storms.

WATER ON THE GROUND

In considering relationships between weather and undesirable movements of the ground, we can focus primarily upon two kinds of features—uncontrolled runoff of exceptionally large amounts of

By RICHARD H. JAHNS

water over short periods of time, and the penetration of additional large amounts into the subsurface over longer periods. Here rainfall is the prime factor in most parts of California, although the significance of other kinds of climatic contributions cannot be denied. For example, more than 600 inches of winter snow and an appropriate pattern of temperatures in the Sierra Nevada can lead to disastrous spring flooding in the Sacramento and San Joaquin Valleys, as occurred at least four times between 1880 and 1907. Or combinations of storm waves and extremely high tides can result in accelerated erosion and local collapse of coastal cliffs, even when no heavy precipitation is involved. But such events either are limited in scope or involve inundation more than movement of the ground.

How much water may the ground be required to deal with during periods of extraordinary precipitation? And what kinds of things can happen? The historic record provides some eyebrow-raising data. In the winter of 1861-62, a most uncharacteristic season within a long sequence of near-average to very dry years, repeated storms doused San Francisco with nearly 50 inches of rain, and in Los Angeles the skies leaked without stopping for a full month. Adobe structures seemed to dissolve under the downpours, while on most valley floors buildings became islands in huge lakes and then were heavily pounded by wind-driven waves. Large parts of the Sacramento and San Joaquin Valleys were converted into an enormous inland sea, and the entire state appeared to be drowning as every river, creek, and dry wash became a torrent of muddy, debris-laden water. According to contemporary accounts, mud as much as five feet deep was deposited in the parlors of some Sacramento homes. This must have been a new sad note for those residents of more than a century ago, but it has an all-too-familiar ring for many persons now living in the state.

In southern California the shallow Lake Elsinore, which had been essentially dry during the preceding year, filled to a depth of at least 50 feet and overflowed in 1862, all within a period of little more than three months. Since that time the lake has gone through numerous cycles of evaporative shrinkage and rainfall-nourished expansion, with at least eight separate episodes of overflow. Some periods of expansion reflected relatively long wet seasons or successions of such seasons, and all of them marked the occurrence of brief storms characterized by high intensities of precipitation.

The mountain ranges fringing the broad lowland area that includes Los Angeles are in a semi-arid region; yet they have received some remarkable contributions of moisture from time to time. During January 1916, for example, 50 to 60 inches of rain fell over much of the San Gabriel and San Bernardino Mountains, with considerable parts of the total coming from one three-day storm. Adjacent lowland areas received 32 to 40 inches during that same month. The western San Gabriel Mountains are particularly noted for short-term precipitation of great intensity, especially on ridges and canyon walls only short distances from Pasadena and other cities along the southerly base of the range. Gauges at Opids Camp, Mt. Wilson, and Hoegees Camp recorded 21 to nearly 26 inches of rain during the three-day period February 28–March 2, 1938—a moisture dosage that only slightly exceeded one from a similar storm during the period February 14-16, 1927. And on January 22, 1943, a 24-hour record of 26.12 inches was established at Hoegees Camp; during that same day 22.32 inches of rain fell at Opids Camp, where the winter season's ac-

The western San Gabriel Mountains, bordering Pasadena (center) and heavily settled parts of the San Gabriel Valley, are particularly noted for short-term rainfall of great intensity. Hoegees and Opids Camps (out of sight at the bottoms of deep canyons) register record rainfall—26.12 inches during one 24-hour period in January 1943, and a winter season's total of 80 inches that same year.

This fossil debris flow, revealed in cross section by a roadcut near Pala in San Diego County, is a chaotic accumulation of blocks, boulders, tree fragments, and stony rubble —a coarse slurry that debouched from the mouth of a nearby canyon at least 10,000 years ago.

cumulation ultimately reached 80 inches.

Such overly generous contributions of water are potent reshapers of the landscape. They form temporary torrents that carve deeply into the steep mountain slopes and pick up enormous charges of debris en route to adjacent valley and basin areas. There uncontrolled parts of the runoff deposit various assemblages of mud, rubble, boulders, and trash, commonly in places where they are not welcome. Parts of the San Fernando, San Gabriel, and San Bernardino Valleys were thus devastated by the great March Flood of 1938, and four years earlier the La Cañada-La Crescenta Valley was invaded by rushing waters and bouldery slurries during the New Year's Day Flood of 1934. The slurries, much heavier and more slow moving than ordinary flood runoff, filled normal channels of drainage and then thrust across settled areas as great tongues that engulfed all objects in their paths. They resulted from cloudburst precipitation—13 inches or more in 24 hours—on adjacent steep mountainsides that had been denuded of protective vegetation by a forest fire during the previous fall season. Large debris flows of this kind have an impressive capacity for incorporating and transporting boulders, automobiles, buildings, and other heavy objects. Though infrequent and spotty in their occurrence, they have visited many parts of the state during the recent geologic past.

What may have been the most spectacular cloudburst in California's historic record seems to have attracted relatively little attention at the time, even though it occurred only a few miles from Pasadena. In the spring of 1926 a week-long storm brought 25 inches of rain to the area centering about San Gabriel Peak, with half of the total falling during a ten-hour period on April 4. At 3:30 a.m. on that day, a gauge at Opids Camp registered 1.02 inches of rain in a single minute and another inch during the following two minutes! One result of this extraordinary downpour was the detachment and removal of everything that was loose or could be loosened from the precipitous northerly slopes of the peak. An unusually coarse debris flow moved downward to the mouth of a gulch at Opids Camp, where it came to rest as a rampart-like slug of granitic boulders and blocks, trees, and finer-grained detritus—250 feet long, 50 to 75 feet wide, and about 40 feet in maximum thickness.

WATER IN THE GROUND

The surface effects of precipitation and runoff are invariably accompanied by less obvious penetration of water into the ground. Much of this water replenishes any existing deficiencies in the soil, most significantly in the root zone of the plant cover, and during extended wet periods substantial amounts may gradually move to deeper levels. But the orderly processes of infiltration are too slow to handle more than a small fraction of the precipitation from heavy storms. When such precipitation is especially intense, the destructive behavior of runoff can be worsened, rather than eased, by contributions of water augmenting the moisture already present in the shallow subsurface.

Here the recipe for prompt and widespread disaster in populated areas calls for steep slopes, an underlying few feet of soil or other relatively loose and uncompacted materials, and a minimum of surface stabilization from deeply rooted plants. Add very large amounts of water in very short periods of time, and the real action begins. Some of the water soaks into the mantling materials of the slope, where it both reduces their cohesiveness and increases their gross weight. Meanwhile, vigorous surface runoff cuts small gullies into the slope, especially where provisions for drainage have failed to prevent undesirable concentrations of flow. Soon parts of the scored slope are progressively loosened and detached as irregular patches, a few square feet to several acres in extent, that then move downhill. Typically they are broken and internally stirred during this descent, arriving at the foot of the slope as mobile slurries or accumulating there as thick masses of incoherent debris.

This scenario repeatedly has been translated into reality, especially at localities where man has modified the natural topography without sufficient note of possible consequences. Unhappy endings have occurred most often in the San Francisco, Los Angeles, and San Diego regions during the past 25 years of increasingly intensive settlement in hillside areas. It does not follow that catastrophes must attend grading of the land on any scale, but certainly the development of raw cuts in weak ground, emplacement of fill without proper compaction, and loading of soft slope materials with heavy, shallow-rooted plants will not contribute to long-term safety. Though widespread in their occurrence during periods of exceptionally intense rainfall, slope failures of the shallow or "skin" type are rarely large. Yet a home clogged with debris representing a fresh scar on an adjoining slope is nothing less than tragedy for the owner.

Equally wide ranging are many kinds of surficial failures in the hills and mountains beyond centers of population. These are nonetheless of real significance to the public, as they can add enormous amounts of debris to storm runoff that gathers in canyons and invades settled valley areas below. This lesson was offered rather violently to southern California residents in 1811, 1825, 1884, 1890, 1914, 1916, 1934, 1938, and 1943—each succeeding time to increased numbers of them. Indeed, it is recognition of the potential impact of future catastrophic floods on a burgeoning population and on correspondingly expanded areas of valuable property that has numerous geologists, engineers, and public stewards glancing uneasily back over their shoulders. To keep pace with growing requirements is a formidable challenge for an already sophisticated program of flood-control installations.

In contrast to the effects of uncontrolled runoff and shallow soaking of the ground are numerous larger slumps and landslides that have plagued Californians again and again. Most of these failures have involved masses of relatively weak or easily detached bedrock that have moved outward and downward on slopes in response to gravity. Triggering of displacement from positions of equilibrium, whether occurring once or many times at a given locality, can be variously ascribed to several factors, acting either singly or in some combination. Among these are earthquake shaking, selective overloading of the ground, removal of support from downslope areas, and increases in amount of subsurface water. Here man often has revealed himself as a disagreeably effective imitator and competitor of nature, for he has triggered many slides through his own reshaping of the terrain and his introduction of water into the ground as local concentrations.

The historic record clearly indicates that naturally introduced water can be the most important prompter of large-scale ground failure. Such failure may closely follow single storms, especially where attendant, severe runoff removes the toes from existing landslide masses that occupy steep canyon walls. The Eel and Russian Rivers in northern California, for example, have thus triggered numerous large slides at times when they were at very high flood stages. More often, however, landslide movements are delayed by days, weeks, or even months following episodes of unusually heavy precipitation, and a few have followed series of successively wet years. Such irregularities in lag times can be ascribed mainly to differences in the patterns of precipitation, the rates at which water infiltrates the subsurface and raises groundwater levels, and the various interactions between water and the subsurface materials. Detailed relationships among these factors are well understood for relatively few of the known landslides in California.

The extraordinary storm of 1938 immediately activated many earthflows in the Ventura area, and with only a little delay quickened the movements of large landslides that had been causing extensive damage to wells and other installations in the Ventura Avenue Oilfield for more than a decade. The weight of the added water must have been an important factor in this early response, but more than two months later a much greater movement was triggered in one of the slides by a fairly small excavation at its base. A similarly delicate state of near-equilibrium evidently now exists in the large Portuguese Bend landslide near Los Angeles, where slow movement has been continuous during the past 12 years. Here strain-gauge readings have shown that a few inches of rain from a single storm is sufficient immediately to double the rate of movement, evidently from the added increment of weight.

An interesting contrast in timing is provided by a large compound landslide mass in Portola Valley, south of San Francisco, that was originally formed in 1890. Precipitation during the winter of 1889-90 was exceptionally heavy, but it came late in a ten-year period of excess rainfall and hence probably augmented a subsurface accumulation that already was near-critical for massive ground failure at this locality. Various parts of the slide complex have been reactivated in subsequent years, most recently in 1967 (right). Additional examples of large bedrock landslides whose initial movements followed series of severe rainstorms or series of unusually wet years are known elsewhere in the San Francisco Bay region, in the Palos Verdes, San Joaquin, and Puente Hills of the Los Angeles region, and in other coastal parts of the state.

YESTERDAY AND TOMORROW

That ground-moving weather has been a recurring and highly important element of life in California is a matter of historic record, and there is every reason to believe that it will revisit us from time to time in the future. But when, and how often? Granting that our period of direct observation has been all too short and that rainfall records during this period seemingly were made only to be broken later on, what trends or patterns can be reasonably projected into the next few decades? Here it is useful to look again at the past.

During Late Pleistocene times, dating back from about 10,000 years ago, California's climate was considerably wetter than it has been since. Doubtless it was no accident that these were times of vigorous and widespread flooding and landsliding in the state, and tens of thousands of shallow topographic benches in the hills and mountains mark sites of ancient ground failure. Many of these benches are now occupied by dwellings, and it is fortunate that relatively few of the landslides have been reactivated during post-Pleistocene time. Quite apart from trends in the frequency of strong earthquakes, it can be suggested that the ground surface has been somewhat less mobile during the past few millenia than it was earlier. But these mere fragments of geologic time are still much too long to be useful for our present purposes.

Detailed climatic records extending back a little more than a century plainly reveal a cyclic pattern in the temporal distribution of California's rainfall. Sequences of relatively wet years have alternated with sequences of much drier ones, and the trends of accumulating rainfall surplus or deficiency have been interrupted only now and then by individual years of countering dryness or wetness. Moreover, this pattern of recurring wet and dry

This small landslide, which occurred in Portola Valley in San Mateo County in the spring of 1967, was a reactivated portion of a much larger landslide complex that originally developed in 1890 following several years of exceptionally heavy rainfall.

The San Gabriel Valley and Puente Hills as they appeared in 1918 through a telephoto lens from Mt. Wilson. Many parts of these hills are underlain by soft, shaly rocks, and portions of their somewhat dimpled topography reflect the presence of numerous natural landslides—a situation that reveals a challenge for the time when residential and business developments thrust further south and up into the hills. (The old Balloon School in Arcadia is in the foreground, and its students seem to be involved in field work nearby.)

periods evidently has characterized the climate of the state for a period of time far longer than that embraced by our measurements of precipitation.

The late Edmund Schulman and his colleagues at the University of Arizona's Laboratory of Tree-Ring Research devoted years of careful study toward determining a centuries-long chronology of climatic changes in southwestern United States.

Some results of their work on moisture-sensitive conifers in the lower forest zones of California show some impressive similarities among growth patterns for different species of trees from widely separated localities. Particularly striking are correlations of growth patterns that are thought to reflect major shifts in trends of precipitation.

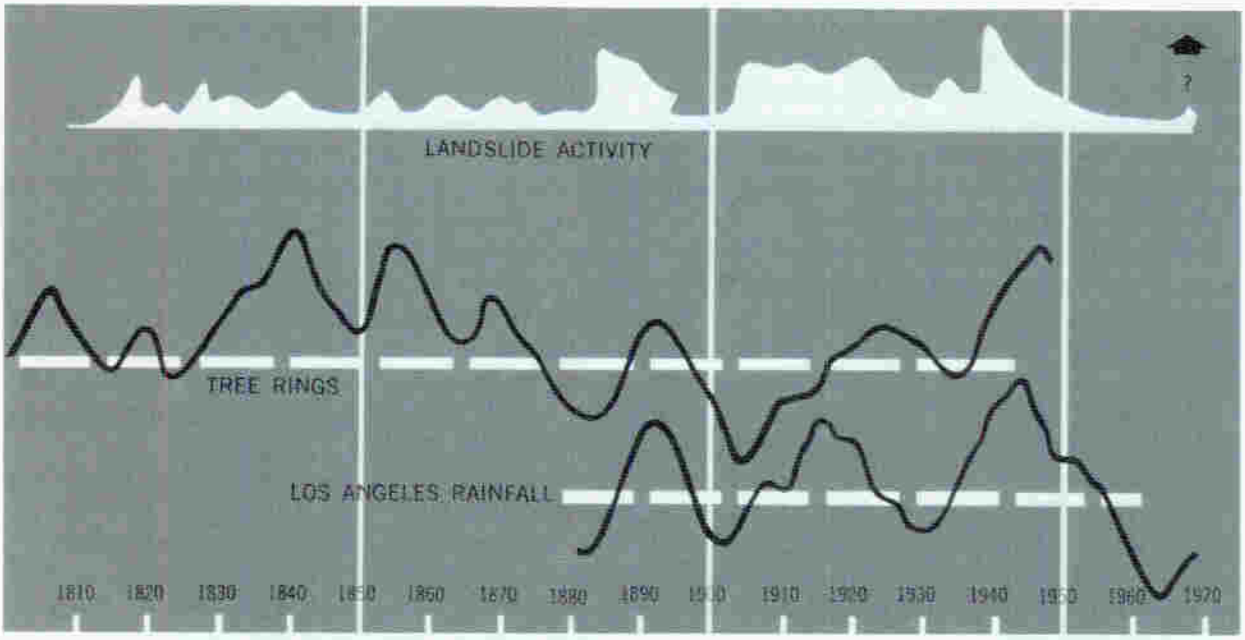
Schulman also turned his attention to some exceptionally long-lived conifers of upper timberline areas, and, since his death in 1958, this work has been continued by C. W. Ferguson and others at the University of Arizona. A 7,100-year tree-ring chronology has been developed for the Bristlecone pine in the White Mountains of east-central California, where a 4,600-year record from living trees has been extended back in time through the addition of data from long-dead ones. Interpretation of this composite record can be expected to indicate the pattern of moisture variations during much of post-Pleistocene time.

Trends in ring growth of carefully selected trees, and their close correlation with available climatic records certainly fortify the notion that California's rainfall has been markedly cyclic in its distribution over many past centuries. During the most recent five and one-half centuries, the average length of dry periods has been 16 years and that of wet periods 13 years. Respective averages of 15 and 12 years apply to the last three and one-half centuries, when the cycles appear to have been somewhat more regular. The latest dry sequence, which began in 1945, was a relatively long one interrupted by a few years of above-average moisture. Yet the record of preceding climatic cycles foretold a shift to a sequence of wet years. This shift appears to have occurred nearly four years ago, but early stages of the new sequence have been partly masked by one very dry year (1968) and by another of about average precipitation. At present we can anticipate a generally wet period that probably will last at least into the mid-seventies. It may well include exceptional storms and ground-moving phenomena reminiscent of those in 1938 and 1943.

Correlations between rainfall and landslide activity in California already have been noted, and the frequency plot (opposite page) reveals the sensitivity to heavy precipitation that has been shown by parts of the ground on which we live. This plot is based upon occurrences of more than a thousand natural landslides in coastal parts of the state between the Eel River and San Diego, as noted in newspapers, journals, and the scientific literature. It is no more than approximate because neither the record nor the survey of the record is complete, but the correlations are nonetheless unmistakable. There also is some indication that ground failure has been most vigorous and widespread during early parts of most wet periods, and that it has tended to taper off during their later parts. The frequency plot dates from 1810 because available reports on older landsliding are too scattered to be of statistical value, and it has not been carried much beyond 1950 because of difficulties in distinguishing wholly natural slides from those prompted in part by the hand of man.

As a sort of final touch, we can recognize yet another correlation that carries interesting implications for our immediate future. Two significant trends were started almost simultaneously a quarter of a century ago—one by nature and the other by man. Just as a long run of wet years gave way to a period of prevailing deficient moisture that was to last for two decades, the end of World War II ushered in a time of tremendous growth in California's population and hillside development. Having mastered powerful new techniques for reshaping the natural terrain, man now applied them on larger and larger scales to provide ever increasing numbers of building sites above the flatlands. The combined effectiveness of bulldozers, backhoes, scrapers, carryalls, and other heavy earth-moving equipment led to substantial changes in the face of the land—as work went forward during year after year of relatively low rainfall. Only with a few heavy wintertime storms did nature give warnings that the existing set of climatic ground rules might be greatly altered for some future series of years.

It is fortunate that these occasional warnings did not go unheeded by everybody. Rainstorms during the 1951-52 season inflicted such grave local damage, especially to newly developed properties in parts of southern California, that the city of Los Angeles instituted its own set of ground rules for hillside development. Through the Grading Ordinance of 1952, specific requirements that included input of geologic data were established for certain kinds of terrain. Partly in response to observed effects of heavy rains in later years, these requirements were subsequently modified and strengthened, especially in the important fields of supervision and inspection. Other cities and several counties have followed the good example of Los Angeles



THE RELATIONSHIP OF NATURAL LANDSLIDE ACTIVITY TO RAINFALL TRENDS IN PARTS OF CALIFORNIA. *The computer-smoothed curve for Los Angeles rainfall, as plotted by students at Stanford University, shows cumulative departures from the long-term annual mean of about 15 inches. Wet and dry periods are indicated independently by the smoothed curve representing cumulative departures of annual tree-ring growth (Bigcone spruce) from a 550-year average. The frequency plot of landslide activity is based on historical data for more than 1,000 episodes of natural sliding in coastal areas of the state.*

in formulating and enforcing new grading codes, and it can be hoped that similar regulatory measures will soon spread with reasonable coordination to all populous areas in the state.

An upward swing in the cyclic moisture curve inescapably promotes higher mobility of the terrain. In some contrast to events of the past two decades, increased flood erosion and deposition, further visitations by flowing masses of debris, the appearance of many new landslides, and some reactivation of existing ones now can be expected during the next decade or so. Ground failures are certain to occur in areas where the hills have been reshaped without proper attention to topographic and geologic relationships, and stern tests will be applied to the effectiveness of grading codes developed during recent years. New scarring of slopes by gullies and slumps will reflect the delivery of mud and other debris to thousands of residential properties, hopefully on a relatively small scale for most of them.

Existing works for flood control will be severely challenged, and immediate needs for additional installations will become rather apparent. As the levels of groundwater gradually rise, a host of more subtle effects may well make an appearance. The lower parts of some cuts will begin to weep, long-dry springs will become active again, and clear streams will grace many canyons that for a long time have been occupied by no more than occasional muddy floodwaters. Where large bodies of relatively impervious fill have been placed in canyons without adequate provision for underdrainage, water may begin to surface at unlikely places above the original canyon bottoms. Seeps beneath homes and in backyards will be among the less pleasant expressions of modified circuits in movement of the augmented groundwater supply.

Thus we can look forward to some interesting and even exciting times. In appraising those happenings that will strike us as most objectionable, we should appreciate the fact that a great number of more serious problems undoubtedly will have been forestalled by established flood-control measures and grading regulations—elements of regimentation that too often have elicited grumblings and resentment from land developers, builders, and the general public. Further, we should have excellent opportunities for improving our understanding of the natural environment, as our attention is perforce drawn to the message repeatedly communicated by Caltech's late John P. Buwalda—"We must never take for granted this ground on which we live."

GEOLOGIC REPORT ON THE PROPOSED TONNER TUNNELS NOS. 1 & 2

(To the Metropolitan Water District of Southern California, November 25, 1971)

By: R. H. Jahns, V.P. Pentegoff, and
T. F. Thompson

Introduction

The two Tonner Tunnels are in the Puente Hills and will constitute parts of The Metropolitan Water District's Yorba Linda Feeder. Together with connecting pipelines they will convey water from the F. E. Weymouth Plant at La Verne to the R. B. Diemer Plant near Yorba Linda.

Tonner Tunnel No. 1 will extend from its north portal, near the intersection of the Pomona Freeway and Dudley Street, approximately 4,600 ft southward to a portal in Tonner Canyon, on the Arnold Ranch property. Tonner Tunnel No. 2 will extend approximately 18,400 ft southward from a point on the Boy Scouts of America property in Tonner Canyon to its south portal in Carbon Canyon, north of the Robert B. Diemer Filtration Plant. Both tunnels will have a finished inside diameter of 8 ft.

These tunnels will be driven entirely in sedimentary rocks of the Puente Formation. Tonner Tunnel No.1 will have more than 200 ft of cover except in the portal areas, and maximum cover will be 390 ft. Maximum cover over Tonner Tunnel No. 2 will be approximately 600 ft. Aside from the portal areas, a minimum cover of approximately 45 ft will be present where the Tunnel No. 2 alinement crosses beneath a small unnamed canyon 3,000 ft north of the south portal. About 150 ft of cover will exist at the canyon bottom at drill hole D-13T, where the tunnel changes slope.

The purpose of this report is to provide the District with geological information in arriving at an estimate of project cost. The scope and results of the District's exploration program are presented, along with our opinion of conditions to be considered in evaluating tunnel design.

Geologic Investigation and Exploration

Preliminary Investigations and Mapping

This report is based upon field investigations started in 1966 and upon compilation of geologic data by the Metropolitan Water District's geology staff. Published information was supplemented by new data derived from field mapping, core drilling, open-cut excavation, surveys of water wells and springs. It also includes information abstracted from a report by D. L. Durham and R. F. Yerkes, published in 1964 as USGS Professional Paper 420-B, *Geology and Oil Resources of the Eastern Puente Hills Area, Southern California*. The geologic data were plotted on portions of the USGS 7.5-minute San Dimas and Yorba Linda quadrangles that were enlarged to a scale of one inch equals 1,000 ft.

Borings

From February 1968 to August 1971, 14 NX and NQ core borings totaling 4,825 linear ft were drilled by Continental Drilling Company, Fred Cannon Company and Boyles Brothers Drilling Company in the exploration of the tunnel route. These borings were logged by the District's geologists and the detailed logs are appended to this report. In addition, the logs of four bucket auger holes, drilled at three portals, are included. The drill cores may be inspected at the Geology Office of the Metropolitan Water District, located at 2100 North Soto Street in Los Angeles, from 8:00 a.m. to 4:30 p.m. on regular working days during the bidding period. Core samples will be made available for testing by potential bidders.

Well and Spring Surveys

Periodic readings of water levels have been recorded for wells and the District's exploratory borings. The flows of four springs in the vicinity of Tonner Tunnel No. 1 also have been repeatedly measured. All these records have been card indexed and correlated with localities plotted on maps.

Trench Near South Portal of Tonner Tunnel No. 2

During late April 1971, an exploratory trench was cut near the proposed location for the south portal of Tonner Tunnel No. 2. The objective of the cut was to explore for evidence of faulting during Holocene (Recent) time along northern reaches of the Whittier fault zone. The cut is available for inspection.

Excavation of the trench was done with a D-7 Caterpillar tractor working southward down slope. The cut was made two tractor widths wide and ranged in depth from 5 to 25 ft. Alluvial material was exposed in the deepest part near the south end, where it is now concealed beneath backfill. The slopes are near vertical, unsupported, and stand well.

The northern end of the trench terminates with a sharp bend across the face of the break in slope. Exposed at this break in slope is a recent landslide that overlies remnants of an older slide. Here siltstone and shale have been smeared into a gouge-like material that occurs as stringers and lenses with no consistent orientation. The sandstone composing the slide mass is extremely friable and soft, but contains some hard calcareous concretions as much as 2 ft in diameter.

The trench exposure suggests that this part of the Whittier fault zone has not been active in sufficiently recent geologic time to have broken the alluvium or the landslide deposits at this locality.

Geologic Setting

The tunnels will penetrate a thick sequence of stratified marine sedimentary rocks of the Miocene Puente Formation. This formation is widely exposed in the Puente Hills, an elongate uplift bounded on the south by the Whittier fault and on the northeast by the Chino fault. In the area of the tunnels the beds dip at low to moderate angles, and some are cut by small faults. Landslides are present in the area, but penetration of landslide debris is expected only at the south portal of Tunnel No. 2.

Summary Description of Formations

Geologic units of late Miocene and younger ages are exposed within the limits of the areas shown. (As a general guide, the following hardness scale is used in this report:

Hard–very abrasive, dense rock that rings when struck with a hammer. May be broken with repeated heavy hammer blows. Grossly equivalent to Mohs hardness > 5.

Moderately hard–rock has dull ring and hammer produces minor indentations. May be broken with one sharp blow of hammer. Mohs 3–5.

Moderately soft–rock is considerably deformed when struck by hammer. May be broken in the hands, but does not crumble readily. Mohs 1–3.

Soft–material can be dug out and crumbled with fingers. Mohs <1.)

Their most pertinent features in these areas are as follows:

Alluvium (map symbol Qal)–Holocene (Recent). Light to dark brown, poorly consolidated gravel, sand, and silt. Thick layers of brown to black soil with shale chips are prominent in cultivated areas.

Fernando Formation (map symbol Tf)– Pliocene. Buff to yellow pebble to cobble conglomerate and sandstone, with thin interbeds of greenish gray micaceous siltstone. The clasts are subrounded to rounded, and consist mainly of crystalline rocks. This formation will not be penetrated by the tunnels.

Repetto Formation (map symbol Tr)–Pliocene. Light greenish gray, thinly bedded to massive micaceous siltstone, dark gray where unweathered. This rock contains numerous bedding-plane faults and is moderately jointed. The beds dip steeply, and in some places they are overturned. The Repetto Formation is present on the south side of Telegraph Canyon, and it is the unit upon which the Robert B. Diemer Filtration Plant was constructed. It will not be penetrated by the tunnels.

Puente Formation–Upper Miocene. The Puente Formation has been divided by earlier investigators into four members: Sycamore Canyon Member, Yorba Member, Soquel Member, and the basal La Vida Member.

Sycamore Canyon Member (map symbol Tpsc). Brown to gray pebble conglomerate and arkosic sandstone with lesser amount of siltstone. The conglomerate and sandstone range from soft and friable to moderately hard, depending mainly upon the degree of cementation. The rock in most outcrops is rippable.

Yorba Member (map symbol Tpy). Typically thin-bedded dark brown to gray siltstone with hackly fracture. Diatomaceous siltstone also is present, along with subordinate amounts of medium- to coarse-grained sandstone. The surface rocks are soft and rippable. Hard, gray calcareous concretions occur in the siltstone.

Soquel Member (map symbol Tps). Upper part is light gray to buff, medium-grained sandstone and pebbly conglomerate, with interbedded light gray to buff siltstone. Numerous large rounded boulders of granite and other crystalline rocks are present in some of the conglomerate. The strata range from hard and well cemented to friable.

Lower part is light gray to buff, thick-bedded to massive, medium-grained, soft to moderately hard sandstone that commonly contains hard calcareous concretions. Some interbeds of siltstone also are present. Where exposed at the surface, these rocks are weathered and rippable.

La Vida Member (map symbol Tpl). Gray to white platy siltstone and shale with white calcareous concretions. Some sandstone also is present. In outcrops the strata are soft to moderately hard and most are rippable. Where fresh and unweathered, much of the shale is medium gray, dense, hard, and relatively massive in appearance. Beds of volcanic tuff, locally altered to bentonite, occur within this member, but they have not been observed near the tunnel alinement.

Earthquake Conditions

The Tonner Tunnels are in an area of known seismicity, but the possibility of a nearby major earthquake occurring in this area during their useful life can be regarded as sufficiently remote to be disregarded in tunnel design. During historic time no fault displacement or creep has been noted in this area, although movement along the Whittier fault may have occurred during Holocene time, i.e., during approximately the past 10,000 years.

Ground-Water Conditions

Water-level measurements in test holes and wells, as well as surveys of springs, indicate that ground water is likely to be present, generally in small amounts, through much of the length of the Tonner Tunnels. Even small inflows, however, may cause running conditions in the more poorly cemented sandstone beds. Substantial quantities of drilling fluids were lost during the course of the exploratory work.

Oil and Gas

The first commercial production of oil in the Los Angeles basin was in 1885 from the Puente oil field, which is now part of the present Brea-Olinda oil field. Oil currently is being froduced in this area from the Puente and Fernando Formations.

Oil is produced south of Tonner Canyon from the Sycamore Canyon member of the Puente Formation, at depths below the proposed tunnels. Oil also is found in producible quantities in the Soquel and Yorba members, hence it is not surprising that many of the District's exploratory borings have shown traces of oil and gas. Hydrogen sulfide odors were encountered in D-5T and in an auger hole at the proposed south portal of Tonner Tunnel No. 2. Some oil-bearing strata and accompanying gas should be encountered in both Tonner Tunnels.

Geologic Conditions Anticipated in the Tunnels

General Statement

The following discussions of anticipated geologic conditions are based mainly upon the distribution and nature of rock types and structural features at the surface and in the shallow subsurface, as determined or inferred from geologic mapping and the exploratory work described earlier in this report. The predicted general behavior of these materials in the tunnels is based on previous experience of the Metropolitan Water District and other agencies.

These predictions have been derived mainly from projection of well-established surface geologic features and their geometric relationships. They should be reasonably accurate because of the rather shallow cover over most of the tunnels, but nonetheless they should not be regarded as complete or detailed.

Tonner Tunnel No. 1

Nearly all of Tonner Tunnel No. 1 will be in the Soquel member of the Puente Formation. In the tunnel, this unit can be expected to consist of gray to brown, medium-grained to pebbly, arkosic, moderately-hard to hard sandstone with interbedded softer gray to buff siltstone and thinly laminated shale. Some beds of conglomerate containing numerous large hard boulders also are present, as are intervals with large calcareous concretions. A thin bentonite bed was cored in drill hole D-lOT.

The Yorba member is present near the south portal, where only a few hundred feet of it will be penetrated by the tunnel. It is dark brown to very dark gray siltstone and platy shale with interbedded sandstone. The bedding trends essentially parallel to the tunnel alinement, and dips at moderate angles to the southeast. The attitude of bedding, however, is complicated by many small folds and crenulations.

Small faults will be crossed, but these are expected to have little effect on the tunnel. Numerous fractures and joints are associated with some of the faults and folds. Exploratory borings for this tunnel were marked by relatively low core recovery and by losses of drilling mud.

Several springs are present in the area, but their yield is small, averaging a few gallons per minute. Some small domestic wells, drilled in the alluvium, lie south of the tunnel. Only minor amounts of ground water are expected to be encountered in the tunnel.

Tonner Tunnel No. 2

The south portal of Tonner Tunnel No. 2 and most of the tunnel itself will be in the La Vida member of the Puente Formation. This member, as exposed in the borings and exploratory trench, is composed of hard gray platy siltstone and shale (some conchoidal fracture), along with hard calcareous concretions and interbeds of soft gray siltstone and sandstone. Tuff beds, some of them altered to bentonite, are present several miles west of the tunnel, and thin bentonite beds were cored in several drill holes. Thicker beds of bentonite were recorded at depths below the proposed tunnel grade from older exploration holes drilled by oil companies.

The northern part of the tunnel will be in sandstones and subordinate siltstones. Hard calcareous concretions as much as 3 ft in maximum dimension are present. The sandstones range from soft and friable to well cemented and hard.

The bedding generally strikes at a sharp angle to the tunnel alinement and dips gently to the north. Several small folds will be crossed. Exploratory borings for this tunnel were marked by relatively good core recovery but with frequent losses of drilling mud.

The Whittier fault zone will be encountered at the south portal, and the rocks are expected to be fractured in this area. The fracturing should diminish north-northward in the tunnel away from the fault. Two other faults are known near the south portal, where they have offset and tilted the beds. Such faults are not expected to be significant as structural barriers to ground water, as no springs have been found along their surface traces.

The tunnel will be wet, but no large, sustained inflows of water should be encountered. All water wells drilled in the Soquel and La Vida members have been poor producers, owing to the low permeability of the siltstone interbeds. Horizontal permeability is very high in the thick beds of poorly cemented sandstone, but availability of water to these beds is restricted by the overlying sequences of siltstone. If a large inflow is encountered, its volume can be expected to diminish rapidly with drainage of the limited reservoir in the overlying permeable strata.

Some soft sandstone beds may develop a "running-ground" condition because of their poor cementation, and some of the siltstone beds also will become very soft when wet.

Conclusions

All known geologic conditions indicate that construction of Tonner Tunnel No. 1 and Tonner Tunnel No. 2 is feasible; no major geologic problems are foreseen.

Some oil-bearing strata and accompanying gas should be encountered in both Tonner tunnels.

Ground water is likely to be present in limited amounts through much of the length of each tunnel. Inflows should not be great.

APPENDIX

METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

HOLE Nº D-1T

SUBSURFACE EXPLORATION LOG SHEET 1 OF 2

FEATURE: YORBA LINDA FEEDER
PROJECT: TONNER NO. 1 TUNNEL
LOCATION: Tres Hermanos Ranch Diamond Bar, L. A. County (See sketch on sht 2)
PROPERTY OWNER: W. Scott
DRILLING CONTRACTOR: Continental Drilling Co.
DRILLER: Art Kueser
HELPER: Jim Simmons Jr. & Sr.

HOLE LOGGED BY: Uchi
DATE BEGUN: 7/14/70, **FINISHED:** 8/7/70
DEPTH OF HOLE: 420'
GROUND ELEVATION: 1387
INVERT ELEVATION: 990
WATER DEPTH & EL: 329 on 11/18/70
DRILLING TIME (HOURS): 21
TOTAL RECOVERY: 73 %

DEPTH	DRILLING RATE (FEET/HOUR) 0 10 20 30 40	LOG	SIZE OF CORE & CASING	CORE REC. %	COLOR	PERMANENT CASING	DESCRIPTION AND REMARKS
0			4' of 10" Rock bit	No core taken	brn	4' of 4½" casing @ surface	0'-2' Soil, brn, sandy silt, scattered pebbles.
20				50, 7, 30, 7			2'-420' Puente fm. Weathered to 175'.
40				0, 5, 60, 77			2'-40' Conglomerate, pebbly sandstone, sandstone, and few thin shales. Tan, generally soft and weakly cemented to occas. hard, w/fair cementation. Fair to mostly poor bedding. Generally sandstone readily washed out by drilling fluid and minor cavings thruout. No mud returns. Occas. bouldery conglomerate, w/size up to 20" in diameter.
60				100, 70, 87, 91			
80				87, 71, 64, 73			
100			3" Casing to 330'	17, 29		360' - 2" PVC pipe placed	
120			N WIRE LINE DIA.	6, 6	Rusty tan		40'-196' Shale, sandstone, conglomerate, and limestone. Tan and rusty to 175'. Soft to mostly hard. General good cementation w/lime. Few bouldery conglomerates w/sizes up to 20" in dia. Poor to good bedding, dipping 13° -14°. Mod. jointed and zones of close to fine fractures. Firm from 190', except for parting of shale. No mud returns. Complete loss of mud from 58'.
140				13, 15			
160				55, 40, 23			
180				43, 40			
200				93, 97			
220				82, 47	Brn & light gray		196'-329' Mudstone, sandstone, & limestone. Mostly soft to occas. hard. Generally very thin bedded or laminated. Beds dip 13°-14°. Sli. jointed and generally sli. fractured. Firm. (Lack of core recovery from 238' to 278' due to non-seating of core tube in barrel.) No mud returns.
240				92, 1			
260				2, 2			
280				0			

LOG SYMBOLS: GRANITE, GNEISS, DIORITE, VOLCANICS, CONGLOMERATE, SANDSTONE, SHALE OR SILTSTONE

EX CORE = ⅞"
BX CORE = 1⅝"
NX CORE = 2⅛"

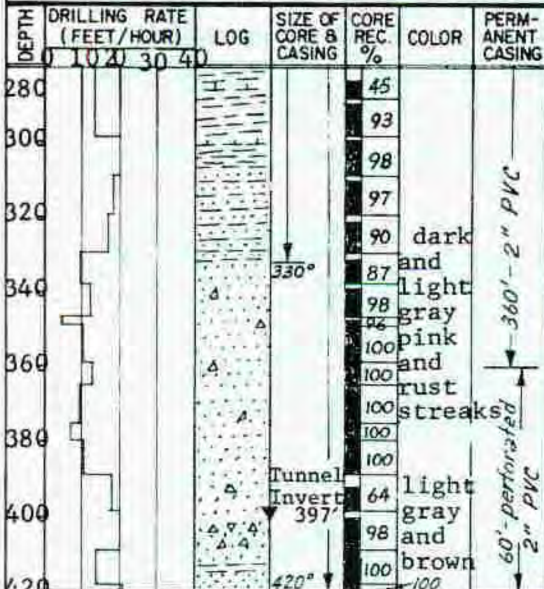
APPENDIX, continued

METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

HOLE Nº D-1T
SHEET 2 OF 2

SUBSURFACE EXPLORATION LOG

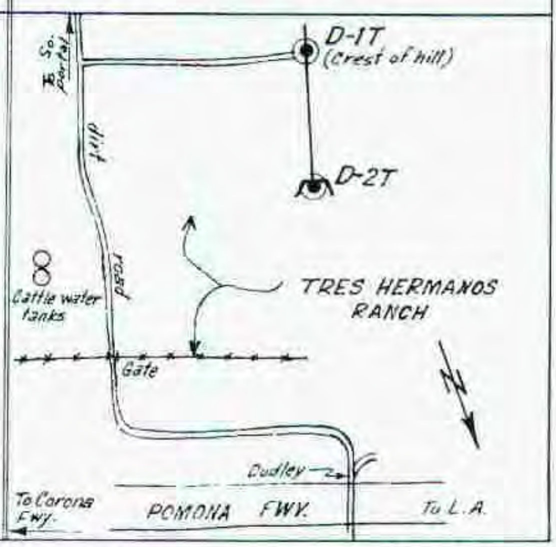
FEATURE: YORBA LINDA FEEDER	HOLE LOGGED BY: Uchi
PROJECT: TONNER NO. 1 TUNNEL	DATE BEGUN: 7/14/70, FINISHED: 8/7/70
LOCATION: *See below*	
PROPERTY OWNER:	DEPTH OF HOLE: 420
	GROUND ELEVATION: 1387
DRILLING CONTRACTOR: *Continental*	INVERT ELEVATION: 990
	WATER DEPTH & EL: 329 on/11/18/70
DRILLER:	DRILLING TIME (HOURS):
HELPER:	TOTAL RECOVERY: 73 %



DESCRIPTION AND REMARKS

329^{8}'-394^{2}' Sandstone
hard and occas. soft and crumbly. Very closely fractured thruout. Generally firm, except for occas. minor cavings.
Numerous rust-coated fractures and small zone of recemented fractures.
No mud returns.

394^{2}-420^{2} Sandstone and shale, mostly hard. Sedimentary breccia, fractured to 404^{2}. Firm.
No mud returns.
Completion: Set 60 ft. of perforated 2-in. plastic tubing and 360 ft. of blank 2-in. plastic tubing. Set and cemented 4½ ft. of 4½" surface csg. w/threaded cap.



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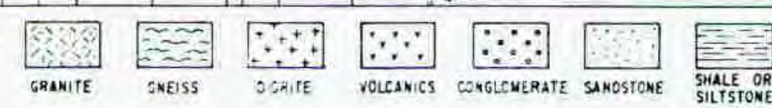

EX CORE = ⅞"
BX CORE = 1⅝"
NX CORE = 2⅛"

THE ROLE OF GEOLOGY IN URBAN PLANNING AND HOW BEST TO ENSURE ITS USE

Authors' Note: An insight into Dick's clear manner of thinking and expressing himself may be obtained by excerpting parts of a *Symposium on Engineering Geology in the Urban Environment*, which was sponsored by AEG at the 1969 Annual Meeting in San Francisco. The proceedings were transcribed and published (1971) cooperatively by the U. S. Geological Survey under the title *Environmental Planning and Geology*. Dick was moderator for the panel.

Moderator: Richard H. Jahns, Dean,
School of Earth Sciences
Stanford University

Panelists: James H. Hickey,
Planning Director,
Association of Bay City Governments,
Berkeley, California

Hon. Alfred E. Alquist, Senator
Sacramento, California

Rosemary Duggin,
Planner,
U.S. Department of Housing and Urban Development,
San Francisco, California

Karl V. Steinbrugge,
Structural Engineer,
Pacific Fire Rating Bureau,
San Francisco, California

Daniel B. Luten,
Professor of Geography,
University of California,
Berkeley, California

JAHNS: Let's hear briefly from Professor Luten.

LUTEN: I am here today as a substitute for a practicing conservationist, so I shall speak up for conservation. I could speak against it, for I think it gets confused at times, but I'd rather speak for it and I shall.

I spoke recently on population to a seminar of graduate students at Berkeley who professed concern for the environment. They asked me what they as economists could do. I suggested the most useful contribubution they could make would be to work out the conditions under which an economy with zero growth could operate. I could see, feel, almost hear them drop out. Only then did I realize what an emotional hang-up economists have on growth. I find, as a matter of fact, whenever I talk about conservation with economists, foresters, or engineers that they get so emotional we really can't carry on much of a discussion. Geologists, though, have always been "real cool," so don't get emotional about what I have to say now.

It's very simple, and I won't detail it: *You are not solving problems; you are part of the disaster*. You are tools of the developers and of a society which is guided by inertia, not by foresight.

In the 19th Century it was said that California would never amount to much because the earthquake hazard was so great that the region was not really habitable. However, the State has grown almost like clockwork for a century, doubling its population every 18 years, increasing 32-fold in one century. We know this rate will not continue because, if it did so, California would contain a billion people in another century. Since the same forecasting technique suggests a billion people for all of the United States, we would have to believe that all Americans would live in California, which seems unlikely.

I have a clipping here, really a profound statement on planning, by Reinhold Knudsen, the Editor of the San Juan Record, a small paper of Fair Oaks, California. It is just as subversive as my own sentiments above. It says, "It was in the year 2000 that John Kiddem, the last surviving member of the public relations firm of Hoodwink, Kiddem and Fabricate, on his deathbed revealed the true story of how California became the Union's most peaceful, happy state. As Kiddem tells it in his own memoirs, it appears that some time in the late 1960's, a far-sighted group, recognizing the dangers of over-population, hired his firm to conduct a program of negative selling for the state. A secret but ample budget was provided with no holds barred. With pardonable pride, Kiddem then related the actions which were instituted. First, by adroit behind-the-scenes work, riots were fomented which ripped the state, starting with the Watts riot which was nationally publicized by television. Next, because the state attracted many students, a successful campaign was launched to raise tuition and fees. When this appeared too slow, riots in schools were instigated. School budgets were pared. Third, Ronald Reagan was elected governor and promptly instituted a hard line on medical care and welfare which discouraged immigration of low-income people." (By the way, California's growth rate has fallen dramatically in the last 3 or 4 years and is now little higher than that of the nation as a whole.) "Fourth, the State Highway Division cooperated by running huge freeways through subdivisions or tourist attractions such as redwood forests. Other roads were lined with signboards to hide the scenery. All advocates of beautification projects were either suppressed or bought off. Fifth, a massive publicity campaign was waged on the growing smog menace, with emphasis on smog deaths. Sixth, disasters. Kiddem would not admit that the great Bel Air Canyon fires were actually set or that the Baldwin Dam failure was contrived. Seventh, much was made of immorality and licentiousness. 'Haight-Ashbury was all my thing,' said Kidden, 'Wasn't it great?' The master stroke was accomplished with the great earthquake scare of 1969, when an authoritative book was published saying that the state was certain to split in half. Despite this, California's beautiful coastline continued to attract immigrants until a skin diver was hired to quietly uncork an oil well off Santa Barbara. All added together, it worked. By the year 2000, only a few fatalistic souls were left in the remaining half of the state. They lived in peaceful, happy contentment, contributing liberally to a chamber of non-commerce dedicated to the joys of non-growth. Kiddem's portrait now hangs in the capitol building to be viewed by school children. If any."

Last night at another meeting, Kingsley Davis, one of the very best of demographers, said, "The higher the level of living, the lower the level of living. The smog control device which adds to the cost of your car also increases the Gross National Product and is counted as an increment to your level of living."

Similarly, *a great deal of what you engineering geologists do only mitigates activities which should never have occurred*, including the bringing of 20 million people into California. You have shown them how to build on faults, on deep alluvium in earthquake regions, on insecure hillsides, and on flood plains, and you have encouraged them to subdivide some of the best croplands of the world. From here on in, every time you tell them how to do something that should never be done, preface your report with a statement that you are working for the devil, not the angels.

But, in conclusion, I can't find it in me to blame you, or us, too much for the past. We always learn these things too late. Still, when we do learn them, let us begin to drag our feet. Pogo Possum has the final word on this matter, as on some others, with his, "We have met the enemy and he is us."

JAHNS: Thank you very much–I think.

HICKEY: I think Senator Alquist had an important message for the geologist along the same line; if you are going to excite the public interest in geology, you must change the form in which your data are packaged for presentation. Perhaps you should do away with picks, shovels, and field geologists in pictures to show scale and go to something a little more glamorous.

JAHNS: Let us open the session now for questions from the floor. I would like to emphasize that each questioner must identify himself, and if at all possible, indicate which of the panelists–one or more–he would like to have respond to the question.

CARL WENTWORTH–U.S. Geological Survey, Menlo Park: One facet of the communications gap between geologists and engineers involves the question of risk, a question which Karl Steinbrugge has mentioned. Determination of risk requires identification of geologic problems and their charac- teristics, determination of the effect of these processes on engineering structures, and evaluation of the consequences of any damage. I ask the panel: How do we obtain explicit consideration of risk by engineers and geologists? Who is to decide what the risk is, and whether or not to accept it?

JAHNS: There is nothing like having one of the most fundamental questions possible posed right away. Who would like to take a crack at that one? Karl, your name was mentioned in the question.

STEINBRUGGE: You mean I volunteered to answer? I think that many of you in the audience were present at my seminar at the USGS. There you heard me talk about 1-1/2 hours, during which time I evaded the answer. So we can continue from there. There are problems before us for which there are no obvious solutions, and indeed can be no precise solutions. The term "risk" has many meanings to many people. During the coming spring, I believe one engineering organization is to devote a day to a discussion of what we mean by the word "risk." The meaning can relate to life safety or it can relate to property damage. In some respects our building codes take poor care of it.

For example, codes allow unlimited property damage as long as people in the buildings are safe. I'm not sure the public always knows that. I am not sure that these standards should necessarily apply to public buildings. Perhaps a private owner can take the risk, but should it be true of a public building, such as a place of public assembly? In other words, the answer to the question of risk may not be solely in the hands of the geologist or engineer. Perhaps the decision belongs partly to the planner, and eventually to men such as Senator Alquist who must pass the laws necessary to implement public thinking. I think it is an interdisciplinary problem. I welcome more discussion on what is meant by "risk" and also on the subject of what input each of us contributes and what output we should receive. What is life worth? We don't like to face that question, but we face it every day on the freeway. How much do we spend on freeway safety? How much should we spend on building safety? There are limits to what we can do. I think the question is fundamental and should be faced more realistically, on an interdisciplinary basis.

HICKEY: I think another dimension to the problem is that in government you are dealing with a very holy commodity–private property–and you can't arbitrarily decide that a certain piece of property is a poor risk, because you may find yourself in a lawsuit, with the owner saying, "what is a poor risk?" We found this out with soil surveys. What's poor, what's good, what's fair, isn't accurate enough. There must be a more definable dimension to such terms if they are to be used as part of local development controls. *Since geologists, like attorneys, reserve the right to argue both sides of a question*, it is not unusual to find a property owner with his geologist and the city with its geologist, the two polarized in their opinions as to adequacy or inadequacy of the property for a particular use.

LUTEN: May I describe a similar situation. During consideration of the Bodega Bay nuclear power plant, there was quite a flap over the magnitude of hazard from an earthquake fault running under the site. Some geologists afterward reported to me that they felt estimates of the hazard were quite concordant. Two groups had studied the site. One opposed Pacific Gas and Electric's proposal, while the other was for it. The former suggested one chance in 500 of a disaster during the life of the plant, the latter suggested only one chance in 2,000. This was only a four-fold difference and, for such a problem, pretty good agreement. I don't know how they could have figured the risk at all, but I suspect that each side concluded that there wasn't one chance in a thousand of a disaster. Then the pessimists multiplied the risk by two and the optimists divided it by two.

JAHNS: That may not be entirely correct, but you are probably on the right track. If I could put in my two-cent's worth here, it seems to me it is very important to distinguish between two related but basically different kinds of questions. First is the matter of appraising risk per se, which is difficult at best and which can precipitate legitimate disagreements because matters of judgment are involved. The other question is one that is rarely asked directly–that of how much risk we are willing to assume in a given project? This one is incredibly difficult, because the proper answer involves not just geology, engineering, and other technical areas, but also financial and political factors and the appraisal of social losses and gains. Even when the issue has been faced up to, complete and objective analyses rarely have followed–a condition that underlies many of the controversial problems of the past decade or two.

JOHN W. ROLD–State Geologist and Director, Colorado Geological Survey: I have two questions. One, for any member of the panel, concerns the mechanism by which we, the geologists, can best communicate with the planners, not only to educate them as to our abilities and services and the science of geology, but also to find out what we need to know from planners. The second question, for Senator Alquist, is: If we are able to achieve this utopia, how can we sell it to the legislators and people so that the concepts can be utilized?

JAHNS: Miss Duggin, the first part of this question should be right down your alley, judging from some of your remarks. Would you like to try to answer it before we nail Senator Alquist?

DUGGIN: I feel there has to be a simultaneous effort, at the technical level where the staff people can communicate with each other, and at the political level. *Ultimately, no matter how well technical people understand each other, the decisions are made by political people.* Some of us who have served with local planning commissions or other local agencies frequently find that no matter how good our technical arguments are they do not always sell well with political people.

JAHNS: It really is most unfortunate that when a group like this gets together–a group that represents a wide spectrum of interest and competence and is very responsive to comments and questions–there is never enough time to pry into the possibilities opened up by the dialogue. This morning is no exception. I think we will bypass any attempt to summarize what has happened during this session, because we are running too late. I'd like to close, though, by expressing thanks–and I am sure I express yours also–to the four speakers and to all members of our panel.

GEOLOGIC HAZARDS, ASSOCIATED RISK, AND THE DECISION–MAKING PROCESS

Dr. Richard H. Jahns

Dean, School of Earth Sciences
Stanford University
Stanford, California

Introduction

For this Conference on Earthquake Risk, Karl Steinbrugge has suggested a general theme addressed to a rather formidable question. How much risk can be accepted? Or, perhaps better put, how much risk should be tolerated? This non-trivial question assuredly is worthy of closer attention and more satisfactory answers than it has elicited to date, but we can agree that it means little unless we specify the particular kind of risk to be considered. Thus a given risk level for property damage is one thing, but the same level for loss of life is quite another. And, practically to determine what level may exist in a given situation, it is essential to know whence the risk derives—as from surface faulting or ground cracking, from a debris avalanche or a tsunami, or from dam failure or collapse of buildings.

I suggest that any effective approach to the general problem of seismic events, as they relate to man and his works, must involve a sequence of four operational steps. The first two steps focus upon geologic hazards, and the others deal with associated risks. For purposes of discussion here, a geologic hazard can be regarded as any set of features and conditions that embodies danger or jeopardy; in effect, it provides a potential for damaging or otherwise undesirable occurrences, in this instance related to earthquakes. If such a potential for unpleasantness exists, it can be examined in terms of probability or degree of risk, and it is in this sense that I would prefer to regard risk as a parameter associated with a given geologic hazard.

The four suggested steps can be outlined as follows:

1. *Recognition* of a (seismically-related) geologic hazard at a given locality or in a given area.
2. *Characterization* of the hazard on the basis of appropriate kinds of study.
3. *Evaluation of risk* associated with the hazard.
4. *Judgment of tolerable risk* in terms of all significant factors at the locality or in the area.

As I have remarked on other occasions, these steps are logical and in large part self-evident, yet they have been too often confused with one another, negotiated incompletely or in improper sequence, attempted by unqualified people, or overlooked entirely. Our record of performance in this area is something less than brilliant, and as a result we have witnessed too many misfortunes that could have been mitigated, too much destruction that could have been diminished. This is not to deny an impressive record of accomplishment in dealing with some of California's challenging physical conditions, but it must be admitted that we could have done better.

To illustrate this important point as a possible guide for the future, a few pertinent examples of disasters can be cited here. Some of these events were related to earthquakes and others were not. Some of them date from long ago, others are of recent vintage, and still others haven't even happened yet. All, however, share a common base in that they can be usefully considered in the light of the four-step approach outlined above.

Dams

The first example, the St. Francis Dam in Los Angeles County, is now a bit of ancient history but its collapse still ranks as California's second greatest disaster in terms of life loss. This massive, moderately curved gravity structure (Figure 1) was built across a narrow part of San Francisquito Canyon in the mid-twenties, and the reservoir behind it was filled for the first time on March 7, 1928. The dam failed abruptly near midnight on March 12, releasing approximately 38,000 acre feet of water as a short-lived but catastrophic flood. Numerous investigating experts subsequently agreed that the dam itself had been soundly designed and constructed, and that the failure was due to poor foundation conditions.

That potentially dangerous ground conditions should have been overlooked is more easily understood than excused, for this project was conducted without benefit of professional geologic examination or advice. Thus there was

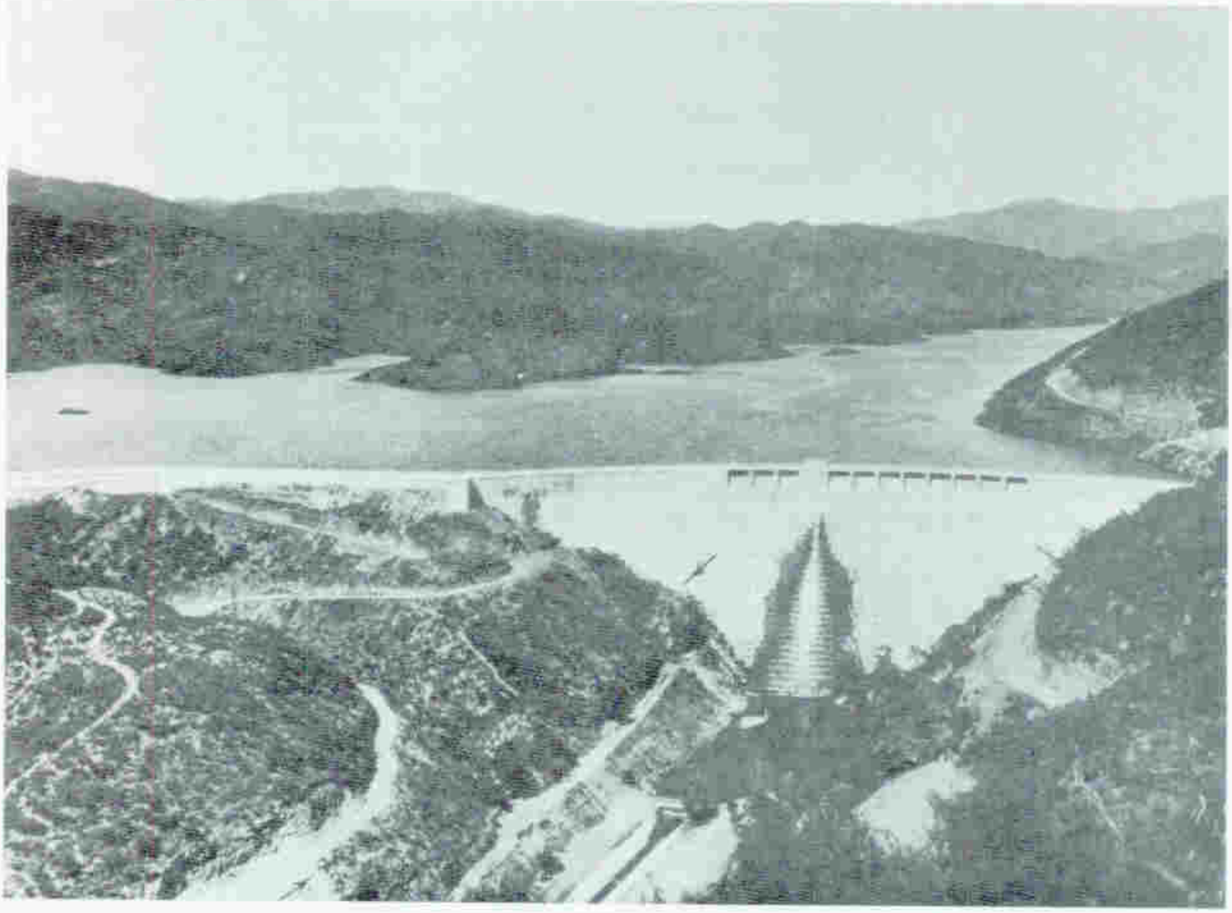

Figure 1. The St. Francis Dam, shortly before its collapse on March 12, 1928. In this upstream (northward) view, the surface trace of a major fault (between arrows) can be seen on the left-hand wall of the canyon above the lower road-bench.

a complete bypassing of all four of the determinative steps I have outlined. No geologic hazard was recognized or evaluated, and therefore no appraisal of related risk could have been made. Small wonder that the project has been cited as a textbook example of what can happen when even a good engineer doesn't consult even a mediocre geologist! It is only fair to add that geologists have since disagreed concerning details of why the St. Francis Dam collapsed, but nonetheless there is general accord in the view that collapse was inevitable under the circumstances.

What were the circumstances at a site that seemingly was so attractive for a major engineering project? The westerly part of the dam and its appended wing wall (Figure 1) were founded upon a section of poorly to moderately well cemented conglomerate and arkosic sandstone, some of which proved to have little strength when saturated with water. The central and easterly parts of the dam were built on much harder rock, a quartz-mica schist, but along the steep easterly wall of the canyon a combination of topography, rock weathering, and attitude of well-defined schistosity proved to be highly effective for the promotion of large-scale ground failure. Indeed, several landslide masses already were present as recognizable features in the site area at the time of construction.

To the mixed bag of potential hazards can be added a major fault, along which the schist and the sedimentary strata are juxtaposed. In this sense the dam, which was built across the fault (Figures 1, 2), could be likened to some of the more recent projects discussed at the present conference. The risk of possible surface ground displacement along the fault at the site actually is vanishingly small, as this break has not moved during the past 15 million years or so, but such assurance was neither sought nor received by the builders of the dam. It has since become common practice to raise questions about surface faulting whenever major structures are to be built in California, but this was scarcely thought of half a century ago.

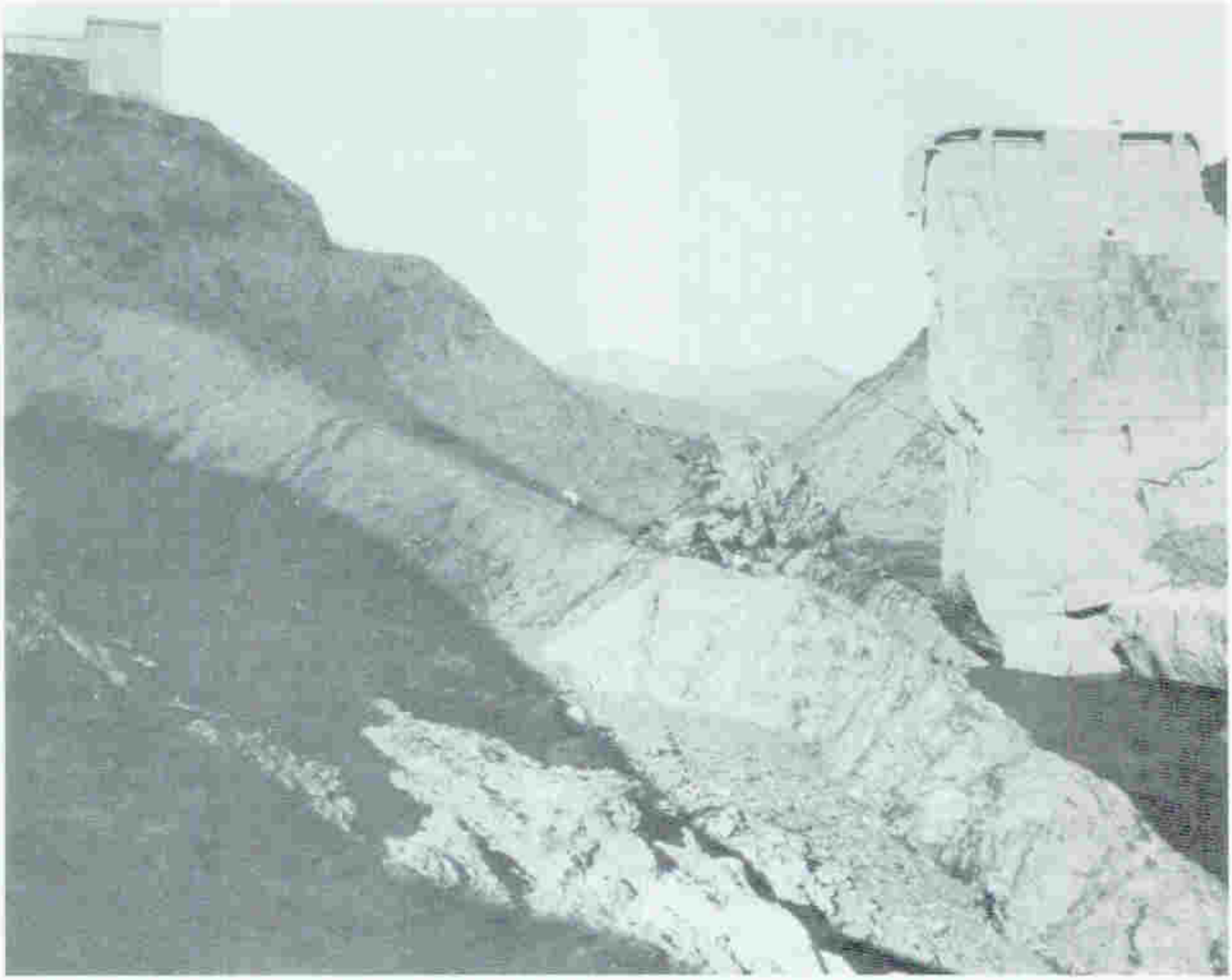

Figure 2. A much clearer exposure of the fault and associated crushed and sheared rocks that lay beneath a part of the St. Francis Dam. Along this slope, scoured by floodwaters rapidly escaping from the reservoir, reddish brown conglomerate (dark) overlies quartz-mica schist (light) along the west-dipping fault. The large standing residuum of the dam, founded upon schist, originally formed the central part of the structure (cf. Fig. 1).

Quite apart from the favorable circumstance of long-time inactivity, the ancient fault movements in the damsite area left a strong imprint on the rocks immediately adjoining the main break (Figure 2). These rocks are highly broken and sheared, and in places they have been ground to the proverbial pulp. As such, they were something less than satisfactory foundation materials for a dam of the design adopted at this site. Whether or not failure of the dam was initiated by a large landslide at its easterly abutment (Figure 3), as seems likely, much of the ultimate collapse can be attributed to piping in relatively weak materials beneath its westerly parts. The severely disturbed rocks along the fault zone are particularly suspect on this score.

A much more recent occurrence of piping led to failure of the Baldwin Hills Dam in Los Angeles on December 14, 1963 (Figure 4), but this case differed in several important respects from the one just described. Breaching of the earth-fill structure fortunately occurred in the daytime, more than three hours after its imminence was recognized, and nearly all of the people in the path of the flood were warned of the impending catastrophe. Five lives nonetheless were lost, and more than $15 million in property damage was incurred. Destruction of the dam was essentially a surprise to everyone, for it had been built only after careful consideration of existing ground conditions. And, sited as it was in a metropolitan area, it was specially designed relative to potential reservoir leakage and strong seismic shaking. It was thought that all hazards had been identified and characterized, and a final judgment of no undue risk had been made prior to the start of construction in January 1947.

Figure 3. Broad scar of the main landslide at the easterly end of the St. Francis Dam. Here an enormous mass of bedrock (quartz-mica schist) moved downward and westward, in part against the dam, and most of it was carried away by floodwaters when the dam collapsed. The central mass of the structure remained standing, but lay out of view to the left when this photograph was taken in 1928.

Figure 4. Vertical view of the empty Baldwin Hills Reservoir after breaching of the dam on December 14, 1963. The rapidly escaping reservoir waters created havoc in a thickly settled area of more than five square miles beyond the upper edge of this view. Pacific Air Industries photo.

Yet the disaster occurred, nearly seventeen years later and in a manner that seems obvious only in retrospect. The dam and reservoir lay within but near the edge of an area in which many small surface ruptures and other expressions of gradual ground subsidence are associated with the Inglewood zone of folds, faults, and oil production. The ground beneath the reservoir is traversed by several minor faults, and progressive movements, evidently not accompanied by earthquakes, occurred along at least two of these breaks after the facility was built. The movements resulted in fissuring and small vertical displacements beneath the reservoir, and in some cracking of the paved reservoir floor. There was little observable indication, however, of the erosion that must have been occurring in the relatively soft foundation materials as leaking reservoir waters coursed through them along the opening breaks. Ultimately collapse occurred along the break that lay beneath the dam, and notch-like failure of the dam quickly followed (Figure 4).

Whether the minor but important movements along the existing ground breaks resulted from nearby extraction of petroleum fluids from the subsurface, from the pumping of water into the subsurface to promote additional recovery of oil, or from tectonic causes, they occurred essentially without detection. The possibility of such movements may well have been considered, but it seems evident that their potential effects were not properly characterized for purposes of design. Ironically, the ground displacements ruptured and blocked a drainage system that otherwise would have provided an indication of serious leakage, and hence of their existence beneath the dam and reservoir floor. Thus, in the clear vision of hindsight, it was not possible accurately to appraise the degree of risk in this case because the hazards were incompletely defined.

The San Fernando earthquake of February 9, 1971, provoked a still different kind of dam distress that is of special interest in the context of hazard and risk. The Upper and Lower Van Norman Reservoirs, in the northern San Fernando Valley (Figure 5), lay behind two relatively old earth dams that had been constructed mainly by hydraulic-fill methods. Under the influence of intense ground motion that accompanied the earthquake, a considerable part of the upper dam was displaced about five feet in a downstream direction, and the crest settled as much as three feet. No water was released from the reservoir, a matter of great good fortune.

The much larger Lower Van Norman Dam was more severely damaged, as a section of this embankment about 1800 feet long slid into the reservoir. The detached mass included much of the dam crest, and the effective height of the part of the embankment that remained in place was less than five feet above the then-existing reservoir level (Figure 6). The waters were retained behind the partly collapsed structure, but further attrition of the embankment or addition of water from failure of the upper dam would have brought catastrophe to a residential area of some 80,000 people on nearby parts of the valley floor. The danger from

Figure 5. The Lower Van Norman Reservoir (center) and smaller Upper Van Norman Reservoir (right) in the northern San Fernando Valley, as they appeared in 1950 before nearly all of the downstream area at left had been developed for residential purposes. Rupture and gross displacements occurred in both of the dams during the San Fernando earthquake of February 9, 1971, endangering tens of thousands of people in the thickly settled downstream area. Pacific Air Industries photograph.

strong earthquake aftershocks was particularly acute on this score, but it was soon removed by emergency actions that included draining of the reservoir.

The lower dam was built during the period 1912–1915, and in subsequent years it was enlarged by several major additions of fill. The smaller upper dam was built in 1921 and 1922. Even 50 years ago, numerous faults had been identified and mapped in this region, but relatively little was then known about the distribution and nature of geologically young breaks in the ground that occupies much of the view in Figure 5. Nor were accurate appraisals of local seismicity then available. To be sure, the region was recognized as one of seismic activity, but the San Fernando earthquake nonetheless came much later as an instructive surprise to geologists, geophysicists, and engineers alike. That much of what it revealed about fault activity, ground accelerations, and structural damage was new information is partly attributable to the limited number of strong earthquakes that have occurred in populated areas of California. No two have been exactly alike.

Design of the Van Norman Dams was by no means as seismically resistant as that of the Baldwin Hills Dam or many other younger structures. Whether or not it might have been based on an evaluation of seismic risk prior to construction, complete identification and appraisal of related geologic hazards could not have been made at that time. Among the factors missing from the first two steps of the evaluative procedure were an active fault at the site of

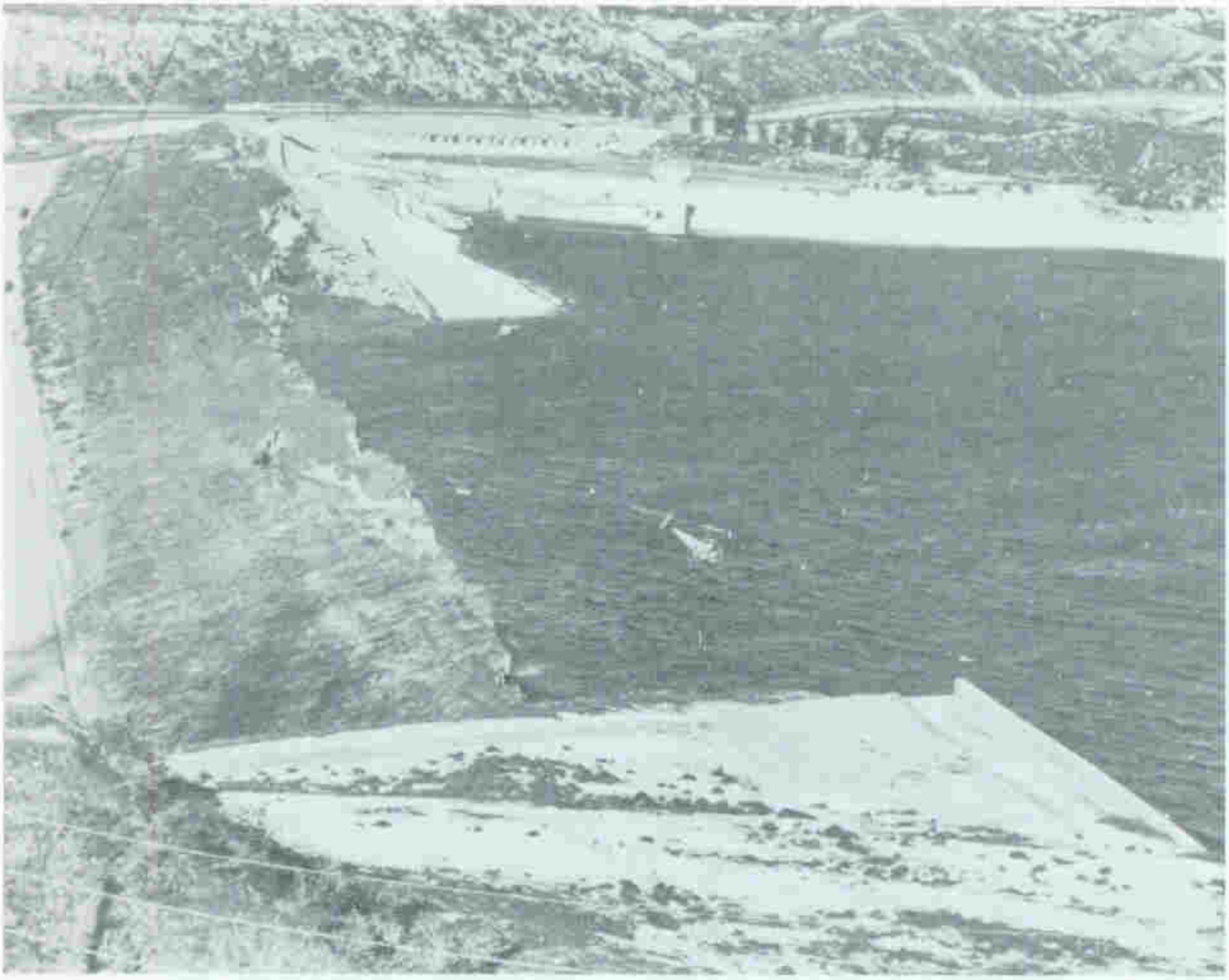

Figure 6. The Lower Van Norman Dam after partial collapse from strong seismic shaking on February 9, 1971. A large portion of the structure has been displaced downward into the reservoir area. Photograph courtesy of Gordon B. Oakeshott, California Division of Mines and Geology.

the lower dam and the high intensity of ground shaking that could accompany an earthquake in this area. In later detailed appraisals of seismic response, the structures were judged to be safe by experts in this field, yet liquefaction of embankment materials led to unsatisfactory performances in 1971. As a case history of great financial loss and grave danger to the lives of many people, the Van Norman Dams thus provide another strong argument for extensive exploration and detailed analysis of ground conditions and probable ground behavior prior to design and construction of major engineering works that affect public safety. Admittedly, this is a lesson more easily learned in principle than applied in practice.

Floods and Debris Flows

Damaging floods have occurred repeatedly in settled parts of California, and some truly spectacular visitations of water have been recorded in historic times. Contrasting combinations of topographic and climatic conditions have led to corresponding variations in the pattern of flood inundation, accelerated erosion, and deposition of debris, but the pattern is relatively well understood in general terms. Owing to observations of flood behavior over a period of many decades, most kinds of associated hazards have been recognized, characterized, and correlated with specific areas, localities, and human developments that affect surface runoff.

Present capability for certain kinds of short-term flood prediction and appraisal of attendant risks derives from analyses of observational factors such as unusually heavy snow packs in mountain areas, periods of unseasonably warm or cold weather, and storms accompanied by exceptional contributions of rainfall. Longer-term risks can be reasonably estimated on statistical bases, either from available records of flood-producing climatic factors or from records of the floods themselves. The recurrence intervals for most potentially damaging events are relatively short, and even the infrequent great storm, with its prompt torrential runoff, can be incorporated into a statistical appraisal of probable occurrence. From such appraisals have emerged concepts of probability-based events like the "ten-year flood," the "hundred-year flood," and the "maximum credible flood," all of which have been useful in considering how much risk should be tolerated in terms of economic, political, and other factors. Judgments of this nature have been effectively translated into the design of flood-control works in many populated areas. Even though the problem of recurring floods is made acute by rapid population growth and inherited patterns of settlement, it has become increasingly understood in terms of hazard and risk.

A more difficult kind of challenge is presented by debris flows, which are moving mixtures of water, air, and solid material ranging from slurries of mud to extraordinarily coarse, bouldery fluosolids. These heavy flows are more localized and less frequent in occurrence than ordinary flood runoff, and they generally move more slowly. They can be devastating in their effects, however, as they clog canals and drainage facilities, occupy buildings, yards, streets, and swimming pools, and carry away heavy objects that lie in their paths.

A coarse debris-flow deposit of considerable historic interest is shown in Figure 7. This huge slug of boulders, blocks, broken trees, and finer-grained detritus moved down a steep slope in the western San Gabriel Mountains and came to rest at Opids Camp during a period of only a few minutes on April 4, 1926. The accumulation, nearly the size of a football field and about 40 feet in maximum thickness, resulted from one of California's greatest historic cloudbursts. As a special feature of a week-long storm that brought approximately 25 inches of rainfall to an area centered about San Gabriel Peak, 1.02 inches of rain fell in one minute and another inch in the following two minutes. This extremely intense precipitation quickly detached and removed an enormous amount of solid materials from the mountain slopes, and the water combined with these materials to form impressive debris flows.

Figure 7. Rampart-like accumulation of boulders, broken trees, and finer-grained debris at Opids Camp in the San Gabriel Mountains. This deposit, here 40 feet thick, represents a slurry of Cyclopean proportions that moved down an adjacent mountain slope during a cloudburst on April 4, 1926.

Even though the Opids Camp occurrence might appear to have been an almost unique historic event, it must be reckoned as geologically ordinary in California. The very alluvial fans on which so much population is now concentrated consist in large part of debris-flow deposits, and hence represent a long period of rather violent constructional events. The building of fans still continues in episodic fashion, as could be attested, for example, by residents of the Montrose-La Crescenta area in 1934, the Wrightwood area in 1941, and the Santa Barbara-Carpinteria area as recently as December 1971. Nor have significant historic effects been confined to settled areas, to judge from a long record of damage to railroads, highways, pipelines, and aqueducts. The new California Aqueduct already has been invaded by several debris flows along the westerly margin of the San Joaquin Valley.

Hazards related to movements of debris have been widely recognized only in recent years, and certainly such recognition has followed rather than preceded most of the urban settlement in the state. The common placement of buildings and other works of man in logical paths of natural slurries has been particularly unfortunate because the hazards are so easily identified and characterized on the basis of topography, climatic factors, and potential sources of debris. They are more difficult to evaluate in terms of risk, but considerable progress is being made in this area. Increasing numbers of high-risk localities have been formally noted, and many of them are now at least partially protected by debris basins and other control works. In some urbanized regions where reshaping of hillside topography by man can increase the probability of damaging debris flows, strict grading ordinances have been enacted to regulate such risk-producing activities. In the meantime, however, judgments of acceptable risk continue to lie beyond the resources available for acting upon such judgments, in large part because high levels of risk exposure have long existed in many settled areas.

Landslides

The potential for landsliding in California has prompted a remarkably wide variety of human responses in the context of hazard and risk. These range from numerous expressions of total ignorance about unstable ground to the penetrating studies that now precede some hillside grading or the siting and design of dams, power plants, and other major structures. Among a host of examples that could be noted, let us first examine the situation in which landslide hazard may be recognized as a possibility but is thereupon dismissed from further consideration. This "no-response" approach, commonly followed in highway design and construction, deliberately by-passes all steps in the investigation of hazard and risk. In effect, it represents a judgment that the level of landslide risk, whatever it might be, is sufficiently low to be ignored in the face of possible results from ground failure. If failure does occur (Figure 8), the situation is corrected as essentially a maintenance operation. This approach has been rather effective in economic terms and it commonly has embodied a few disadvantages beyond temporary inconvenience, yet the trade-offs have not been uniformly favorable.

practical terms. For an increasing number of major projects, the older approach has been abandoned in favor of one comprising a sequence of investigative steps, and in most cases the complexity and cost of geologic studies and risk evaluation have proved to be surprisingly small relative to the benefits obtained.

A wholly different kind of problem exists in countless localities where hazard is obvious, either from casual inspection or from the historic record. The man who lives on a river flood-plain, for example, clearly is exposing himself to a high degree of risk. He may be unaware of this risk until his property is inundated, or he may have considered the record of past inundations and judged the risk to be acceptable. The citizen who resides on a well-known land-

Figure 8. Toe of a landslide that moved across the roadway during construction of Interstate 280 west of Los Altos Hills in November 1967.

slide or at the edge of a cliff may have made a similar judgment, or he may remain happily ignorant of risk until the landslide is reactivated or a large section of the cliff falls away. Episodic cliff recession along the California coastline, generally attending storm-wave erosion and ground failure of various kinds, is a fact of life that hardly can be ignored, and serious encroachments on developed land can occur even at localities now protected from direct wave action (Figure 9). Confronted with progressive reduction in yard space and house support over long periods of time, many cliff-rim residents of Pacific Palisades and other communities assuredly have been provided with the necessary data

Not all of the failures have been little ones, nor have all of them occurred early enough to be handily corrected prior to project completion. Economic losses have been objectionably high in a growing number of situations where enormous amounts of clean-up work have been needed, where traffic or utility service has been endangered, where failure has occurred repeatedly, or where major redesign or relocations of alinement have been required. In some cases there has been serious jeopardy of life as well. With the proliferation of such experiences among projects of larger and larger dimensions, the wisdom of an early examination and appraisal of hazard has been well demonstrated in for judgment of tolerable risk. In few places can the shape of the future be so clearly defined.

Now let us consider situations that are somewhat less well defined, perhaps obvious to a geologist but not to a house builder or resident. Typical among these is the currently inactive landslide, of which there are thousands in California. As an example, the ground shown in Figure 10 forms part of a large landslide complex near Portola Valley, where failure first occurred in 1890. Despite published accounts of this and subsequent gross movements, no person involved in recent land development appears to have been aware of the hazard and associated risk until 1967, when a part of the slide complex was reactivated. This points up the need for improved communication of existing data, as it is particularly tragic when risk goes unrecognized in the presence of known hazards.

Identification of an existing hazard unfortunately does not guarantee the accurate characterization essential for appraising risk and taking responsive action. An excellent case in point is the Portuguese Bend landslide in the Palos Verdes Hills. This currently moving mass of ground, about 260 acres in area, is part of a much larger landslide complex that was reported in the scientific literature as early as 1926. The full extent of the complex was not then recognized, however, nor was its potential for renewed local failure properly assessed before much of the ground was developed for residential purposes. Relatively casual examinations by several geologists and engineers had led to opinions of "no risk" or "minimal risk," yet failure began to occur in 1956 and soon grew to serious proportions. During the following years more than a hundred homes were destroyed, and property damage reached the $10-million level as 60 million tons of rock and debris continued to move slowly toward the ocean.

Figure 9. Local detachment and collapse of cliff-forming alluvial deposits along the coastline at Pacific Palisades, November 1966. Clearly visible in this view is evidence of earlier encroachments on the residential area above the cliff. Pacific Air Industries photograph.

Figure 10. Deep cracks in active landslide mass, Vista Verde area near Portola Valley. The ground movement, which wracked the newly-built home at left, represented 1967 reactivation of part of a large landslide complex that was originally developed in 1890.

A final example, also from the Palos Verdes Hills, illustrates how easily a 1960 disaster might have been forestalled through the application of investigative methods now routinely required by the County of Los Angeles. In grading for residential development during 1957, the top of a small ridge in Rolling Hills Estates was removed and much of the excavated material was placed as fill on an adjacent slope. The fill was carefully engineered and of good quality, but the ground on which it was founded included soft, weathered bedrock and a moderately large natural accumulation of unstable material that had been slowly moving down the slope for a long period of time. Under the heavy load of fill and newly-built homes, these weak materials failed and a well-defined slide mass was formed in the thick blanket of overlying fill (Figure 11). Two homes were wracked and ultimately destroyed (Figure 12), and a third was left with only partial foundation support. Like the St. Francis Dam, this project had received good engineering input but no geological advice, here an effective recipe for property loss and family heartbreak. The experiences of these and similarly unfortunate homeowners were not wasted, however, because they led to subsequent tightening of regulations for investigative procedures and grading operations in many of California's hillside areas.

Figure 11. A small slide that destroyed two homes and left a third with only partial support, Rolling Hills Estates in the Palos Verdes Hills. This slippage, which occurred in 1960, was caused mainly by the placing of structures and masses of fill upon an unstable slope.

Figure 12. Acute structural distress in buildings, walls, and pavement founded on the subsiding ground shown in Figure 11.

Faults and Earthquakes

Problems associated with fault and earthquake movements are examined by other participants in this conference, so I shall confine my attention here to only a few examples of earthquake-related hazards and risks. The primary hazards can be grouped into three categories--surface faulting, gross changes in elevation of the land, and strong ground shaking. Secondary effects such as cracking, fissuring, lurching, and warping of the ground, disruption of surface and subsurface drainage, triggering of slumps, landslides, and avalanches, and generation of tsunamis and seiches, represent an added potential for damage, destruction, and life loss. Each of the hazards can be identified as a possibility in one or more parts of the state, and each fortifies the concept that nothing coupled to the ground is entirely free from risk.

Deforming effects of severe ground shaking, especially on man-made structures (Figure 13), have been so widely reported that there is little question about identifying and describing most of these hazards. Fully defining them and estimating associated levels of risk, however, can be formidably difficult. Relationships among factors that include location and style of fault rupture, propagation of ground motion, dynamic ground response as it depends on regional and local geologic conditions, and attendant response of structures are at best imperfectly understood. And probability assessments for the occurrence of major earthquakes in given areas still derive almost wholly from the limited statistical base of historic experience.

Imperfect as they are today, the characterization of hazards from strong earthquake shaking and the estimation of losses these hazards could cause leave no doubt that present risks are objectionably high. In effect, too many

Figure 13. Severe deformation of railroad track during the San Francisco earthquake of 1906, South Pacific Coast Railroad near Wright's Station in the Santa Cruz Mountains. This section of dual-gauge line was kinked and shortened by strong ground motion associated with activity along the nearby San Andreas fault. Photograph from Collection of Roy D. Graves, San Francisco.

disasters are merely waiting for our next great earthquake to happen. But must this implied commitment be met in full? Substantial reductions in risk levels would be achieved, for example, through the strengthening or razing of relatively old and unreinforced buildings, of which there are thousands in Los Angeles or San Francisco alone. And the recent partial collapse of the Lower Van Norman Dam could be our last event of its kind if all other dams in the state were to meet appropriate earthquake-resistant standards. Insistence on such application of present engineering standards to structures built in earlier years would represent a judgment of acceptable risk, just as most of the past resistance toward upgrading or eliminating inadequate structures has reflected contrary judgments based in part on more immediate economic considerations.

Gross changes in elevation of the land have accompanied only a few earthquakes in California, among them the Owens Valley quake in 1872, the Arvin-Tehachapi quake in 1952, and the San Fernando quake in 1971. Significant damage to pipelines, canals, and other works of man has been attributed to some of these changes, which in general were associated with fault movements having major components of dip slip. Of far greater import have been abrupt offsets of the ground surface along faults during these and other historic earthquakes in the state. Displaced streams, roads, railways, pipelines, fences (Figure 14), buildings, and other reference features lying athwart the faults have indicated permanent offsets ranging from a fraction of an inch to more than 15 feet. During the San Francisco

Figure 14. Offset fence at main surface break formed along the San Andreas fault near Black Mountain (now a part of Los Altos Hills) during the San Francisco earthquake of 1906.

earthquake of 1906, for example, predominantly horizontal surface displacement occurred along perhaps as much as 270 miles of the San Andreas fault, and during the recent San Fernando earthquake oblique displacements occurred along several breaks in the Santa Susana – Sierra Madre fault zone.

The drastic results of surface faulting beneath a man-made structure are not hard to imagine. Even though such rupturing is confined to narrow strips of ground, and even though its aggregate length during historic time in California is considerably less than a thousand miles, the effects of this uncontrollable activity can be so specific and so serious that they should be avoided wherever possible. The hazard along active fault traces is so plain that one wonders how schools, hospitals, and freeway interchanges could be built across them, or how residential developments could be superimposed across the 1906 break on the San Andreas fault near San Francisco and a geologically recent break on the same fault near San Bernardino.

More to the point, how can we prevent future construction, especially of buildings intended for human occupancy, across the traces of active faults? The hazard is by now well known, and the risk certainly is serious enough to bespeak strong legislation, but the matter is complicated by difficulties in defining the hazard. Given the San Andreas, the Hayward, or the San Jacinto fault zone, across which breaks should certain kinds of construction be prohibited? Only the one along which the most recent movement occurred? All those showing evidence of historic or recent prehistoric movement? Or all breaks in the zone, thereby restricting development in some fairly extensive areas of high property values? And what kinds of construction should be forbidden? Viewing the problem in another way, how well could potential surface faulting in the San Fernando area have been defined for purposes of legislation prior to the recent earthquake? All these questions are tough to handle in the context of how much risk can be tolerated, but some reasonable answers must be produced —and sooner rather than later. Granting that extensive studies will be required for better defining the hazards of surface faulting, it should be possible to solve at least a significant piece of the general problem by addressing legislation to a limited number of areas in which the critical relationships already are known.

Decision Making

The four operational steps here discussed impress me as essential for an effective approach to the problems embodied in major seismic events. And many additional examples of man's works could be cited in support of the thesis that these steps must be negotiated by qualified experts in proper sequence if a given problem is to be solved, but I shall close instead with some comments about decisions implicit in the sequence of recommended operations.

The geologist and the seismologist must be primarily responsible for recognizing and confirming the presence of earthquake-related natural hazards, and at a relatively early stage in dealing with a project or problem. But, vital as it may be, identification of hazard and potential risk is only a start along an integrated path. Unnecessary confusion and consternation too often have followed announcements of possible risk by persons who have then let it go at that. Withdrawal from the scene without an effort toward suggesting probabilities, or otherwise placing the possibilities in perspective, can be a real disservice to everyone concerned.

Recognition of natural hazards should be followed by their definition and characterization, which necessarily involves interpretations and substantive decisions. Here the input from both geologist and seismologist should be progressively coordinated with the work of engineers, work that may well include appraisals of hazard embodied in buildings and other structures. Succeeding evaluation of risk associated with a given hazard is an even more complex task, and decisions in this area logically depend upon the joint efforts of qualified professionals. The final step, resulting in decisions of tolerable risk that are essential for design, construction, or other kinds of practical response, requires additional input from many kinds of specialists. Here various combinations of technical, economic, social, and political factors must be considered, and no single expert can do it all.

The complete procedure has been increasingly employed for new projects during recent years, and it has been most effectively formalized for the siting, design, and construction of nuclear power plants in the important context of seismic and geologic risk. The Atomic Energy Commission requires detailed geologic mapping and study of proposed site areas, and this work generally is backed up by extensive subsurface exploration. The potential for surface faulting is given special attention at sites in California. Thus the Diablo Canyon site in San Luis Obispo County was investigated by means of large trenches (Figure 15), in order to determine whether any of the small faults in the Miocene bedrock extend into overlying terrace deposits of Pleistocene age. The terrace deposits, known to be at least 80,000 years old, were shown to extend across the faults without break, thereby placing a minimum age upon the latest fault movements.

The results of geologic work in the site areas are interpreted relative to various kinds of risk, and they are coordinated with analyses of regional and local seismicity. Engineering properties of site foundation materials generally are determined by exploratory drilling, field and laboratory testing, and *in situ* seismic testing. The seismic, geologic, and engineering data ultimately lead to plant design that will meet extremely demanding requirements of tolerable risk. Final decisions concerning risk necessarily rest with the Atomic Energy Commission, whose staff and expert consultants must review and approve all basic data,

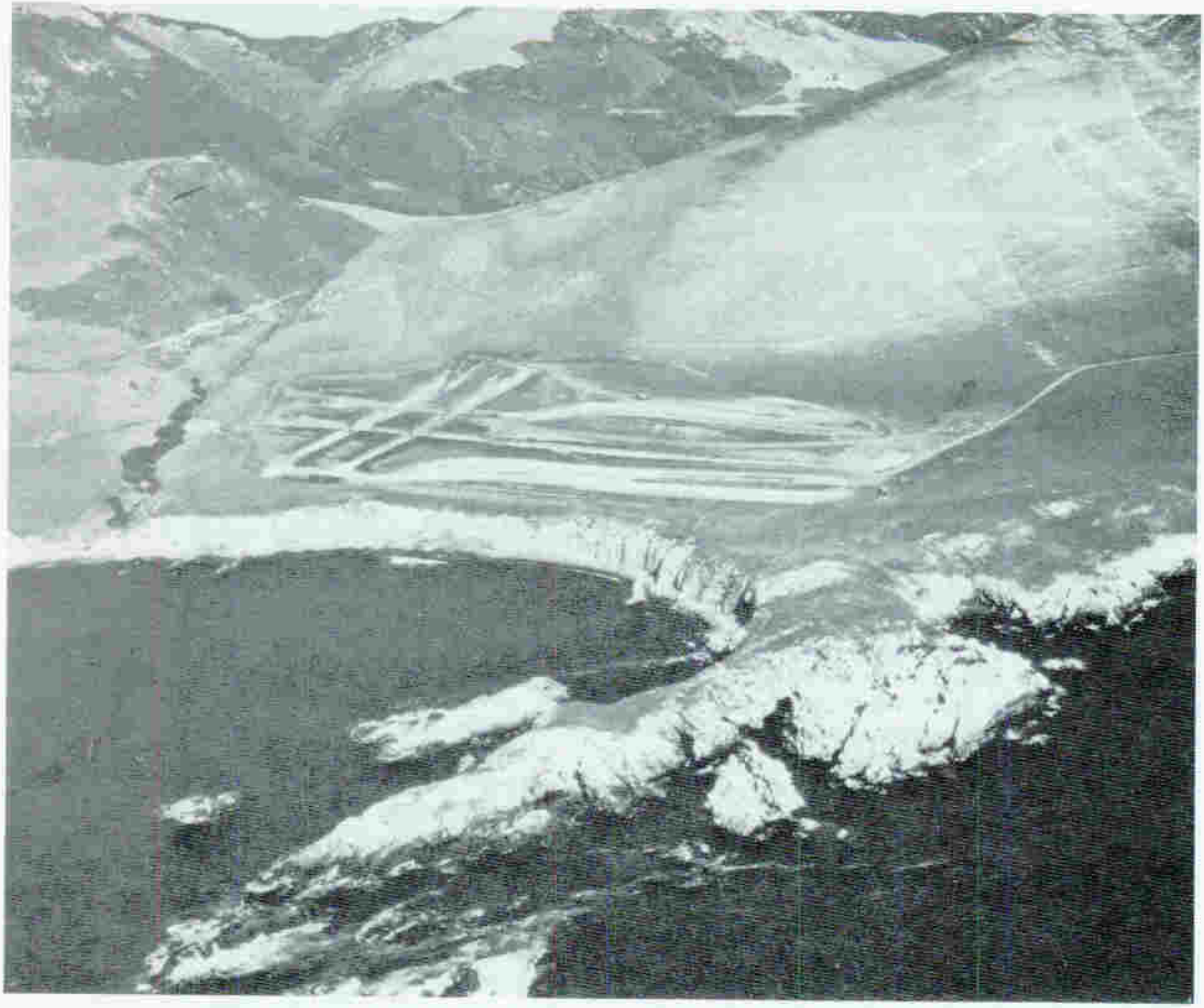

Figure 15. Exploratory trenches at nuclear power plant site on coastal terrace adjacent to Diablo Canyon, San Luis Obispo County. These trenches were excavated to obtain geologic data for appraising the probability of surface faulting at the site. Pacific Gas and Electric Company photograph.

analyses, and design specifications before a construction permit can be granted.

Variants of this almost ideally stylized procedure have been employed for other kinds of major projects, and it seems fair to ask whether a similar approach would make good sense for the development of entire areas or regions. Consider, as a final example, the possibility of coordinated planning for further development of the San Francisco Peninsula. As shown in Figure 16, the physical situation is complex. Most of the relatively flat land adjacent to the Bay already is thickly settled, and so are many of the nearby hills and parts of the trench-like valley that marks the trace of the San Andreas fault zone. Considerable pressure for additional development perforce has been directed toward marsh land fringing San Francisco Bay (top center, views in Figure 16) and toward hillside and valley areas on both sides of the San Andreas fault.

Fortunately, a wealth of geologic and seismic information already is at hand for this region, and much of it is being compiled into highly useful forms by the U. S. Geological Survey and the California Division of Mines and Geology. The number and distribution of recognized natural hazards can be regarded as impressive, exciting, or sobering, depending upon one's point of view. Clearly, however, the San Andreas and other faults, extensive landslides and other expressions of unstable ground, and the susceptibility of certain areas to flooding or to strong seismic shaking must be reckoned with in any intelligent land planning. Some progress already has been made on this score, chiefly at the level of individual communities that

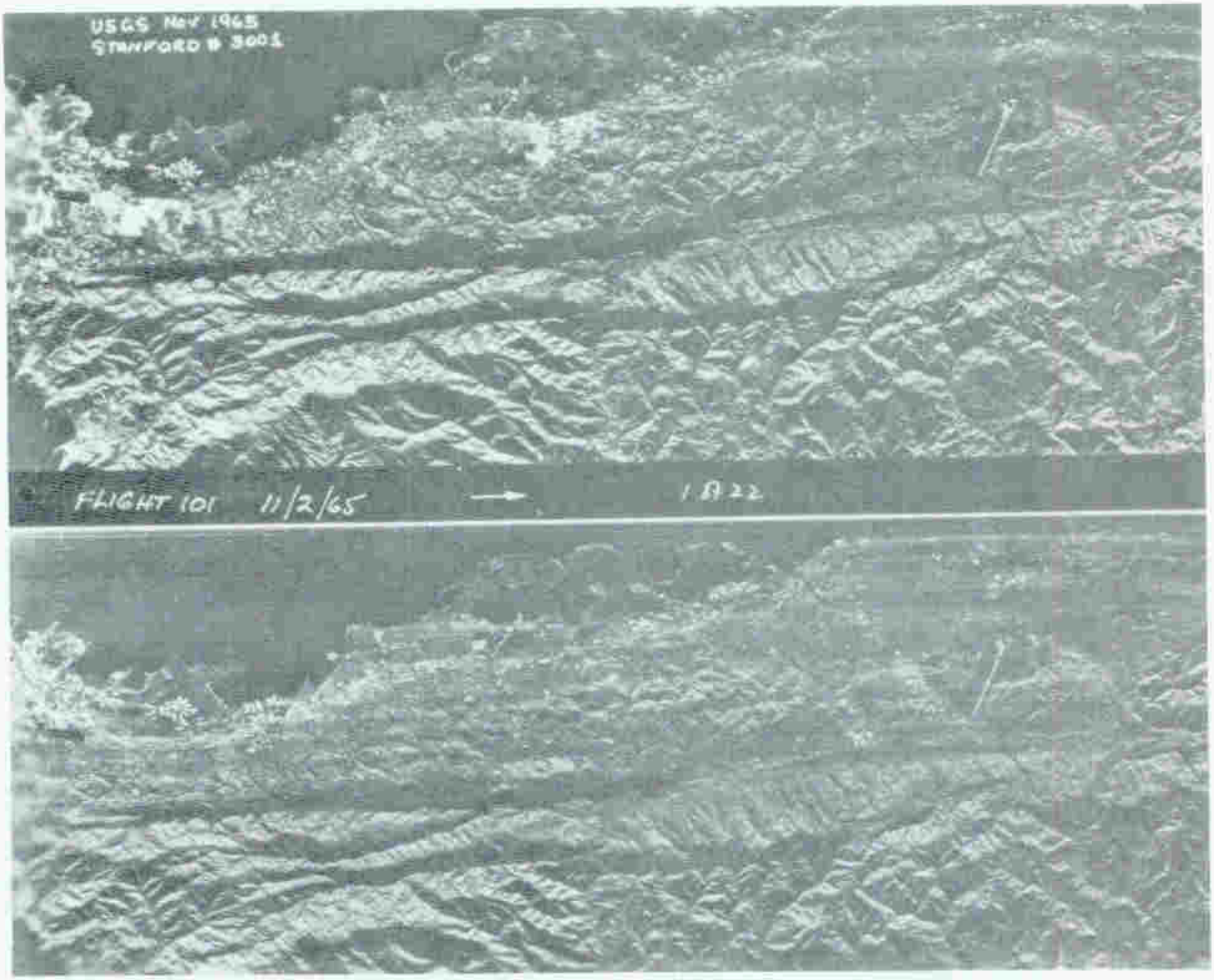

Figure 16. Infrared images of a part of the San Francisco Peninsula, showing trench-like trace of the San Andreas fault zone. San Francisco Bay and International Airport are in upper left, and the two-mile Stanford Linear Accelerator (white line) is at right. Images courtesy of Ronald J. P. Lyon, Stanford University.

have responded to immediate and obvious problems of hazards. Moreover, there also are pleasing indications of some useful responses at county and regional levels.

Let us suppose that a heretofore apathetic or uninformed public were united in support of a regional approach to land planning, and that the stage were set, in economic and political terms, for an action program. How would we stand in terms of required input in the areas of hazard and risk? Available basic data on natural hazards should permit negotiation of the first steps in a general way, and for some areas in considerable detail. Most of the hazards have been identified. Fewer have been properly characterized, so that much added attention is needed here, but this is no justification for delays in taking some firm strides toward judgments of tolerable risk. As Karl Steinbrugge has pointed out, there is little sense in doing nothing until we have *all* the information! The data now at hand provide a reasonable platform from which the most critical questions can be dealt with—what are the kinds and levels of risk, how are the risks distributed throughout the region, who can best make judgments concerning acceptable risk levels, and how can final decisions best be reached?

SOME HISTORICAL PERSPECTIVE OF RESPONSES TO GEOLOGIC HAZARDS

By R. H. Jahns

(1974 Proceedings of Workshop on Physical Hazards and Land Use: A Search for Reason; San Jose State University)

Today's workshop on Physical Hazards and Land Use has been highly instructive, and certainly it has been an effective vehicle for many contrasting messages. Perhaps, though, it also has been a bit frightening in the collective impact of those messages. That the San Francisco Bay region has its share of geological problems is hardly news to most of us, but it is one thing to outline any such problem and quite another to formulate a satisfactory solution in the full context of physical, economic, social, and political constraints. For the thoughtful and concerned individual, whether geologist, engineer, land-use planner, public official, or private citizen, this can be an arena of frustration and discouragement. Yet it need not be if we consider some of our problems in historical perspective, and here I shall try to indicate why this is so.

Geologists have long been raising their voices about earthquakes, landslides, and other physical hazards, but as recently as two decades ago not many people were seriously listening. To be sure, occasional disasters have caused widespread stirs and have forcibly brought certain frail elements of our physical environment to the attention of the public– but for how long? The attention span of humans, adults and children alike, would appear to be unfortunately short. How concerned right now are most people about specific implications of the February 1971 San Fernando earthquake? Or for how long did residents of this State retain a lively interest in lessons provided by the Long Beach earthquake of 1933? Granted, the Field Act was a prompt and important result, but subsequent events have demonstrated that enactment of legislation does not automatically guarantee attainment of objectives. Today thousands of California children occupy school buildings that are prime candidates for seismic demolishment, despite the formalized intentions of more than four decades ago.

Nevertheless, the situation has been changing for the better. More people have been developing and retaining an awareness of constraints in our physical environment, and increasing numbers of them have been demanding that we all do a better job of living within these constraints. Just when these shifts in attitudes and priorities began to develop real momentum is hard to determine, even with the advantages of retrospect. Perhaps they came with growth of the so-called "environmental movement" of the 'sixties (and 'seventies), and perhaps they date farther back to the Long Beach earthquake and to several devastating floods in the 'thirties.

In any case, it is worth reminding ourselves of some important check-points in the area of useful responses. The Field Act, despite the loopholes that were diligently sought for and found, did prove to be effective in eliminating a host of unsafe school buildings. A special grading ordinance in 1952 established the City of Los Angeles as a world pioneer in forestalling landslides and other kinds of ground failure associated with ill-advised reshaping of the landscape, and it was subsequently used as a model by many cities and counties in the State. The original ordinance has been repeatedly strengthened, just as additional legislation has been enacted at the State level, better to accomplish the objectives of the Field Act. As further examples in a very small sampling, recent State legislation requires more careful siting and improved standards of construction for hospitals in the context of seismic shaking and other physical problems, and another useful act provides for special studies in areas where surface faulting could be a problem for certain kinds of proposed structures. And, as we have heard earlier today, similar steps have been taken or are under consideration at more local levels in various parts of the State.

It seems fair to conclude, from an inspection of the record, that a growing number and variety of physical hazards is being pointed out, and that more and more people are listening carefully. So score a big point for history. As for the geologist, he now finds himself, often to his surprise and not rarely to his discomfort, in the center of an arena where until recently there was little action and he was no more than a vocal spectator. The game is well under way, and he is perforce a part of it.

If the first step toward coping with physical hazards is recognition, then the next step must be accurate characterization. What kind of hazard is involved? What are its dimensions, its causes, the scope of its potential effects? Correct answers to such questions provide the necessary base for a third step, which is appraisal of risk associated with the hazard. And only when the level of risk has been established can the final step be taken–judgment of whether the risk is tolerable under the existing circumstances.

I suggest that all four of these steps are essential, and that they must be negotiated in the order I have indicated if the best possible results are to be achieved. A review of any past transformation of a physical hazard where something has gone wrong, whether at nuisance or disaster level, quickly reveals that one or more of the steps was omitted, was taken out of proper order, or was just plain incorrect.

No man-made structure that is coupled with the ground can be regarded as entirely free from physical hazard and risk. Location, design, and completion of any such structure therefore must represent a final decision, reached consciously or unconsciously, that the associated risk either is at an acceptable or tolerable level or can be reduced to such a level. Satisfactory long-term performance of the structure may reflect a wise decision based upon recognition and careful analysis of hazard and risk, or it may reflect no more than good luck with a decision not so soundly based. And, if physical hazard and risk were neglected altogether, the decision was made essentially by default.

A compelling example of disaster from a decision by default was the collapse of the St. Francis Dam in 1928, still California's second greatest catastrophe in terms of life loss. Here was a major structure designed and built without geologic investigation of the site, at which some serious foundation problems were present. Failure of the dam resulted from failure to recognize and to characterize critical hazards embodied in the local ground. Thus all but the last of the four investigative steps I have outlined were skipped, and there was no saving substitute in the form of good luck.

It is interesting to speculate on what might have happened if a geologic investigation had been made when the site was being considered for a dam. Let us suppose that a part of the proposed foundation materials were recognized as subject to partial solution and piping, as concluded by a special group of investigators appointed by Governor Young following the actual disaster, and that a dam were designed and built in accordance with this important factor. Under such circumstances, the dam might well have failed anyway. Why, if a hazard were recognized and properly appraised? Because another hazard also was present in the form of a large potential landslide at one abutment of the dam, where slope failure was capable of destroying the structure. Collapse of the dam would have reflected an incomplete or inaccurate negotiation of those important initial steps, recognition and characterization.

That such speculation is not unrealistic can be demonstrated by numerous actual occurrences, among them the 1963 failure of the Baldwin Hills Reservoir in Los Angeles. This reservoir and its containment, designed to resist strong seismic shaking, were built across several small faults that had been recognized, carefully examined, and judged to be inactive. Yet small movements subsequently occurred along at least one of these faults, with resulting failure of the containment. Here, then, a good first step of recognition had been taken, but the next steps of behavioral characterization and appraisal of risk were flawed, regardless of whether the subsequent fault movements were tectonic adjustments or resulted from shifts in the distribution of subsurface fluids in an adjacent oil field.

Nowhere today are all aspects of possible physical hazards and risks considered more carefully than in the siting and design of nuclear power plants. This is only proper, for the penalties of omissions or mistakes could be extremely serious. But it is interesting to note that some questions of tolerable risk have not been directly answered, even though responsibility for the making of final decisions has been specifically assigned. In the context of surface faulting at the site, for example, below what level of risk may the possibility of such displacement be disregarded in design of the plant? Almost by necessity, the erstwhile Atomic Energy Commission answered this question indirectly by defining an active fault and requiring demonstration that no such fault exists in the vicinity of the plant site. This bespeaks neither obliquity nor confusion, but it does testify to the extraordinary difficulties in specifying acceptable risk levels for some kinds of possible occurrences.

As the evaluation of more and more new projects is being extended to include factors of physical hazard and risk, and as increasing numbers of existing structures are being reevaluated in such terms, we can score another big point for history. If we are in a mood further to consider pluses in the balance sheet, we can add yet another point for some notable progress in developing systematic approaches, in assigning responsibilities, in delivering pertinent information, and in achieving reasoned analyses. To be sure, not all of our input is yet as sound or as consistently on target as it should be, serious gaps in necessary communications still plague us, and not all adversary situations have yet been dissolved in an atmosphere of co-operation, but we should remind ourselves that we are still learning how to cope with problems whose full dimensions remain to be determined.

At least some of the pieces have been falling into place. The geologist, for example, has improved his capacity for identifying many kinds of hazards, and, often in collaboration with the engineer, for characterizing them and estimating the seriousness of risk they present. Too, he is learning that his input is only a part of what is needed, and that it is better to say, "You should consider this problem before you decide on this site, on this design, or even on a general 'go' or 'no-go' for the project," than flatly to state, solely from his own findings, "This site is no good," "The design must be changed," or "The project should be abandoned." And rarely does the engineer insist, "We have no problems of physical hazards here, or at least none that we cannot accommodate in design," unless he has good reasons for doing so. All of which is fortunate, because accurate combined input from such sources is an absolute necessity for wise final decisions that also require attention from experts in other fields. In many instances, public agencies or parts of the public sector are inescapably involved as well.

Perhaps I can bring these somewhat generalized pronouncements into focus by briefly sketching the many years of struggle by the City of Los Angeles with problems related to hillside grading. Here, at the close of World War II, was a growing metropolis in which most of the relatively flat land already had been put to urban use. Pressure for additional land development perforce was directed upward into the hills, and at a time when a new arsenal of mechanized tools was available for large-scale modification of sloping terrain. These tools were quickly put to use in slicing ridges and filling canyons, and by 1950 a new style of land development had been established. For one residential tract in the Santa Monica Mountains the grading costs alone amounted to more than $5,000 per lot, a hitherto unheard-of kind of investment. But it soon became almost par for the course, and before long it was exceeded substantially in some areas.

Then the rains came, and with torrential force during storms in the winter season of 1951–52. Enormous amounts of material slid or were peeled from the fresh faces of new cuts and new prisms of fill, and were carried downward among homes, new and old alike, that lay below. The results were devastating, even though they provided splendid examples of landsliding, gully cutting, and debris-flow activities for geology field trips. Property damage amounted to nearly $8 million, and prompted a great public outcry that, to the surprise of many, begat almost immediate results.

Gilbert Morris, a tough-minded engineer who then headed the City's Department of Building and Safety, had been trying unsuccessfully for years to obtain regulatory legislation for hillside grading. But this dedicated man had not given up, and when he saw opportunity in the form of a temporarily aroused public, he stepped forward with responsive legislation already in hand. Almost before its citizenry knew what was happening, Los Angeles had adopted the Grading Ordinance of 1952, the first regulatory measure of its kind anywhere. Soon a different kind of outcry arose. Not only from land developers, as one might imagine, but in large part from individual property owners. Nobody, it would seem, becomes more irritated than the person who is told that, for his own good, he may not do something. Never was this more clearly demonstrated than in Los Angeles when some relatively mild constraints were first imposed on grading activities.

The ordinance, desirable as it was, prompted a new series of operational problems, thereby revealing once again that good legislation is often no more than a good beginning. As a state senator once put it, in a different but related context, "If you're lucky, you have entered a den of somewhat sluggish snakes that can be subdued over a period of time, but if you're not, you have opened Pandora's box." The subsequent record suggests that the Los Angeles experience was something in between.

Once some rules were laid down for new grading in hillside areas, and once such areas were defined, a new Grading Section was established within the Department of Building and Safety in order to apply the rules through inspection and certification. Grading permits were required, and they were not issued until the plans had been examined and approved. A team of inspectors was assembled, trained, and put to work in the checking of grading as it was being done. The action was lively and yielded salutary results, despite much early confusion and some serious problems. Most problems of substance were geologic, which was unfortunate because no geologists were then included among the Department's staff. Engineers of the Grading Section made some astute decisions in identifying properties for which geologic reports should be required, but when such reports were delivered, it was no easy task to review them for accuracy, pertinence, and soundness of recommendations.

It was an uneasy time, during which occurrences of ground failure in some carefully engineered projects could be traced to lack of geologic understanding. In most of these projects nothing beyond engineering analyses had been made, but in others the grading plans had been backed up by geologic reports. At the request of the City, several experienced engineering geologists reviewed these reports and made discouraging discoveries. Nearly half of the reports obviously had been submitted by people with little or no experience in geology as applied to engineering works, and at least half of them either were essentially without pertinent data or presented no more than generalized information rather crudely abstracted from the published record. Little more than one out of ten contained maps or sections that had been prepared at an appropriate scale or in suitable detail. With a few refreshing exceptions, these reports offered various combinations of no data and firm conclusions, no data or conclusions but much discussion, some data without discussion or conclusions, and so on; name a combination, and it was present somewhere in the pile. Less than ten percent of those reports would have been regarded as acceptable when submitted, had the City of Los Angeles then been favored with the kind of geological staff it has today. So this was a major problem.

There were many competent geologists in the Los Angeles area at that time, as there are now. But how could they be recognized and how could more of them be attracted to this important work? How could decision-makers in the Grading Section be spared reviews of when the ancient seas came in and when they went out in a particular area, or discussions of faults in the desert a hundred miles away? How could they instead be assured, for example, of three-dimensional analyses that might better contribute to reasonable conclusions on local ground stability?

For openers, the Department established an Engineering Geologists Qualification Board, with responsibilities for examining applicants and judging their experience and capabilities. Thus the City undertook some of the difficult, and at times painful, procedures that the State of California later employed in establishing criteria for the licensing of geologists. Technically unqualified opportunists thereby were dealt out of the game, and soon there was a growing number of effective match-ups between problems and practitioners. Even so, there were some slip-ups. There also were continuing irregularities in the contents of geologic reports, so that the Board found it necessary to issue a set of guidelines indicating desired coverage and, where appropriate, lines of detailed inquiry.

And so it went, with the system being improved incrementally from a growing body of experience. Then, in the winter season of 1961–62, the effects of severe storm rainfall revealed a need for further tightening of the ground rules. This was done in 1963, with special attention given to means for insuring thorough pre-grading studies, translation of the study results into specifications, and inspection of graded sites to determine whether all specifications had been met.

The resulting regulations were the toughest anywhere at that time, and they have served as models for many other cities and counties. That they have been well worth the effort is indicated by impressive reductions in frequency of ground failure and amount of associated damage. The financial losses that have been forestalled cannot be readily estimated, but they could well be at an average annual level of millions of dollars in the City of Los Angeles alone.

The systematic, monitored approach to grading and other forms of land development has long since spread into the San Francisco Bay region, albeit not uniformly by any means. Here we have learned much from experiences in areas to the south, but we also hear many of those old, familiar questions. How does one identify a good geologist? How can good geologic and engineering input be assured? How can the small-property owner be well served? And how can geologists and engineers continue to undertake certain kinds of investigations that, though required by law, seem to invite expensive lawsuits? We still have more challenging questions than good answers, but let us not be discouraged.

I'll finish here with a few comments about the Alquist-Priolo Act, the mention of which has been made repeatedly in the discussions today. This Act has not been welcomed by all; in part because it imposes certain new constraints, and in part because its intent and specifications often have been misread or misunderstood. Maligned or not, it is likely to join the 1933 Field Act and the 1952 Los Angeles Grading Ordinance as a piece of landmark legislation. Addressed to the problem of surface faulting, which admittedly is only a thin volume in the long bookshelf of physical hazards, it is a pioneering effort to scale down future disasters, an effort made from an unavoidably incomplete base of the detailed data required for specific regulations. It is a negative answer, and happily so in my view, to the old question of whether we must wait until we learn all there is to know about a hazard before we make formal attempts to deal with it.

The Act derives from the single and simple premise that it makes little sense to place a structure intended for human occupancy across an active fault trace. But conversion of this premise into effective legislation proved to be no simple matter. Which faults in California are active? Exactly where, in a given area, are individual active fault traces? What kinds of structures should be specified under the Act, and what regulations should be applied to their siting? And, not least important, who should decide on such matters?

Here the State took a leaf from the book of the Atomic Energy Commission, a leaf representing years of wrestling with the same problem in the critical context of nuclear power plants. The basic approach is to begin with a full assemblage of existing data, then to recognize that for most localities the assemblage is incomplete, and finally to provide guidelines for further studies where they are necessary for an understanding of hazard and risk. Thus the Alquist-Priolo Act specifies only four of the State's major active faults, and provides for special studies to be made before certain kinds of structures are built within zones delineated along these faults by the State Division of Mines and Geology. Primary responsibility for translating results of these studies into decisions on siting of the subject structures rests at city and county levels, with provision for special appeals at the State level. This seems to have presented few serious procedural difficulties for those cities and counties already concerned and experienced with responses to physical hazards.

Some people have worried about possible reduction of land values along traces of the specified faults. Thus far, most of these concerns appears to have been exaggerated, but on this score it is fair to paraphrase a question that was courageously raised by Don Nichols earlier in the day: Should property values govern our responses to physical hazards, or should we revert to those earlier times when it was fashionable to speak softly about the existence of our active faults, to times when a Berkeley professor mapped parts of the Hayward fault zone but in effect was enjoined from including this information on his geologic map when it was published? If we should, there is little reason for a workshop of the kind held today. Somehow we must be more effective in communicating the message that some ground is poorer than other ground in terms of such factors as intrinsic stability, behavior under seismic loading, and liability to fault rupture.

From time to time we remind ourselves that we live in a period of human history when vast changes are being made in our resource base and life style. Let us be consistent and also remind ourselves that the problems discussed and lamented here today reflect transitory stages in a sort of evolutionary progression, and that most of our troubles on this score are akin to growing pains. We really have no choice but to respond and learn. This should not take too long if we react positively to the lessons of workshops like this, and if we can concentrate on "getting it all together" in the form of more systematic treatments of what must be accepted as highly complex problems. In almost anyone's view, the next decade should be an exciting and fruitful time.