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PRELIMINARY MAPS SHOWING LOCATION OF REPORTED DAMAGE AND INTENSITY OF SHAKING IN PART OF NORTHERN SANTA CLARA AND SOUTHERN SAN MATEO COUNTIES, CALIFORNIA, FROM OCTOBER 17, 1989 M 7.1 LOMA PRIETA EARTHQUAKE

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Preliminary maps showing location of reported damage and intensity of shaking in part of northern Santa Clara and southern San Mateo Counties, California, from October 17, 1989 Loma Prieta M 7.1 earthquake

by

Earl H. Pampeyan and Robert A. Loney

Effects of the Loma Prieta M 7.1 earthquake of October 17, 1989 were distributed over a broad area of the San Francisco Bay region. The heaviest damage in Santa Clara County occurred in Los Gatos; the next heaviest concentration of damage was in the northwest corner of the county, about 40 km north-northwest of the epicenter (fig.1). Widespread but localized shaking here caused damage to, or loss of, personal property such as glassware, china, appliances, furniture, etc., and numerous structures sustained damage to windows, walls, chimneys, utility connections, and foundations, enough damage to render many structures temporarily or permanently unsafe for occupancy. An unexpected aspect of the distribution of damage was that the areas where heavy damage was expected–the flatlands underlain by loosely to moderately consolidated alluvial and estuarine deposits–sustained relatively minor damage whereas areas expected to sustain less damage–foothill areas where bedrock (sedimentary, metasedimentary, and igneous rocks) is exposed–fared much worse (Borcherdt and others, 1977).

The heavy damage in northwestern Santa Clara County occurred in a relatively narrow north-northwest-trending zone on ridges along the west edge of the flatlands subparallel to Interstate 280 (I-280). Los Gatos lies to the southeast and Stanford University to the northwest in line with this zone. A map showing the intensity of seismic shaking in approximately the same area (pl. 2) tells a similar story, that the shaking was more severe in a narrow zone of the foothills. Ridge tops were hard hit, for example, La Cresta Drive in Los Altos Hills, as were some small conical hilltops. Seismic energy may have been focused by topographic features and possibly amplified by phase interference of different seismic waves (Plane and Griggs, 1990) and by critical reflection from the base of the crust or by lateral velocity contrast across the San Andreas Fault (Lomax and Bolt, 1992). In addition, a zone of low-angle faults which cuts the study area may have played a part in reflecting and(or) refracting the seismic energy. Damage along ridge tops away from the main surface ruptures was noted after the 1906 San Francisco (Lawson and others, 1908, p. 253), 1957 San Francisco (Bonilla, 1959, p. 35), 1959 Hebgen Lake (Hadley, 1964, p. 137), 1968 Borrego Mountain (Clark, 1972, p. 182), and 1971 San Fernando (Nason, 1971, p. 98) earthquakes and referred to as churned ground, shattered or tossed earth, and plowed and harrowed ground.

Data recorded on the damage map (pl.1) were obtained from city offices (Los Altos, Los Altos Hills, Menlo Park, Mountain View, and Palo Alto), newspaper reports, community support groups, individual contacts, and drive-by observations. Location of all known sites in Los Altos, Los Altos Hills, Menlo Park, and Mountain view were confirmed in person and were plotted on AAA street maps or 1:24,000-scale topographic maps but most of the Palo Alto sites were not confirmed. Categories of structural damage indicated on the accompanying damage map (pl. 1) are based almost entirely on city reports because personal inspection and evaluation of each site

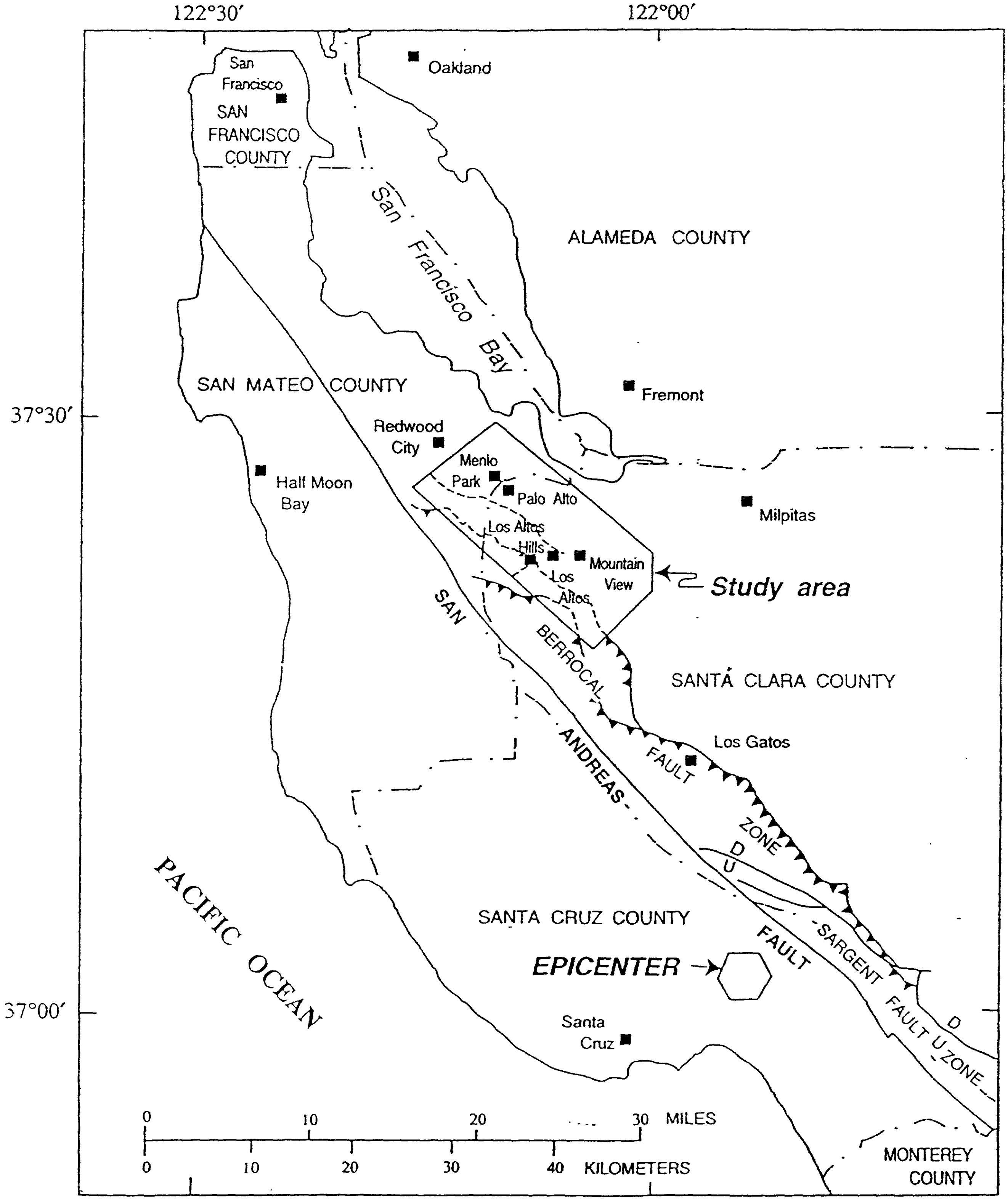

Figure 1. Index map showing study area and its relation to the epicenter of the Loma Prieta earthquake, of October 17, 1989, the San Andreas Fault, and the Sargent-Berrocal Fault Zone of McLaughlin (1974).

was not practical. Only a few sites were examined in detail by Pampeyan. The categories of damage are interpreted in large part from abbreviated–and sometimes cryptic–notes of municipal personnel, and minimally from newspaper reports, and drive-by observations. The damage data are known to be incomplete because some property owners did not report their losses, the reported damage was over- or under-estimated initially, and there was a lack of uniformity in how various municipal offices responded to residents' requests for assistance in assessing perceived damage. The actual amount of damage, therefore, may have been greater or less than indicated by map symbol. Even though the data are incomplete a significant pattern of damage is shown and worthy of further study.

Intensity data (pl. 2) were collected by Loney from neighbors and fellow workers at the U.S. Geological Survey in Menlo Park about the degree of damage to their houses and that of their neighbors and friends. Later he made observations in the field to supplement these reports. He then devised the classification scheme listed below, a scheme meaningful only when comparing buildings of a similar kind and age, in this case single family residences of relatively recent construction (see age of construction, p. 4).

The damage was classified into a local intensity scale, loosely based on the Modified Mercalli (MM) scale (see Iacopi, 1964, p. 44-45), by the following criteria, in order of increasing intensity:

- **4** A few unstable objects (books, small knickknacks, etc.) fell from shelves. (Corresponds to MM IV-V.)
- **5** A large number of unstable objects fell. (Corresponds to MM V-VI.)
- **6** Furniture moved locally in the house, unattached bookshelves fell over, dishes, and bottles fell from cabinets. (Corresponds to MM VI.)
- **7** Similar to **6** but general throughout house with much breakage, large furniture and refrigerators moved a number of feet and/or were overturned, some window breakage. (Corresponds to MM VI-VII.)
- **8** Similar to **7** but with a few cracks in foundation, walls, fireplace and chimneys, or house and chimneys shifted on foundation but no serious structural damage. (Corresponds to MM VII.)
- **9** Similar to **7** but with serious structural damage such as: house shifted off foundation, many breaks in floors and walls, separation of parts of the house, extensive window breakage, chimneys fell through roof, etc. (Corresponds to MM IX.)

As the data accumulated, it became apparent that there was a wide range in intensity levels that seemed to have no obvious relation to the Loma Prieta epicenter or to the location of the San Andreas Fault. For example, although Loney's house had a relatively strong intensity of 4, neighbors located on similar Franciscan bedrock 2 km to the SW, and thus nearer to the San Andreas fault, had a shaking intensity of no greater than 1. In figure 2 the dotted line bounds an area in which the intensity of shaking was 4 or greater; outside of this area intensities fell off rapidly and the reported damage to most of the houses was of an intensity of 1 or less (undetected damage).

Also plotted on plate 1, and on figures 2 and 3, are traces of known faults in the damage zone. Where exposed, most of these faults dip southwest at low angles and form a zone at or near the eastern edge of the foothills of the Santa Cruz Mountains known as the Sargent-Berrocal

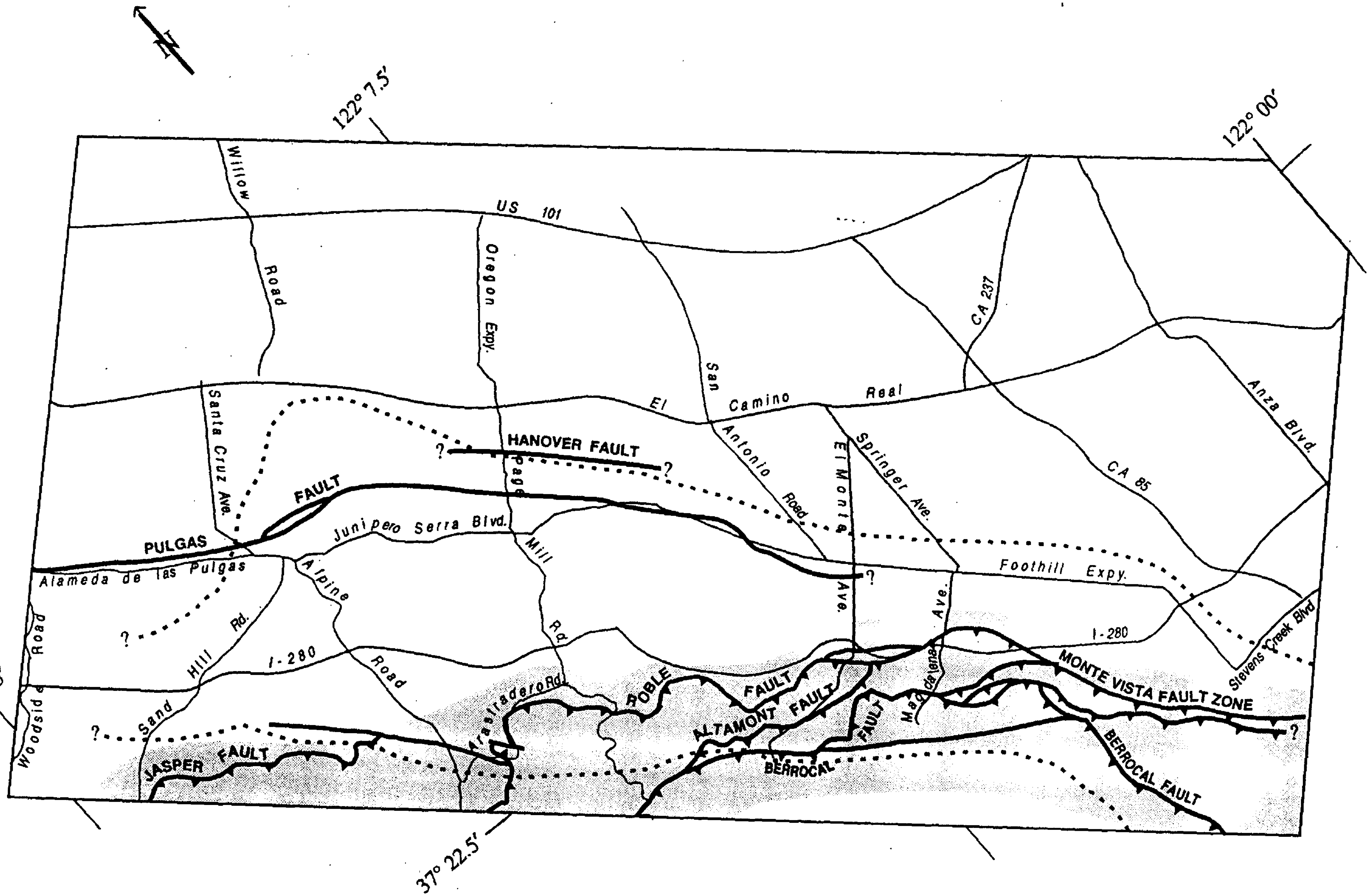

Figure 2. Significant faults and belt of maximum damage in study area. Stippled area is Sargent-Berrocal Fault Zone of McLaughlin (1974); dotted lines enclose belt of maximum damage of this report (intensity 4 or greater).

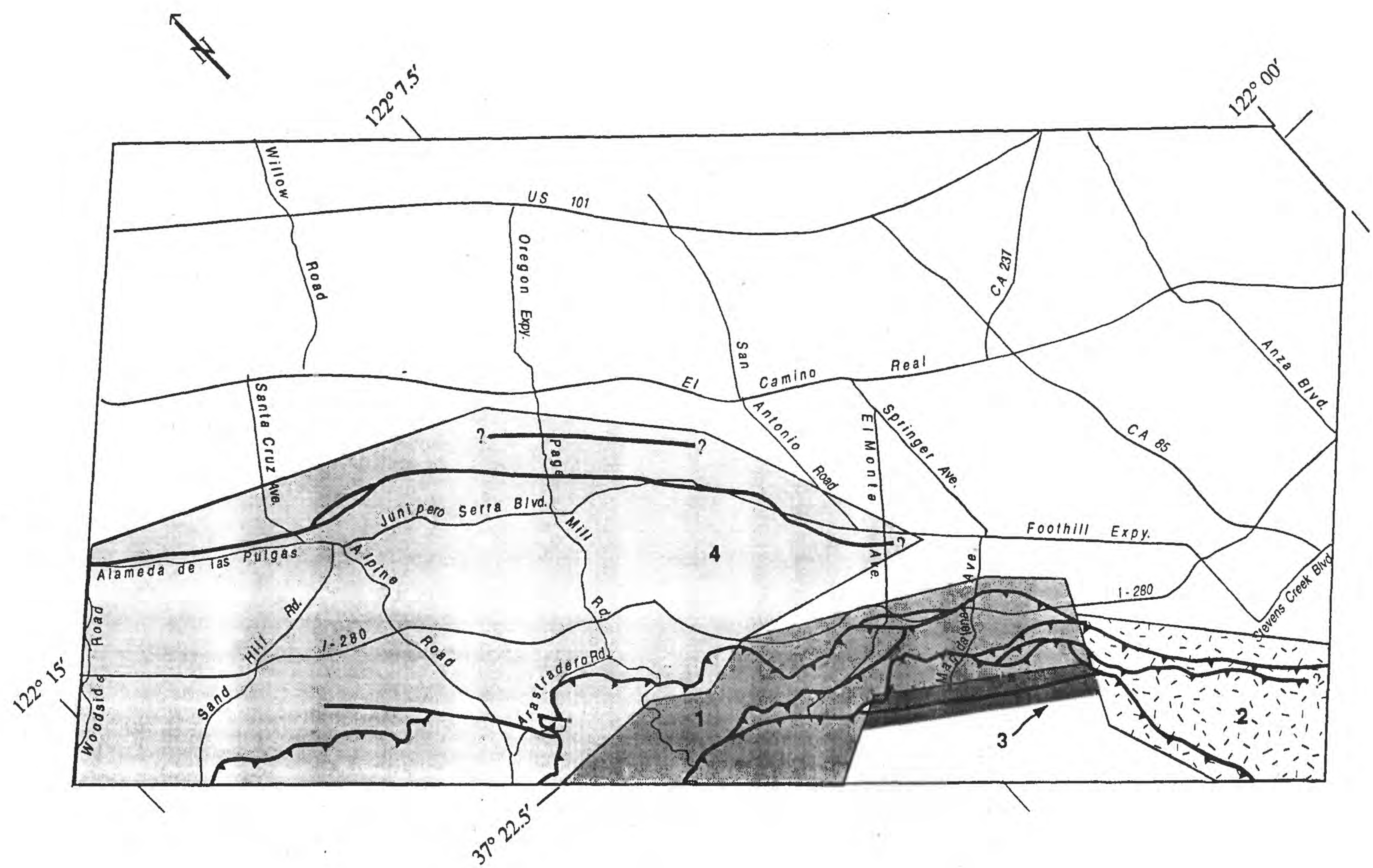

Figure 3. Sources of fault data: 1, Dibblee (1966) and Wm. Cotton and Associates (1978); 2, Sorg and McLaughlin (1975); 3, Rogers and Williams (1974); 4, Pampeyan (1993; Unpubl. data, 1989). Note: Northwest part of Berrocal Fault of Wm. Cotton and Associates (1978) is Black Mountain Fault of Dibblee (1966).

Fault Zone of McLaughlin (1974). This zone of faulting extends southeast through Los Gatos where buckled sidewalks and other damage indicated compression across the zone (Haugerud and Ellen, 1989; 1990). Although the Pulgas and Hanover Faults (Pampeyan, 1993) are shown outside of the Sargent-Berrocal zone they most likely belong to that zone. Traces of these latter two faults are drawn on one poor exposure (Pulgas), subtle topographic evidence, and subsurface data.

The relationship between distribution of damage and fault pattern is not known but appears to be significant, judging from the concentration of symbols in the fault zone (pl. 1). Along I-280 significant damage was manifested by settled highway- and overpass approach-fills, cracked support columns, and compressional effects (Haugerud and Ellen, 1989); damage to highway structures, however, also occurred outside recognized fault zones, for example, in northern Mountain View.

Within the study area slip on the Sargent-Berrocal Fault Zone was not reported, but five shallow (<2.5 km) aftershock events define a southeast-striking line in the foothills between Stanford University and Foothill College which appears to be in the fault zone (Olson and others, 1991). The coseismic compressional deformation along the Sargent-Berrocal, Shannon, and Monte Vista Faults in and near Los Gatos, however, may have extended farther north and caused the damage to pavements and structures at Page Mill Road (Haugerud and Ellen, 1990). The damage pattern reported in our paper occurred during the main Loma Prieta event and appears to have a close relationship to the reverse faults in the study area.

A recent report by Hitchcock and others (1994), stresses the probability of coseismic activity in the Sargent-Berrocal Fault Zone during the main Loma Prieta earthquake, and possibly during older earthquakes as well, in the area immediately southeast of the area covered by our report. Their report discusses the question as to whether such compressional movements resulted from independent seismic sources or from secondary events related to the large-scale events on the San Andreas Fault. They propose that there was coseismic slip on the Monte Vista, Shannon, and Berrocal Faults during the main 1989 event, a proposal reinforced by fault plane solutions indicating coseismic slip on northeast-verging reverse faults during after shocks of the main 1989 earthquake.

Page Mill Road at I-280 showed both extensional and compressional damage in an area where no faults were thought to exist (Haugerud and Ellen, 1989). Of interest here are comments referring to cracks in this area showing lateral offset which occurred during the 1906 earthquake (Lawson, 1908, p. 108, loc. 15?, atlas pl. 22).

Age of residential construction in the area along I-280, where much of the serious damage occurred, is relatively young (typically less than 30 years old). This is in contrast to the flatland areas where damage, though not nearly as severe, was in older residential areas (typically more than 30 years old). Symbols on the map (pl. 1) represent types of damage reported or observed and, with only a few exceptions, each symbol represents a single site. In the hills the symbols are located as close to the site as the map scale permits; on the flatlands some of the symbols are approximately located owing to vagaries in street numbering systems in irregular street-grid areas. Some addresses reported are known to be incorrect, possibly because of typographical errors, but they amounted to less than two percent of the total number. The intent of this report is not to specifically identify properties but to display the general distribution of damage to see if some correlation with geologic, topographic, or geographic features was evident. A detailed study of a small unincorporated area was commissioned by Santa Clara County (Terratech, Inc., 1990), and several sites from that study are included on plate 1 (◉) without categorizing the type of damage. Damage in the small area was widespread and did not appear to be related to local topography or geology.

Some engineered structures, including low light-industrial, multi-level apartment, and high-rise buildings in the damage zone reportedly sustained damage totalling millions of dollars. In the foothill area along I-280 the incomplete data indicate all or parts of at least 41 residential structures were rendered uninhabitable by the earthquake and more than 51 chimneys fell, and the Terratech, Inc. (1990) study adds to these numbers. Many of the fallen chimneys, regardless of age, were neither reinforced nor properly tied to the structure, but some did contain the required steel bars suggesting type of construction or quality of workmanship may have played a part in the amount of damage sustained. Damage was significantly less in the flatland area northeast of I-280 and Foothill Expressway and generally affected chimneys and foundations of older less-well reinforced types of one-and two-story residential construction. Damage to multi-story buildings was reported in some areas, mainly as damage to stairwells or to structures with large open spans with few internal shear walls. Stanford University is in line with the main zone of damage and it suffered heavy damage (Stanford Observer, 1989), chiefly to older buildings. Though it is not sited on ridge tops or at the edge of the foothills, it is in the zone of concealed faults which cross the campus (Willis, 1924; Brabb and Olson, 1986; Oliver, 1990; Pampeyan, 1993).

Damage reported in adjacent parts of San Mateo County (Menlo Park) was very small relative to Palo Alto; also, little damage was reported in the map area southeast of Palo Alto. In general, the residential part of Palo Alto with widespread damage consisted of pre-1950 structures whereas urban development in adjacent parts of Menlo Park and southeast Palo Alto began in the early 1950's. This implies that construction practice rather than geotechnical conditions was responsible for the damage pattern. In Mountain View some older unreinforced masonry buildings were damaged, some masonry veneer fell, and some newly erected tilt-up walls whose bases had not been permanently fastened were shifted.

Directional effects of shaking were reported by many as having definite compass orientations, for example, furnishings being moved or thrown down in a north-south or east-west direction, but a sampling of those data from personal contacts were inconclusive for they indicated the direction of initial shock and subsequent shaking varied from area to area, possibly being controlled by local topographic setting and focusing mechanisms.

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