Appendix A: California Fault Parameters for the National Seismic Hazard Maps and Working Group on California Earthquake Probabilities 2007

By Chris J. Wills[1], Ray J. Weldon II[2], and William A. Bryant[1]

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California Geological Survey

[1]California Geological Survey, Sacramento, California
[2]University of Oregon, Eugene, Oregon

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California Fault Parameters for the National Seismic Hazard Maps and Working Group on California Earthquake Probabilities, 2007

C.J. Wills[1], R.J. Weldon II[2], and W. A. Bryant[1],
[1] California Geological Survey
[2] University of Oregon

Introduction

This report describes development of fault parameters for the 2007 update of the National Seismic Hazard Maps and the Working Group on California Earthquake Probabilities (WGCEP, 2007). These reference parameters are contained within a database intended to be a source of values for use by scientists interested in producing either seismic hazard or deformation models to better understand the current seismic hazards in California. These parameters include descriptions of the geometry and rates of movements of faults throughout the state. These values are intended to provide a starting point for development of more sophisticated deformation models which include known rates of movement on faults as well as geodetic measurements of crustal movement and the rates of movements of the tectonic plates. The values will be used in developing the next generation of the time-independent National Seismic Hazard Maps, and the time-dependant seismic hazard calculations being developed for the WGCEP. Due to the multiple uses of this information, development of these parameters has been coordinated between USGS, CGS and SCEC. SCEC provided the database development and editing tools, in consultation with USGS, Golden. This database has been implemented in Oracle and supports electronic access (e.g., for on-the-fly access). A GUI-based application has also been developed to aid in populating the database. Both the continually updated "living" version of this database, as well as any locked-down official releases (e.g., used in a published model for calculating earthquake probabilities or seismic shaking hazards) are part of the USGS Quaternary Fault and Fold Database http://earthquake.usgs.gov/regional/qfaults/ . CGS has been primarily responsible for updating and editing of the fault parameters, with extensive input from USGS and SCEC scientists.

Fault Data

The WGCEP has developed a database of fault parameters, the “California Reference Fault Parameter Database”, to contain that information necessary for development of seismic hazard and deformation models. This database includes information on the geometry and rates of movement of faults in a “Fault Section Database” and information on the timing and amounts of fault displacement in a “PaleoSites Database”. The information in the “Fault Section Database” is discussed in this report. This data set includes the faults included in the National Seismic Hazard Maps (Petersen et al., 1996; Frankel et al, 2002; Cao et al., 2003) updated and modified for the WGCEP.

In the “Fault Section Database” currently developed in Oracle by USGS and SCEC, each entry contains the following information:

- fault name
- fault trace (list of latitudes and longitudes)
- average dip estimate
- average upper seismogenic depth estimate
- average lower seismogenic depth estimate
- average long-term slip-rate estimate
- average aseismic-slip-factor estimate
- average rake estimate

This information, except for the lists of latitudes and longitudes that define the geometry, is shown in tabular form in Tables 1 and 2 for each entry in the database. The term "estimate" implies that a formal uncertainty is given. Finally, alternate geometric representations were developed by CFM for some faults; alternate representations are mutually exclusive (meaning if one accurately represents the fault, the other does not).

Each fault entry in the database and Tables 1 and 2 is described by the parameters listed above, and is distinguished from adjoining faults by a change in any of those parameters. The database is nearly (and deliberately) identical to the information used in the model developed for the 1996 and 2002 National Seismic Hazard Maps (Petersen et al. 1996b; Frankel et al. 2002; Cao et al. 2003, referred to here as NSHMP 1996 and 2002). Entries in the "Fault Section Database" are not identical to fault sections as defined by the National Quaternary Fault and Fold Database (Haller et al. 1993; U.S. Geological Survey and California Geological Survey, 2006, http://earthquake.usgs.gov/regional/qfaults/). This occurs because in "Q-faults" sections "may be defined on the basis of relative age criteria, by fault geometry, by the presence or preservation of scarps, by a single trench, or from other geologic data (gravity, structure, etc.)." (Haller et al. 1993). The "Fault Section Database" described here combines adjacent sections from Q-faults where the slip-rate and other parameters listed above are the same. The result is that the entries in the "Fault Section Database" may be composed of one or more "fault sections" as defined in "Q-faults". In this report, new fault sections on the southern San Andreas, San Jacinto, and Elsinore faults are split from the previously defined fault sections listed in Q-faults as described below. Table 1 lists both the fault name and the fault section ID's designated in the Quaternary Fault and Fold Database to allow readers to correlate the information on a given fault.

This database does not use the term "segment", because in many cases geologists associate the word segment with the occurrence of characteristic earthquakes that are limited by a segment's boundaries. Later discussions of earthquake recurrence models will use segments in that sense, but because this database is intended to include the basic descriptive information about faults, and not recurrence model information, the term "segment" is not used here except in referring to segments defined by previous Working Groups.

Previous working groups on California earthquake probabilities have described faults as being divided into segments, in the sense that each segment is a source of characteristic earthquakes. In the current database, sections are described separately, so as not to imply a specific earthquake rupture model. Previously described segments, however, have either been included as sections or subdivided into smaller sections. All segment boundaries defined by previous working groups have been retained as section boundaries or modified as described in this report. In subsequent earthquake frequency models, all segments consist of one or more sections.

Development of the database of fault parameters followed a simple process: we adopted the CGS/USGS fault model developed for the NSHMP 1996 and 2002. We also adopted the fault traces from the rectilinear version of the CFM (CFM-R) (Plesch et al., 2002; Shaw et al., 2004, http://structure.harvard.edu/cfm-r_project/cfmr.html). Fault dips given in CFM-R were averaged to give the dip for an entire fault or fault section. CFM-R provided updated traces, dips, and depth for many of the faults in southern California. In particular, the upper and lower seismogenic depths are more precisely determined for CFM-R using the base of seismicity surface of Nazareth and Hauksson (2004). Where fault sections were included in both the 2002 National Seismic Hazard Map model and in CFM-R, we adopted the nomenclature of the 2002 model, and the more detailed surface trace and top and bottom of seismicity. In practice, this meant that in most cases the trace and dip from CFM-R was adopted, and the top and bottom of seismicity from CFM-R was always adopted.

Faults included in the CFM include well-known faults with well-constrained slip rates and earthquake histories, such as the San Andreas fault, and other faults for which the geometry is well-constrained from the CFM, but the recency or rate of movement is unknown. These additional geometric models of faults may be defined by reflection seismic profiles, such as the Oceanside blind thrust fault of Rivero and others (2000) or be defined by a single earthquake and its aftershock sequence, such as one in

Santa Monica Bay. For the current update of the NSHMP time-independent seismic hazard model, or the subsequent WGCEP time-dependant model, faults from CFM which lack information on the recency of faulting or the slip rates cannot be used in calculating seismic hazards. Two tables in this report list the fault data. Table 1 includes the list of faults and parameters that are sufficiently complete that they can be included in a seismic hazard model. Table 2 includes faults where the fault parameters are not well constrained, or the slip rate is not available, so that the fault representations will not be used in the current NSHMP or WGCEP seismic hazard models. Both tables indicate the source of the fault trace information and include brief comments on the sources of new information on geometry or slip rate on these faults. Future seismic hazard models, which utilize deformation models where the total slip in the region is resolved onto known fault surfaces, should be developed using the well constrained geometric extent of faults from CFM-R including those that the present lack of information on activity rate prevents us from using.

Rake values are included in this database, but were not in previous tables. These values were derived from the descriptive designations in the 2002 NSHMP model using the convention of Aki and Richards (2002):

- left-lateral strike-slip = 0,
- right lateral strike-slip = 180,
- reverse slip = 90 and
- normal slip = -90

Oblique-slip faults are designated in the 2002 NSHMP table with abbreviations of their strike-slip and dip-slip styles and the letter "o". For example, "ll-r-o", meaning left lateral-reverse oblique. In converting these designations to rake angles, we assumed that the initial movement type listed was dominant, so this fault was a left-lateral fault with a reverse component. A fault listed as "r-ll-o" is assumed to be a reverse fault with a left-lateral component. Because these are general categories, with very little precision, we only designated rake angles in 30-degree increments. A rake of 30 degrees is obtained for a fault previously listed as "ll-r-o", while 60 degrees is obtained for a fault listed as "r-ll-o". Rake information is included in the database for all faults that were in the 2002 model. Faults that were not in the 2002 model generally do not have rake information that has been evaluated through the community-wide process, and rake information is not included.

An aseismic slip factor is also included for each entry in the database. These factors represent the proportion of slip on the fault that occurs aseismically, as creep, afterslip, triggered slip, etc. If slip is occurring aseismically, that proportion of the seismic moment is not available to produce earthquakes. The aseismic slip factor is applied in calculating the area of a fault that releases strain seismically. In this compilation, we make the conservative assumption that the aseismic slip factor is 0 for all faults that do not exhibit creep, triggered slip or significant afterslip unless is has shown to be higher. Faults that are known to have significant aseismic slip, in any of these forms, are given an aseismic slip factor of 0.1, unless a well constrained value has been developed. In the San Francisco Bay Area, WG2002 calculated the seismogenic scaling factor "R", the proportion of the fault slip that occurs seismically. In Table 1, the aseismic slip factor is simply 1 – R for all faults considered by WG2002. WG2002 determined that the proportion of aseismic slip varied from as high as 80% on the Calaveras fault, 40% on the Hayward fault, and are typically 10% or less on faults that are not known to have surface creep. Aseismic slip factors for the Hayward and Concord-Green Valley faults are also applied to their northern extensions, the Maacama and Bartlett Springs faults, which are also known to creep. Aseismic slip factors were calculated for the creeping section and the Parkfield section of the San Andreas fault by finding the factor needed to reduce the area of the section to be consistent with historic earthquake magnitudes. No other faults in California outside the Bay Area are known to have substantial fractions of their long-term slip rates expressed as creep. Several faults in the Imperial Valley, however, have had significant afterslip following earthquakes or triggered aseismic slip following earthquakes on other faults. Based on preliminary analysis of the amount and modeled depth of creep from Sieh and Williams (1990), we apply an aseismic slip factor of 0.1 to the Imperial, Superstition Hills, Coachella section of the San Andreas, and Borrego section of the San Jacinto faults. Until studies are done to determine the range of possible aseismic slip factors for other faults, the current working group has elected to keep the assumption that the aseismic slip factor is 0 unless determined to be higher for all other faults in California.

Accuracy of Fault Parameters

The locations of faults are described using a series of points along the surface trace and a single dip for a fault section. These fault traces are simplified and condensed from more detailed information. The fault locations in map view consist of straight line-segments, up to tens of kilometers long, that are generalized from a fault map. In the third dimension, faults sections are projected to depth with a constant dip. More detailed representations of all of these faults are available in map form (Bryant, 2005) and detailed triangulated surfaces are available for those faults in the SCEC “Community Fault Model” (CFM) (Plesch et al. 2002; Shaw et al. 2004). Similarly, the slip rate information compiled for each fault section considers detailed geologic investigations of slip on a fault, regional compilations of geodetic deformation across the region, and the overall rate of movement between the Pacific and North American Plates. The rate values were developed in an extensive process to gather input from experts in many fields of geology and geophysics and develop “best estimate” values that consider all of that input. This process included workshops held in Northern California on July 26, 2005, and in Southern California on September 11, 2005 to solicit new information to add or modify the fault parameters. Workshops focusing on slip-rates and earthquake frequency models on major faults were held in Northern California on November 8, 2006, and on Southern California on November 13, 2006. These workshops, contacts with individual geologists who develop fault data, and review of published literature allowed for revisions of the fault section data as described in Table 1.

Updating Fault Section Data

It is important that the geologic data that goes into the construction of the seismic hazard model be "best available" science. Ideally, all of the data would be independently verified and published in refereed journals. However, in practice there are contradictions between published sources, different levels and qualities of publication, unpublished or "gray literature" sources that are common knowledge (and thus affect expert opinion), and precedent established by previous Working Groups that may have been little more than educated guesses or hunches. Thus, the Working Group has established a data hierarchy and flexible guidelines to decide what information to use. These guidelines are: 1) The highest quality data has been peer reviewed and published. Unreviewed but published sources, such as abstracts and field guides can be used if there is no published data, unpublished data can be used if there is no other source and it has been vetted by consensus, such as a Working Group process. 2) Changes to the input parameters require a compelling reason. A compelling reason would be a source of data that is more thoroughly vetted; such as data from a refereed published source replacing a gray literature source like an abstract or field guide, or demonstrated error in the existing data or interpretation. 3) The necessary threshold of evidence quality required rises with the significance of a change's impact on the hazard and the level of pre-existing data. 4) Lower quality data can be used if that is all there is. The WGCEP recognizes that any data is always better than no data. Less thoroughly vetted data, such as unpublished and gray literature is acceptable if there is no other source, and that adding it simply fills gaps and thus does not contradict vetted data or significantly change precedent.

Changes in Fault Sections on Faults in Northern California

The current WGCEP has adopted the fault traces, dip, and depth developed by the WCCEP (2002), for the Bay Area. In the database, each fault segment defined by WCCEP (2002), is described as a fault section. Most of the segment boundaries were based on similar criteria to what we are using to define section boundaries and are discussed below as “sections”. As discussed above, we prefer not to have “segments” with the connotations of a specific rupture model, in the database, which should contain only descriptive information about the faults. In contrast to the WCCEP (2002), sections are described in the database without quantitative uncertainties on their end point locations.

In the WGCEP (2002) model, the Calaveras was divided into northern, central and southern sections. These sections were based on major changes in seismicity, creep rates, and long-term slip rates. The Hayward-Rogers Creek was divided into the Rogers Creek and northern and southern Hayward sections. The section boundary between the Rogers Creek and northern Hayward fault is defined by the 6 km wide releasing stepover beneath San Pablo Bay. The boundary between the northern and southern Hayward sections was defined by the extent of rupture in the 1868 earthquake. For the San Andreas fault, the current WGCEP has adopted the boundaries of the San Andreas Offshore, North Coast, Peninsula, and Santa Cruz Mountains segments defined by the WGCEP (2002) as section boundaries. These boundaries are defined by the change in strike of the fault offshore of Point Arena, along with inferred decrease in displacement in the 1906 earthquake in the same area; the intersection of the San Gregorio fault and a 3 km wide stepover offshore of the Golden Gate, a major lithologic change and the northern end of the Loma Prieta aftershock zone and the north end of the creeping section near San Juan Bautista.

Outside of the area considered by the 2002 Working Group, we have made several updates to fault locations and activity rates. The location, dip, and activity rates of several faults along the west side of the southern Sacramento Valley have been updated based on the work of O’Connell and Unruh (2000) and the West Tahoe fault has been added based on the work of Kent et al. (2005).

Southern California fault sections

San Andreas Fault

In southern California, incorporation of fault traces and dip from CFM-R lead to significant revisions to sections of the southern San Andreas fault and minor changes to the modeled location of the San Jacinto and Elsinore faults. The 1988 Working Groups and the NSHMP 1996 and 2002 divided the southern San Andreas into six segments: the Parkfield, Cholame, Carrizo, Mojave, San Bernardino, and Coachella segments. We have evaluated these as sections. Whether they are also segments, which define the extent of individual ruptures, is the subject of later analysis. The Parkfield section, of course, is defined by recurring M~6 earthquakes. Previously designated segments south of Parkfield were defined largely based on differences in slip in the 1857 earthquake as mapped by Sieh (1978) and major changes in trend or slip rate along the fault. The revised section boundaries presented here are based on similar criteria: section boundaries may be major changes in the amount of displacement in prehistoric earthquakes, changes in trend of the fault or in structural style in the region surrounding it, and junctions of faults that may add or subtract slip from the San Andreas.

In this report we have divided the southern San Andreas into ten sections: the Parkfield, Cholame, Carrizo, Big Bend, Mojave north, Mojave south, San Bernardino north, San Bernardino south, San Gorgonio-Garnet Hill, and Coachella (Figure 1). The addition of segments in the Big Bend and northern Mojave was motivated by separating the more rapidly slipping Carrizo section from the northern Mojave and possible terminations of the early historic 1812 AD ruptures. Addition of sections in the San Bernardino region was motivated by slip rate changes associated with currently accepted models of how slip is transferred between the San Andreas and San Jacinto faults in that region. These are described below from north to south.

The Parkfield and Cholame sections are unchanged from the 1988 Working Group and 1996 and 2002 NSHMP. The Parkfield section was believed to have up to 1.5 meters of displacement in the 1857 earthquake (Sieh, 1978) as well as the well known series of M ~ 6.0 earthquakes. To the south, the Cholame section was believed to have 3 to 4 meters of slip in 1857, as measured by Sieh (1978). Lienkaemper (2001) re-examined many of the sites measured by Sieh (1978) and concluded that slip ranged from 5.4 to 6.7 m, and that measurement uncertainties were large. Despite the difference in slip in 1857, there do not appear to be significant changes in the long-term fault slip rate or fault geometry at the boundary between the Parkfield and Cholame sections, or at the boundary of the Cholame and Carrizo sections to the south. The section boundaries are based exclusively on historic earthquakes: the sequence of M ~6.0 earthquakes defines the Parkfield section, and previously interpreted differences in slip in 1857 distinguish the Cholame and Carrizo sections. New paleoseismic work near the boundary of the Cholame and Carrizo sections should help define the extent and frequency of earthquakes in this region and thus help define the section boundaries. This work is discussed briefly in Appendix E, but until its implications are fully explored and published, we retain the existing section boundaries.

The Carrizo section had up to 9 m of slip in 1857, as measured by Sieh (1978), and other reported offsets that suggest that this section has repeatedly had slip of about this magnitude (Sieh and Jahns, 1984, Liu, 2004). The interpretation of this area of relatively large slip is that the Carrizo section represents a relatively strong patch of the fault zone that only ruptures in large displacement earthquakes. Slip in 1857 decreased to the south (Sieh, 1978) to about 6 –7 m south of the Carrizo Plain and to about 4.5 m south of Elizabeth Lake. The Working Group on California Earthquake

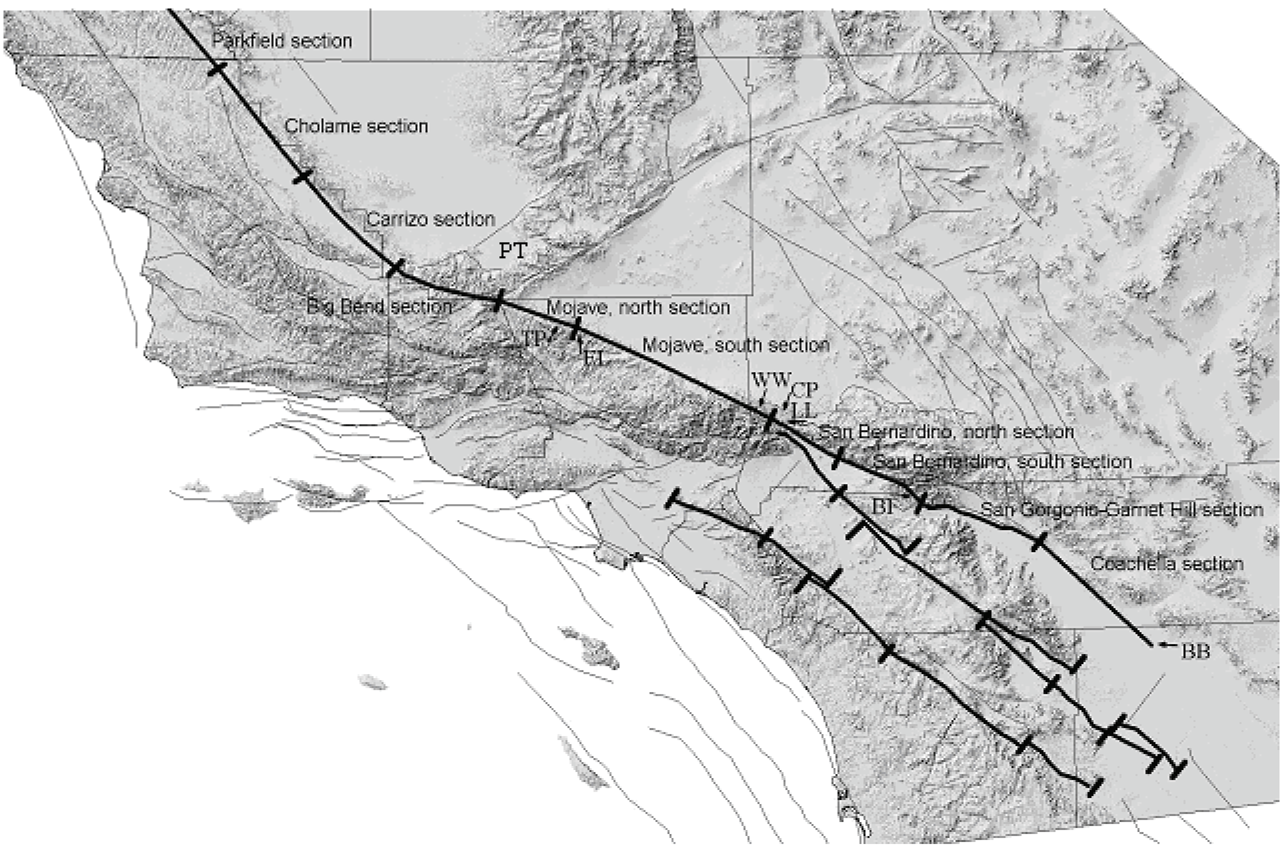

Figure 1. Sections of the southern San Andreas, San Jacinto , and Elsinore faults, showing proposed new section names for the southern San Andreas. Localities referred to in text are: PT- Plieto thrust fault, TP- Three Points; EL- Elizabeth Lake; WW- Wrightwood; CP- Cajon Pass; LL- Lost Lake; BF- Burro Flats; BB- Bombay Beach.

Probabilities (1988) defined the southern end of the Carrizo segment near Elizabeth Lake where the amount of slip interpreted by Sieh (1978) slip decreased to about 4.5 m.

In our review of fault section boundaries, we noted two significant changes in the fault south of the Carrizo Plain. The first of these is at the south end of the Carrizo Plain where the San Andreas changes strike from about 40 degrees to about 70 degrees west of north. This change in strike, long known as the Big Bend, is also accompanied by the appearance of compressional geologic structures on both sides of the San Andreas, most notably the Plieto thrust to the north. Based on the change in strike of the fault, and change in tectonic style in the surrounding area, we have defined a section boundary at the south end of the Carrizo Plain and named this section the Big Bend section. Slip in the 1857 earthquake, as interpreted by Sieh (1978), also appears to be smaller south of the Carrizo Plain. Slip in the southern Carrizo Plain was 7 – 9 meters, but decreased to 5 – 7m south of the Carrizo Plain. The area of the fault bend and associated thrust faulting ends to the south near the junction of the Garlock fault and the San Andreas. We designated this as a fault section boundary because of the change in tectonic style and intersection of the Garlock fault. In addition to the change in slip in 1857 between the Carrizo Plain and the fault to the south, including this section, this new section would allow smaller earthquakes, such as the possible relocation of the 12/21/1812 event suggested by Toppozada et al. (2002).

South of the junction of the Garlock fault, the San Andreas is straight, with no known changes in long-term slip rate or major changes in geometry where it forms the boundary between the Mojave Desert and the Transverse Ranges. Nevertheless, slip in 1857, as interpreted by Sieh (1978), decreased from 5 – 7 m through the Big Bend and in the northwestern part of the Mojave Desert to about 4 - 5 meters south of Elizabeth Lake. The decrease in slip led the 1988 Working Group to establish the boundary between its Carrizo and Mojave segments near Elizabeth Lake and subsequent Working Groups have followed this lead. This point has been retained as a section boundary, but we call the two sections the Mojave North and Mojave South. The Mojave North Section extends from the junction of the Garlock fault to the previously defined segment boundary near Elizabeth Lake, and the Mojave South Section extends from there to near Cajon Pass. Besides the decrease in slip in 1857, the earthquake of 12/8/1812 occurred on the Mojave South section (Jacoby et al. 1988; Fumal et al. 1993), and may not have extended onto the Mojave North section. Additional section boundaries also allow the change in long-term slip rate (from 34 mm/yr on the Carrizo to 28 mm/yr on the Mojave) to be modeled at the junction with the Garlock fault, which seems more reasonable than between the straight and simple Mojave sections as in previous models.

At the southern end of the Mojave South section, a significant amount of slip transfers from the San Andreas fault to the San Jacinto fault. As much as 12 mm/yr has been estimated as the slip rate of the northern San Jacinto fault (Working Group on California Earthquake Probabilities, 1995; NSHMP 1996, 2002). This slip begins to leave the San Andreas fault at the junction of the Mojave South and the adjacent San Bernardino North sections, resulting in a lower slip rate on the San Bernardino North section and subsequent sections to the south. We moved the boundary between the Mojave South and San Bernardino North sections about 5 km to the northwest of the segment boundary defined by previous Working Groups to a point halfway between documented 1857 displacement at Wrightwood (Jacoby et al. 1988) and the first place to the south where no offset was documented (Lost Lake; Weldon and Sieh, 1985). This point is also the closest point to the northwestern termination of the active San Jacinto fault, as discussed below.

Late Pleistocene to Holocene slip rates appear to decrease from northwest to southeast on the three sections along the southern front of the San Bernardino Mountains, leading us to define new San Bernardino North, San Bernardino South, and San Gorgonio Pass-Garnet Hill sections. Slip rates have been estimated to be about 24 mm/yr near Cajon Pass (Weldon and Sieh, 1985) and at Pittman Canyon (Seitz and Weldon, 1994). The long-term slip rate may be similar at Badger Canyon, but lower at

Plunge Creek to the southeast, based on preliminary data from McGill et al. (2006). At the southeastern end of the San Bernardino Valley, the San Andreas fault enters a very complex area where faulting is distributed over a broad area. South of this point, the region around the San Andreas is known as the San Gorgonio Pass structural knot, due to its complexity (Langenheim et al. 2005).

In the San Gorgonio Pass knot, the San Andreas fault was shown as a single through-going strand in the 1996 and 2002 CGS/USGS model. This representation was probably appropriate for a seismic hazard model, but an over-simplification for a deformation model. Accordingly, we developed a revised fault model for the San Gorgonio Pass area using the mapped strands included in CFM-R. The San Andreas fault in this region is divided here into two sections, the predominantly strike slip San Bernardino South section and the oblique San Gorgonio Pass-Garnet Hill section. Other significant faults in this area include the San Andreas north branch (Mill Creek) fault, the Mission Creek fault, and the San Gorgonio Pass faults. Sieh et al. (1994) reported a preferred late Quaternary slip rate of 2.1±0.5 mm/yr for the Mill Creek fault (North Branch San Andreas fault) at City Creek. Several other faults in the area may have slip rates of >1 mm/yr (Fumal et al. 2002; Yule and Sieh, 2003). Much of the long-term strain in this area may be accommodated on short, discontinuous active faults (Yule and Sieh, 2003). To allow for this complexity, we have added a section boundary on the San Andreas fault at its junction with the Mill Creek fault and the beginning of the San Gorgonio Pass knot. This new section boundary between the San Bernardino North and San Bernardino South sections is also in the area where additional slip may leave the San Andreas fault and be transferred to the San Jacinto fault through the Crafton Hills fault and related structures along the southeast side of the San Bernardino Valley, as proposed by Morton and Matti (1993). From its junction with the Mill Creek fault, the San Andreas continues straight, then bends abruptly to the south through the Burro Flat area, before bending back to nearly an east-west trend through the San Gorgonio Pass. We added a section boundary at the point where the San Andreas bends to an east-west trend, south of Burro Flat. The change in trend at this point is also related to a major change in tectonic style along the fault. The San Bernardino South section, north of this point, appears to be a near vertical strike-slip fault. The section east of this point, which we call the San Gorgonio-Garnet Hill section, appears to be oblique strike-slip with a major thrust component. The section continues on the same trend eastward through the San Gorgonio Pass and into the northern Coachella Valley. There it bends southward at its junction with the north branch (Mission Creek fault). The boundary between the San Gorgonio Pass-Garnet Hill section and the Coachella section to the south is at this change in trend and fault junction. From this section boundary to its southern end at Bombay Beach there do not appear to be additional changes in fault geometry, structural style, or slip rate.

San Jacinto and Elsinore Fault Sections

Updates for the current database are much less extensive for the San Jacinto fault and Elsinore faults. On both of these faults, the changes consist of showing the fault zone in the model as two parallel strands bounding a pull-apart basin, rather than a simple single strand. On the San Jacinto fault, the San Jacinto Valley and Anza sections are parallel to each other for about 24 km on either side of a pull-apart basin. The 2002 model created a "segment" boundary approximately in the center of the basin, resulting in both sections being about 12 km shorter than they really are. We modified these sections to show both parallel strands of the San Jacinto across the step-over area, but designated these as separate sections, so that the slip rate on each can be half the overall fault rate. Also, we extended the San Bernardino section of the San Jacinto fault to the northwest limit of the active scarps along the San Jacinto fault zone in the San Gabriel Mountains. This location is consistent with the southern end of the 1857 rupture on the subparallel San Andreas and thus best represents the locus of slip transfer between these two faults.

We made similar minor adjustments to the Elsinore fault zone, splitting off small sections where there are two parallel strands on either side of a step-over. Additionally, the modeled Elsinore fault from south of Corona through the Temecula area was shown on the west side of the trough defined by the fault system. We have re-drawn the fault model through this area to more closely follow the major active faults on the eastern side of the trough.

Changes to Other Faults in Southern California

The most significant changes for this database involve the addition of faults and modifications in the geometry of faults based on the CFM, as discussed above. The changes are summarized in Tables 1 and 2 and depicted in Figure 3.

Alternative Fault Models

In several areas, different investigators have developed alternative models for the detailed geometry of faults. Some of these alternatives involve differences in the trace of the fault, but most involve alternative dips or alternatives in the way faults may intersect with depth. Most faults are projected from their surface traces using estimated dips. This may lead to fault intersections, particularly for faults with low dips. In most cases it is not clear whether these fault surfaces pass through each other and continue to depth, or if they merge and what shape the merged fault would be. Alternative fault models were developed for the CFM-R for several faults. In the case of intersecting faults, CFM developed alternative models in which the two faults merge with depth, then follow the projection of either of the two faults. Each fault in Table 1 or Table 2 that has alternative models of the geometry

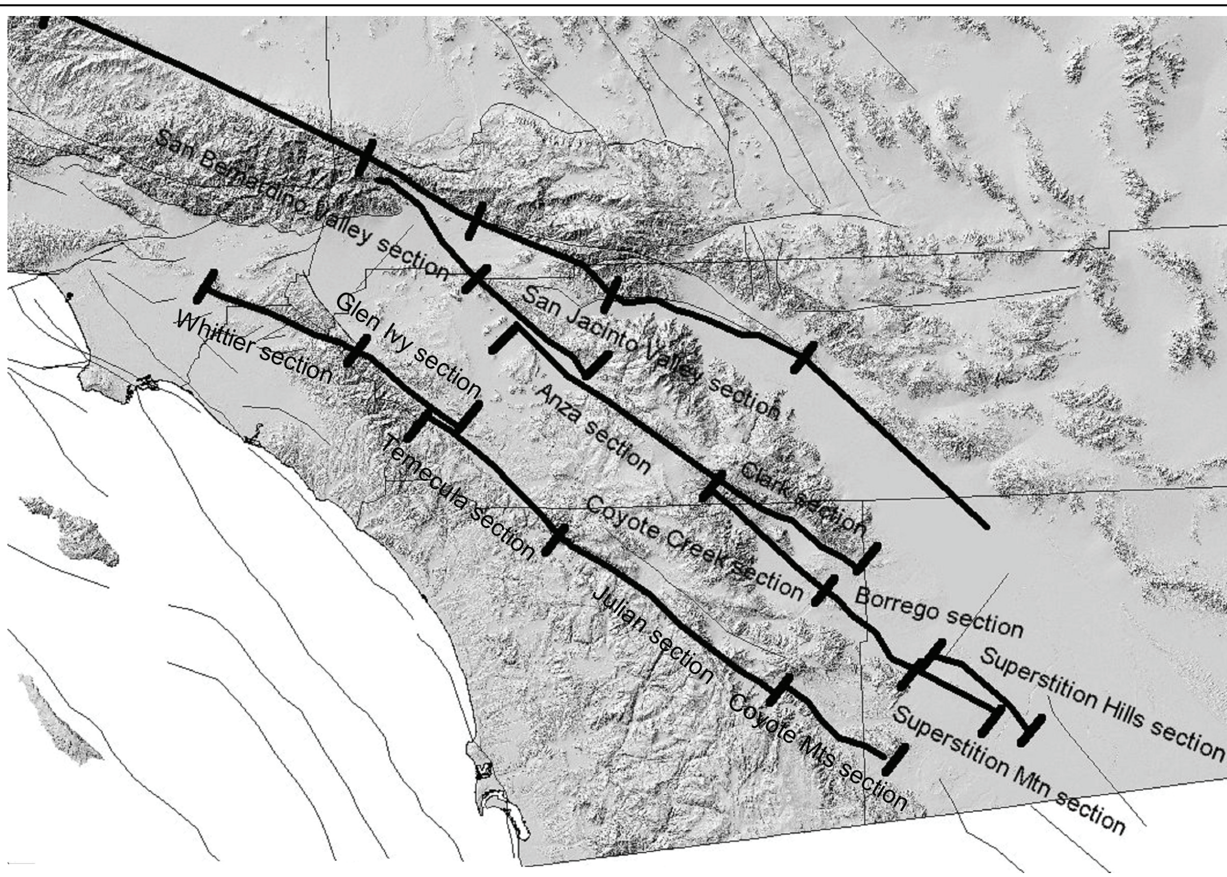

Figure 2, The Elsinore and San Jacinto faults, note the overlap between the Glen Ivy and Temecula sections of the Elsinore fault and the San Jacinto Valley and Anza sections of the San Jacinto fault. In these areas, separate sections are defined with one-half the slip rate of the adjoining sections.

has a model name listed in the "model" column. If there is no entry under "model" then there is only one version of the fault geometry and that geometry is used in all fault models. The model names are intended to be descriptive so that it is clear which faults are part of an alternative model and what major feature distinguishes the two models. In the case of two faults that dip toward each other, such as the Chino and Whittier, the two models are named "Whittier extends to base of seismicity" and "Chino extends to base of seismicity". In these examples the first named fault extends to the base of seismicity and the second extends to the average depth that it merges with the first.

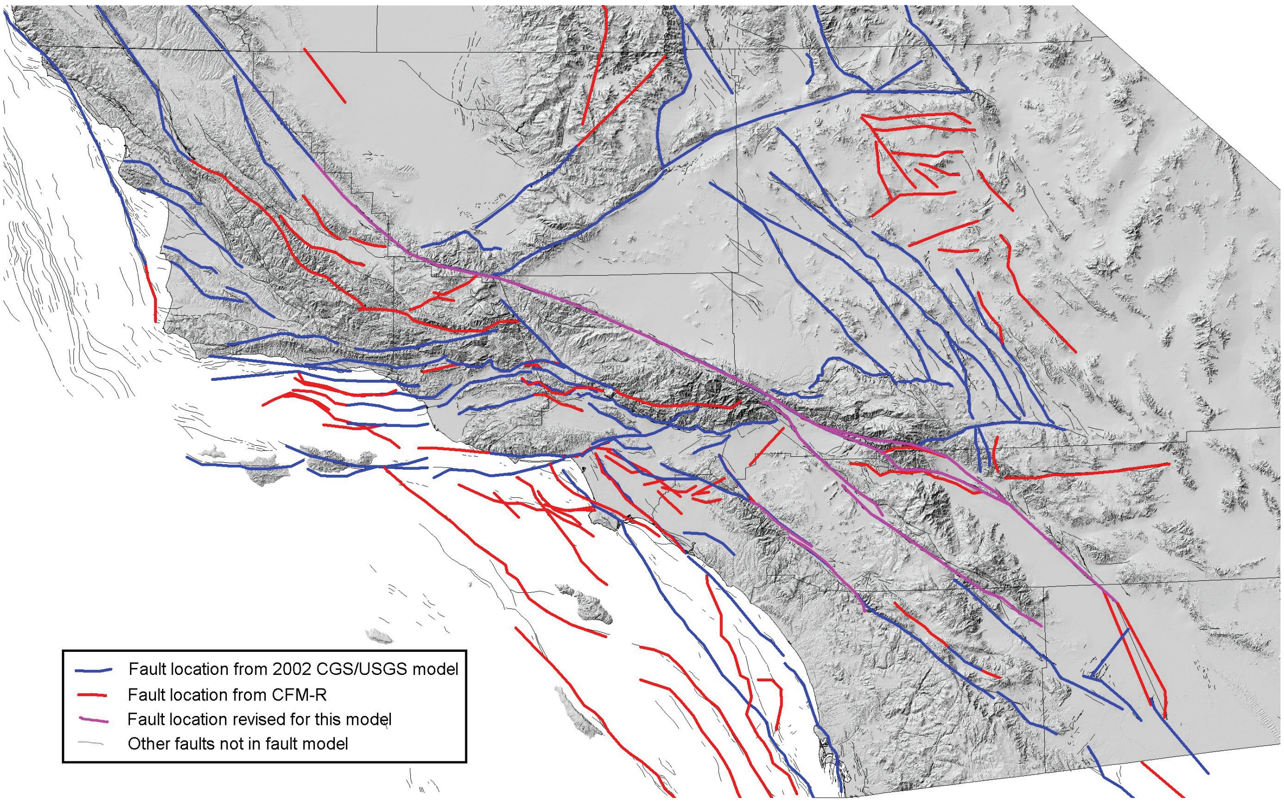

Figure 3. Revised fault sections in southern California.

In the database of fault parameters, we have designated two fault models: model FM2.1 and FM2.2. Each fault model includes one complete, statewide set of the geometric representations of faults. For faults where alternative geometric representations were developed for the CFM, one alternative is included in model FM2.1 and the other in FM2.2. It would be more complete and correct to include each individual alternate fault model as an independent logic tree branch, and sample those branches. However, the alternative models of individual faults generally do not drastically alter the length or slip rates of the faults involved, and tend to be relatively small and geographically separate from each other. For this reason, some of the alternate fault geometries may result in no difference in ground motions. Others may result in significant differences because one alternative raises the potential for ground shaking near or above low-angle faults, for example. With the two alternate statewide models we will be able to calculate ground motions and compare differences. If the alternative models do not significantly affect ground motions, they could be omitted to simplify future analysis.

The most complex of the alternative models covers the Santa Barbara Channel area (Figure 4). The main difference between the alternate models is in the north-dipping thrust faults: model FM2.1 has the low-angle (16 degree) Lower Pitas Point-Montalvo thrust fault while model FM2.2 has the relatively steep (26 and 42 degree dips) North Channel and Upper Pitas Point faults. For these faults, the overall convergence on the north-dipping faults in the 2002 model (the North Channel Slope and Oak Ridge-offshore) was either applied to the low-angle fault or split equally between the high-angle thrust faults.

Other alternate models are simpler, usually consisting of alternate representations of one or two faults. For three alternate models, involving 1) the Anacapa-Dume and Malibu Coast; 2) Santa Susana, Holser and Del Valle; 3) Whittier and Chino faults, the faults converge with depth. In each case it is possible to construct a model where the slip on the two faults merges onto a down-dip projection of either fault. Alternate models for the Santa Monica fault differ in the dip of the overall zone; the model with the lower angle dip has a greater seismogenic width, which may result in significantly higher ground motion hazards. Alternate models for the Redondo Canyon fault show two different traces, from two different source maps. Alternate models for the Newport-Inglewood fault differ in that one is subdivided in en echelon strands, while the other is depicted as a single through-going fault. Alternate models for the Puente Hills thrust are similar: one is the detailed depiction of three separate thrust ramps developed for the CFM, while the other is the simplified single surface used in the 2002 model. In this case there is not a question which of the models is a more accurate depiction of the fault, but if there is no effect on the resulting ground motion calculations it may be appropriate to keep the simpler fault representation.

Fault Slip Rate Values

Slip rate and slip rate error values in this database represent the values developed over the past 10 years through an inclusive process that has attempted to solicit and incorporate input from all parts of the seismic hazards field. In the current WGCEP model, set of kinematically possible, internally consistent slip rates on the entire fault model is a deformation model. The WGCEP has developed a deformation models that incorporate “best estimate” slip rates for most faults in the state, with alternate slip rates for the major faults in southern California. Slip rates given in Table 1 are the rates from deformation model 2.1 as described below. The slip rates that are dependant on choice of deformation model are designated in Table 1.

It is difficult to quantify the error in slip rate estimates from such a wide variety of data. For many faults the uncertainty in slip rate is estimated as an arbitrary fraction of the slip rate: 1/4 for well constrained faults and 1/2 for poorly constrained. Nevertheless, the range of slip rates is inferred to encompass about 95% of the observations and represent approximately 2σ in uncertainty. Ranges in

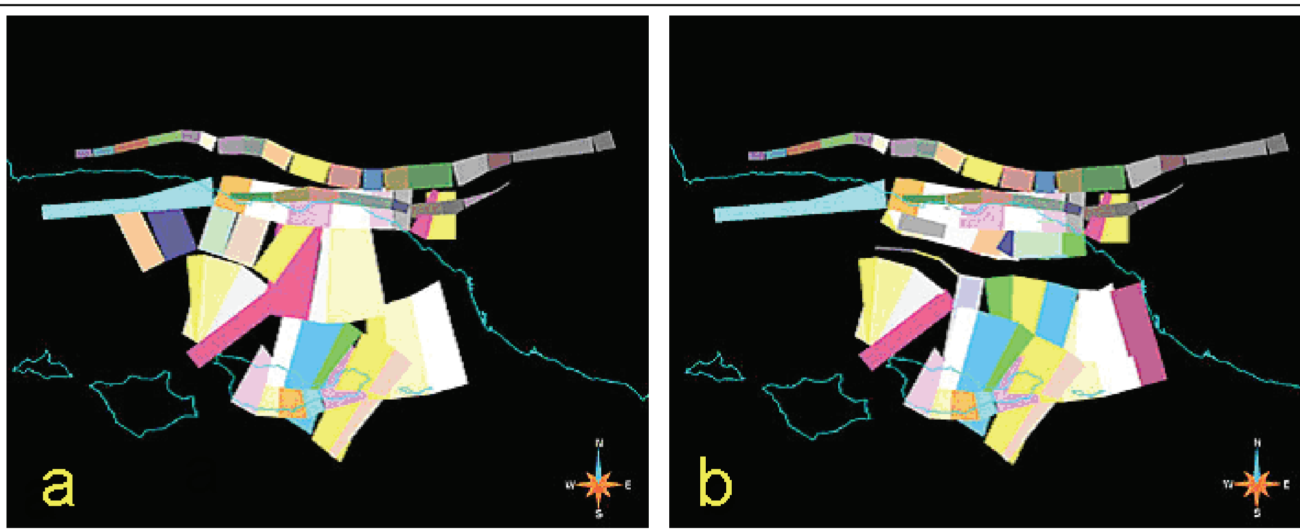

Figure 4: Alternative fault models of the Santa Barbara channel region. Both alternatives include the Santa Ynez, Mission Ridge-Arroyo Parida-Santa Ana, and Red Mountain in the north and the Channel Islands Western Deep Ramp in the south. In the central channel, alternative a has the Lower Pitas Point-Montalvo fault, which dips gently to the north. Alternative b has the North Channel and upper Pitas Point faults dipping steeply to the north and the Oak Ridge fault dipping gently to the south. Images from CFM web page http://structure.harvard.edu/cfm-r_project/cfmr.html

slip rates are represented symmetrically about the mean for simplicity and because we found it difficult to assign more detailed uncertainty estimates based on sparse slip rate information.

In developing the 1996 CGS/USGS model for the NSHMP, Petersen et al. (1996b) conducted a comprehensive survey of the available slip rate information through literature searches and many discussions, meetings, and written correspondence with the authors of the fault studies to assign earthquake activity rates and slip rates along faults. They also evaluated published compilations of slip rates given by Bird and Rosenstock (1984), Clark et al. (1984), Wesnousky (1986), Ziony and Yerkes (1985), Thenhouse (personal communication), Humphreys and Weldon (1994), Petersen and Wesnousky, (1994), Petersen et al. (1996a), WGNCEP (1996) and McCrory (1996). Petersen et al. (1996b) considered slip rate to be well constrained if the direction, amount, and timing of displacement have been demonstrated. Moderately constrained slip rates generally have significant uncertainty for one of these components. Poorly constrained slip rates have either significant uncertainty with respect to both amount and timing of displacement or else the reported slip rate is a long-term (late Cenozoic) average rate. These rankings, along with the slip rate references from Petersen et al. (1996b) are included in the slip rate details field in Table 1. Slip rates for some faults were changed for the 2002 CGS/USGS NSHMP model. Slip rate references and comments from Cao et al. (2003) are also included in Table 1. The slip rates in this database are essentially unchanged from values in the 2002 CGS/USGS model for the NSHMP except as noted. We include slip rates for all faults in the 2002 model, regardless of whether the fault trace and depth was changed to correspond with CFM-R. Faults that were not in the 2002 model generally do not have slip rate information that has been evaluated through the community-wide process and as a result no slip rate information is included for those faults.

New data on slip rates and their implications on deformation across the fault system were major topics at workshops in Northern California on July 26, 2005 and November 8, 2006 and in Southern California on September 11, 2005 and November 13, 2006. The workshop participants considered alternative models for the potential trade-off in slip between the southern San Andreas and San Jacinto faults, for relatively high and low slip rates in the Eastern California Shear Zone across the Mojave Desert and for relatively high and low slip rates the strike-slip faults in the Peninsular Ranges. No new data was presented that would require changes to the recently developed fault slip rate estimates for the Bay Area by WGCEP-2002. In southern California, workshop participants reached a consensus that slip rates in the Peninsular Ranges were appropriately modeled by the current estimates of slip rate and uncertainty but that right-lateral shear in the Eastern California Shear Zone was higher than previously modeled and that a deformation model would have to subtract this slip from the San Andreas system near the north end of the Coachella Valley. This transfer of slip from the Coachella section of the San Andreas fault to the faults of the Eastern California Shear Zone is a significant change from previous models, and is found in all of the deformation models currently considered. Workshop participants also concluded that there was much new preliminary data concerning the trade-off between slip rates on the San Jacinto and San Andreas faults, and that it was not possible to reach a consensus, single, "best estimate" model at this time. Consequently, this trade-off warrants development of alternative deformation models.

Our main effort was to develop a preferred deformation model that is consistent with the geological slip rate studies as well as with geodetic rates and the plate rate. For those parts of California where we are using the 2002 model without modifications, that model was compared to geodetic rates and the plate rate when it was developed in 1996 (Petersen et al. 1996b).

Our guiding principle in developing deformation models was that the rates on the faults across the plate boundary had to sum to the plate rate and that slip along fault zones had to be constant between fault intersections or splays. In some cases where the slip rates on faults do not sum to the plate rate, geodetic models suggest high rates of shear, and surface faults have not been thoroughly studied, we show an area as a “zone of distributed shear”. Zones of distributed shear were established in the 1996 NSHMP for western Nevada and northeastern California, to show areas where there appeared to be a large discrepancy between the geodetic deformation in a region and the slip rate that had been determined on the faults in that region. This concept can also be applied to other areas of California. Slip rates on the modeled faults, plus zones of distributed shear are assumed to sum to the overall plate rate. Constraining the slip rates on the major faults to sum to the plate rate is a conservative assumption because it neglects the deformation on numerous minor faults. If seismic hazard models need to account for widely scattered earthquakes on minor faults, which may be modeled as “background seismicity”, the rates of motion on the other faults could be reduced by the total moment of the “background seismicity”.

In developing the deformation models, we checked that the slip on an individual fault zone was constant along its length. The Elsinore and San Jacinto faults both have multiple strands. The slip on those strands should sum to the slip rate on the fault zone as a whole. For areas where there are two parallel strands, we assign half the overall slip rate to each strand unless there is more detailed information available. We applied half the overall slip rate to sections on either side of pull-apart basins on the San Jacinto and Elsinore faults. Similarly, slip on the Julian section of the Elsinore fault is reduced 1 mm/yr from the adjoining sections to the north to account for slip on the parallel Earthquake Valley fault.

In the 2002 model, the San Jacinto fault does not have a consistent long-term slip rate along its length. The 12 mm/yr modeled slip-rate on the Anza section remains the same to the south end of the fault zone, including the area where the parallel Coyote Creek fault slips at 4 mm/yr. In all of our revised models, we split the Anza section at the north end of the Coyote Creek fault, creating a new Clark section of the San Jacinto fault. In all deformation models, slip on the Anza section, to the north, is the sum of the sub-parallel Coyote Creek and Clark sections to the south. All of our deformation models have significant long term slip extending to the south end of the Clark fault. South of that point, there does not appear to be a through-going fault at the surface.

Alternative Deformation Models

Three different deformation models (or sets of slip rates) have been derived to reflect uncertainties in slip-rate partitioning between the southern San Andreas and San Jacinto faults in southern California. Our motivation for considering variations in these parameters is the growing number of studies, both geologic and geodetic, suggesting that the slip on the San Jacinto fault zone is sub-equal to that on the San Andreas, in contrast to previous models where slip on the San Jacinto was about half that of the San Andreas. In many ways these recent studies reflect, and attempt to answer questions raised by Allen (1957) regarding how slip on the San Andreas fault system is transferred through, or around, the San Gorgonio Pass area. Recent studies include geodetic models (Fay and Humphreys, 2005; Fialko, 2006; Bennett et al. 2004, Meade and Hagar 2005), geologic studies resulting in short-term and long-term slip rates for the San Jacinto fault; (Kendrick et al. 2002; Dorsey, 2003; Janecke et al. 2005), and slip rate studies of the San Andreas fault (Yule and Sieh, 2003, van der Woerd, 2006).

These recent studies place new emphasis on older studies, such as Sharp, 1981 and Morton and Matti, 1993 that suggested slip rates on the San Jacinto fault could be outside the range allowed in previous models. In developing the alternative deformation models we considered the trade-off in slip rate between the San Jacinto and San Andreas faults. For both faults, there is a wide range of slip rates that are possible within the results of geologic or geodetic slip-rate studies. It is highly unlikely, however, that the slip rate on the San Jacinto is at the low end of the possible range and the slip rate on the Coachella section of the San Andreas Fault is at the low end the possible range. If both were true, the sum of the known slip rates across southern California would be much less than the plate rate. Similarly, both San Jacinto and Coachella San Andreas rates can’t both be at the high end of their possible range, because the slip rates across southern California would be higher than the plate rate. In this case where the choice of one parameter restricts our choice of the other, we can develop alternative models for a low San Jacinto with a high San Andreas slip rate, a high San Jacinto with a low San Andreas, and a central “preferred” value for each. In each of these models, the estimated error in the slip rate within the model is smaller that the estimate of error from geologic studies overall, because we are in effect saying that “if the rate on fault A is in this range, the slip on fault B must be in that range” so that slip-rates on all the faults sum to the plate rate. Table 3 below summarizes the models that we thought were consistent with all available geologic and geodetic rates.

Based on recent work and workshop participants’ views, there appears to be a growing view that the slip on the Coachella section of the San Andreas and the San Jacinto fault are approximately equal. As a result, the deformation models with that proportion, D2.1 and D2.4, are currently considered the communities best estimate and collectively given 50% weight in the WGCEP model. There remains a significant body of opinion that the San Andreas is the dominant fault in the fault system and carries most of the slip. As a result, deformation models 2.3 and 2.6 are given 30% weight in the WGCEP model. Deformation models in which the San Jacinto fault carries more slip (D2.2 and D2.5) are supported by some recent data but not currently favored by a large proportion of the community. Those deformation models are given a collective 20% weight in the WGCEP model.

There are no new data on the slip rate on the northern sections of the San Jacinto fault, but all the alternative models include increasing slip rates southward on the San Jacinto from its junction with the San Andreas near Cajon Pass. These slip rates are constrained by slip rate studies along the San Andreas, the San Jacinto to the south, and the requirement that the sum of the slip rates on the two faults equal the slip rate on the San Andreas north of their junction. Because the long term slip rate on the San Bernardino, north section of the San Andreas is only a few mm/yr lower than the Mojave section, the modeled slip rate on the San Bernardino Valley section of the San Jacinto fault is only 6 mm/yr in deformation model 2.1. This is less than the slip rate in previous models and only one third of the slip rate on the sections of the San Jacinto to the south, implying that significant slip transfers from the San Andreas to the San Jacinto across the San Bernardino Valley or farther south.

Future development of deformation models is anticipated to explicitly include geodetic deformation data, and attempt to resolve the rates of deformation on and off of the major faults. It is anticipated that more sophisticated deformation models will allow for determination of slip rates on many faults in southern California, as recently modeled by Cooke and Marshall (2006) for the Los Angeles basin. The next generation of deformation models may also allow us to solve long-standing problems in the Bay Area, including discrepancies in slip rates as slip is transferred among the Calaveras, Hayward, Greenville, and Concord-Green Valley faults. The current deformation models attempt to provide alternatives for the most significant uncertainty in the distribution of slip: the proportion of slip on the San Jacinto and southern San Andreas fault. There are numerous smaller discrepancies to resolve, however, before a complete, kinematically consistent deformation model is available.

Zones of Distributed Shear

The 1996 and 2002 NSHMP included zones of distributed shear in northeastern California and western Nevada for areas where all of the shear could not be accounted for on known faults. These zones of distributed shear are modeled with 4 mm/yr of right lateral shear, faults within these zones accommodate additional shear. South of those zones, in the western Basin and Range, right-lateral faults accommodate approximately 8 mm/yr of right lateral shear. South of the Garlock fault, slip rates on the faults within the eastern California shear zone do not equal the total right-lateral shear indicated by geodetic or plate-rate studies. In order to make a statewide deformation model that is more kinematically consistent, there must be a zone that transfers plate-boundary shear from the San Andreas northward across the Mojave Desert. Slip within this zone should be consistent with the right-lateral shear on the faults north of the Garlock and with right-lateral shear on the existing shear zones and faults to the north. Geodetic deformation rates across the Eastern California Shear Zone in the

Mojave desert prior to the Landers earthquake were estimated to be about 8 mm/yr (Savage and others, 1990). Long term geologic rates were estimated to be 6-12 mm/yr (Dokka and Travis, 1990). More recently, geodetic deformation rates across the Mojave suggest 14-16 mm/yr of right lateral shear (Meade and Hagar, 2005). Rates that include GPS data from the 1990's, however, may include some post-seismic strain from the Landers and Hector Mine earthquakes, so it is probably not appropriate to consider the total current deformation rate in a long-term seismic hazard model. Our preferred rate of deformation across the eastern California shear zone, considering right-lateral shear on faults north of the Garlock fault, geodetic rates, the long term plate rate, and long –term geologic rates is 10+ 4 mm/yr. Most of this slip is occurring on the known mapped faults. Oskin (in press) has determined slip rates on faults within the eastern California shear zone that total about 6 mm/yr. The remaining 4 mm/yr may occur on faults that have not been studied, such as the Ludlow or Goldstone Lake faults, may be accommodated by block rotations and slip on several east-west trending faults, or may occur on other faults that are not currently known to be active.

Another zone of distributed shear covers the Imperial Valley, south of the end of the San Andreas fault and southeast of the end of the San Jacinto fault. At the north end of the zone, The San Andreas is slipping at 20 mm/yr and the Clark section of the San Jacinto fault is slipping at 14 mm/yr (in deformation model 2.1). In the Imperial Valley, the Imperial fault is slipping at 20 mm/y and the Superstition Hills and Superstition Mountains faults are slipping at 4 and 5 mm/yr respectively. This leaves 5 mm/yr unaccounted for through the entire area. In the northern Imperial Valley east of the Coyote Creek fault (south of the end of the Clark and San Andreas faults and north of the Superstition Hills fault) 30 mm/yr is unaccounted for. Much of this slip may be released as microseismicity in the Brawley Seismic Zone and other "background" seismic sources. Some of the slip is also released as aseismic creep, triggered slip and as afterslip, which accounted for significant proportions of the surface slip in the 1968 Borrego Mountain; 1979 Imperial Valley; and 1987 Superstition Hills earthquakes (Clark, 1972; Sharp and others, 1982; Kahle and others, 1988). Since most, or possibly all, of the additional slip in the Imperial Valley zone of distributed shear is occurring aseismically or in small "background" earthquakes, this zone may have no large earthquakes beyond those on the included faults.

Nevertheless, we are including this zone to balance the kinematic model. If all of the slip in this zone is aseismic or in "background" earthquakes, it will have no effect on the seismic hazard model because background earthquakes are already accounted for (see Appendix J). Future work may find that aseismic slip and small earthquakes cannot account for all of the shear in this area, and the potential for larger earthquakes from the area needs to be considered.

The third new zone of distributed shear includes the area in San Gorgonio Pass, called the San Gorgonio Pass knot, along the San Andreas fault. In this area, as much as half the shear at the surface is accommodated by other, generally short, right lateral and reverse faults (Yule and Sieh, 2003). It is not known if these faults will produce independent earthquakes or slip with major ruptures on the San Andreas fault. Yule (personal communication, 2006) estimates that the zone of complex, short, right-lateral faults extends from the surface to about 5 km depth, and below that the San Andreas is likely to be a through-going fault. This estimate is consistent with structural models of Langenheim et al. (2005), which show the complex zone of thrust faulting to 5 to 10 km depth, and through-going strike-slip faults below that. Half of the motion in approximately one-third to one-half of the crust being taken up off of the San Andreas fault suggests that approximately one-sixth to one fourth of the motion on the San Andreas fault through San Gorgonio Pass should be apportioned to the San Gorgonio Pass zone of distributed shear.

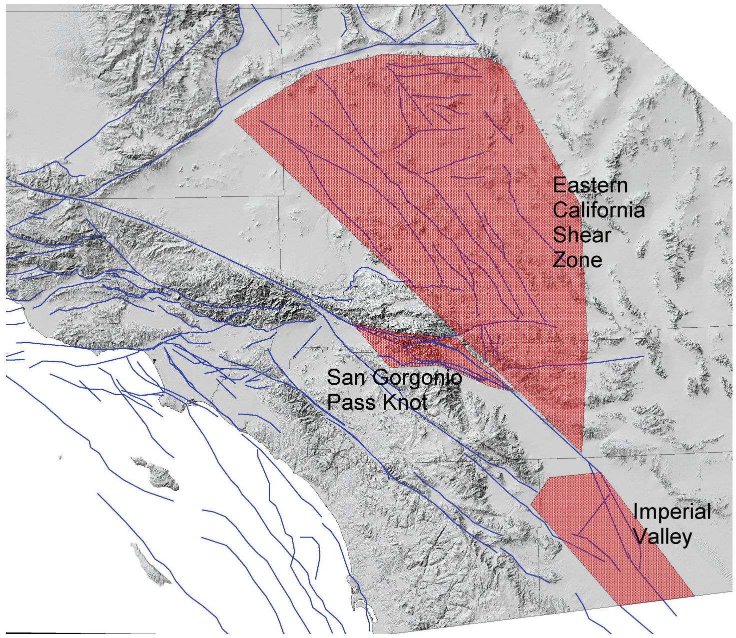

Figure 5. New C-zones in southern California

Fault Rupture Model Designations

In subsequent development of seismic hazard models based on the fault parameters described here, we have adopted descriptive designations for types of fault zones based on how detailed our knowledge of those zones is, and how detailed our models of earthquake recurrence on those zones can be. In building fault rupture models, previous working groups and the NSHMP have adopted the characteristic earthquake model based on segmented faults. Each segment is composed of one or more fault section. Segments, the smallest source of a characteristic earthquake, may be composed of more than one section, but in no case is a section split to form segments. Faults in the seismic hazard models are designated Type A, B, or C based on the classes in the 1995 Working Group Report (WGCEP, 1995) and the 1996 and 2002 National Seismic Hazard Maps. "Type A" faults are those where previous working groups or the NSHMP has developed detailed earthquake recurrence models based on segments where all of the modeled earthquakes rupture the entire segment or multiple segments. That is, earthquakes on "Type A" faults are modeled as characteristic earthquakes on segments or combinations of segments. In order to develop these models, there must be sufficient data on timing of past events and slip-per-event to determine the extent of past earthquakes and the relative frequency of earthquakes ruptures on different segments or combinations of segments. "Type B" faults are "major faults with measurable slip rates but inadequate information on segmentation, displacement or date of last earthquake" (WGCEP, 1995). In the NSHMP, "Type B" faults have "characteristic earthquakes" that rupture the entire section of the fault. Both "Type A" and "Type B" faults may also have smaller earthquakes that rupture less than a complete segment, or parts of adjacent segments. Earthquakes that may occur without regard to segment boundaries are commonly referred to as "floating earthquakes". "Zones of distributed shear" are designated "Type C" zones, which "may contain diverse or hidden faults" (WGCEP, 1995) and can be thought of as areas where the overall deformation rate, fault orientation, and style of faulting are known, and earthquakes may occur on one of a number of recognized or unrecognized faults. Our designation of fault zones uses the same definitions and adopts the designations of the NSHMP, 2002, with a few exceptions. In southern California, the Garlock fault has sufficient data from recent paleoseismic investigations that it can now be classified as a "Type A" fault.

One significant change has affected how faults are modeled in the San Francisco Bay Area. The 2002 Working Group Report (WCCEP, 2003), calculated time dependant hazards based on segmented models for all faults in the region, including some that had been designated as Type B faults in the NSHMP (1996), and one that had not previously been considered. The 2002 National Seismic Hazard Maps used the values from the 2002 Working Group Report for all the faults in the region, essentially treating all the listed faults as Type A faults. This change was not noted in the documentation for the 2002 NSHMP. In reviewing these models, we found that there are a number of faults with little or no data on dates or displacements of previous earthquakes. At workshops in November, 2006, there was extensive discussion of how these faults with minimal available earthquake recurrence data (the Greenville, Mount Diablo, San Gregorio, Monte Vista-Shannon and Concord-Green Valley) should be modeled. Generally, it was recognized that the segmented models developed for these faults by Working Group 2002 are poorly constrained, but if all faults were to be treated as segmented faults, the models for these faults were the best that could be assembled from the available data. Given the choice of modeling these faults as Type A or Type B faults, however, attendees were about evenly split between those who felt that they should be modeled as Type B faults and those who felt that the poorly constrained Type A models should be used. To resolve this dichotomy we considered the possibilities of 1) making A faults of all faults with data of similar quantity in other parts of the State or 2) allowing faults with similar levels of data to have different classifications. We concluded that consistency was most important, and since it was impossible to make A faults out of dozens of poorly understood faults elsewhere in California that it was necessary to develop a simple rule for distinguishing Type A from Type B faults. The factor that distinguishes the types of faults is the amount of data available about segmentation and recurrence. We classify faults as “Type A” if there is paleoseismic information on two or more segments so that recurrence histories can be compared. Faults with more segments require more paleoseismic data to develop Type A recurrence models. Faults where earthquake recurrence histories are unknown or known from only one segment are classified as Type B. Application of this rule results in our treating the poorly understood faults in the Bay Area listed above as B faults.

Potential Changes to Earthquake Recurrence Models

Since development of the WGCEP (2002) fault segments, Fumal et al. (1999, 2003) have found that earthquakes have occurred on the San Andreas at Arano Flat every 105 years, on average, a higher rate than calculated for the Santa Cruz Mountains segment by the WGCEP (2002). At the northern California workshop on 11/08/06, Tom Fumal presented his results from Arano Flat, implications of the recurrence and average slip at that site, and whether trenches at Grizzly Flat (Schwartz et al. 1998) constrain the model. Three options are possible: 1) do not use Fumal’s data because only the average recurrence is published, a full description and analysis of the site, including the critical earthquake displacements, are not. 2) Construct a model where some earthquakes at Arano Flat are assumed to rupture only the southern part of the Santa Cruz Mountains segment, or 3) modify the model so that ruptures on the Santa Cruz Mountains segment (including floating earthquakes and multi-segment ruptures) occur every 105 years. These options were discussed by the group at the workshop. Most felt that the recurrence and average slip data from Arano Flat should be used when fully documented in a publication. Distinguishing between options 2 and 3 center on the size of earthquakes at Arano Flat, and whether the work at Grizzly Flat can show that any of them did not rupture the entire Santa Cruz Mountains Segment. It was pointed out at the workshop that the 30 km length of the southern part of the Santa Cruz Mountains segment is too short for typical ground-rupturing earthquakes of M>7.0. Average displacement of 2 m also does not appear to be consistent with a short segment. On the other hand, trench logs from Grizzly Flat do not record the pre-1906 earthquake recorded at Arano Flat. A possible explanation for this is that fault strands in older material at Grizzly Flat represent one or several of the recent earthquakes at Arano Flat. The preponderance of views at the workshop was that there was insufficient data to justify sub-dividing the Santa Cruz Mountains segment, but that the Arano Flat earthquakes could represent the full segment ruptures, multi-segment ruptures, or floating earthquakes allowed by the existing model. Once Fumal’s study has been peer-reviewed and fully published, it may result in substantial modifications of the existing model, probably increasing the rate of earthquakes on the Santa Cruz section and perhaps the adjacent Peninsular section of the San Andreas fault to be consistent with the recurrence at Arano Flat.

The other broad change in the current model compared to the 2002 NSHMP model involves how the earthquake recurrence is modeled on Type B faults. All Type B faults are assumed to have potential earthquakes that range from M6.5 up to the maximum magnitude that is consistent with the total length of the fault. In most cases a single fault section, is considered a complete “type B” fault. In some cases, earthquake rupture models for the NSHMP (1996 and 2002) combined a series of fault sections along a fault zone into a single “Type B” fault. Examples from the NSHMP 2002 include the Maacama and Bartlett Springs fault zones in northern California. In the Mojave Desert single “Type B” fault models were assembled from sections of different named faults. There are several examples of faults that are divided into sections in the Quaternary Fault and Fold Database (Bryant, 2000; Hart and Bryant, 2001) but modeled in the NSHMP (2002) and described here as individual faults. It was noted in workshops in Northern California on 11/08/06 and Southern California on 11/13/06 that several additional faults were essentially continuous, with similar style of faulting and slip-rate, and are only modeled as different faults because of changes in nomenclature or small stepovers or slight changes in trend. Examples include the Newport-Inglewood, Newport-Inglewood (offshore) and Rose Canyon faults. At both workshops the participants thought the current models, showing these as separate faults should be changed, and the faults combined. A preliminary list of additional faults that should be combined included the Palos Verdes and Coronado Bank; Newport-Inglewood, Newport-Inglewood (offshore), and Rose Canyon; Anacapa-Dume and Santa Monica; Oakridge (Offshore) West Extension, Oakridge (Offshore), and Oakridge (Onshore); Pitas Point (Upper) and Ventura-Pitas Point; Santa Ynez (west) and Santa Ynez (east); Sierra Madre (San Fernando) and Sierra Madre; Death Valley (N of Cucamungo), Death Valley (Northern), Death Valley (Black Mts Frontal Fault) and Death Valley (South); Hunter Mountain-Saline Valley and Panamint Valley; Little Salmon (offshore) and Little Salmon (onshore). Other possible connections were examined and may be considered in the future, but these faults appear to be the most similar. Several faults were specifically mentioned as inappropriate to connect into larger B-faults including connecting the Raymond/Hollywood with the Santa Monica because there are significant changes in style of faulting or slip rate between faults that, in map view, appear to be continuous. Each of the faults within these groups are very similar in style of faulting and long-term slip rate, and have minor discontinuities separating the strands with different names along strike. In modeling the earthquake recurrence, these combined faults with corresponding larger maximum magnitudes should be modeled as B-faults. The original, uncombined fault sections should also be considered as B-faults. Because the connections between these faults are uncertain, and the original un-connected model may also be correct, the combined B-faults and the original uncombined B-faults should be equally weighted in the seismic hazard model.

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate	slip rate error	Aseis-mic slip	top depth	bottom depth	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Main strands of the San Andreas fault system											
San Andreas (Offshore) [1a]		2002	180	90	n/a	24	3	0	0	11	Slip rate based on Niemi and Hall (1992) and Prentice, et al. (1991). WG99/WG02 source parameters used in 2002.
San Andreas (North Coast) [1b]		2002	180	90	n/a	24	3	0	0	11	Slip rate based on Niemi and Hall (1992) and Prentice, et al. (1991). WG99/WG02 source parameters used in 2002.
San Andreas (Peninsula) [1c]		2002	180	90	n/a	17	4	0	0	13	WG99/WG02 source parameters used in 2002.
San Andreas (Santa Cruz Mtn) [1d]		WGCEP 2007	180	90	n/a	17	4	0.1	0	15	WG99/WG02 source parameters used in 2002 for Santa Cruz Mtn section. Frequency of earthquakes revised in 2006 based on more frequent earthquakes at Arano Flat (Fumal et al. 1999, 2003).
San Andreas (Creeping Section) [1e]		2002	180	90	n/a	34	5	1	0	12	WG99/WG02 source parameters used in 2002.
San Andreas (Parkfield) [1f]		CFM-R	180	90	n/a	34	5	0.8	0	10.2	Slip rate reported by WGCEP (1995)
San Andreas (Cholame) [1g]		WGCEP 2007	180	90	n/a	34	5	0	0	12	Slip rate based on analogy with Carrizo section.
San Andreas (Carrizo) [1g]		WGCEP 2007	180	90	n/a	34	3	0	0	15.1	Slip rate based on Sieh and Jahns (1984)
San Andreas (Big Bend) [1g]		WGCEP 2007	180	90	n/a	34	3	0	0	15.1	Slip rate based on Sieh and Jahns (1984). Section split from 2002 Carrizo section because of difference in trend and possible differences in slip distribution in 1857 and 1812 earthquakes.
San Andreas (Mojave N) [1g, 1h]		WGCEP 2007	180	90	n/a	27	7	0	0	15.1	Slip rate based on Sieh (1984), Salyards et al. (1992), and WGCEP (1995) Section split from 2002 Mojave section because differences in slip distribution in 1812 earthquake.
San Andreas (Mojave S) [1h]		WGCEP 2007	180	90	n/a	29	7	0	0	13.1	Slip rate based on Sieh (1984), Salyards et al. (1992), and WGCEP (1995) Section split from 2002 Mojave section because differences in slip distribution in 1812 earthquake.
San Andreas (San Bernardino N) [1i]		WGCEP 2007	180	90	n/a	22	6	0	0	12.8	Slip rate reported by Weldon and Sieh (1985) Section split from 2002 San Bernardino section at intersection of north branch (Mill Creek fault).
San Andreas (San Bernardino S) [1i]		WGCEP 2007	180	90	n/a	16	6	0	0	12.8	Slip rate reported by Weldon and Sieh (1985) Section split from 2002 San Bernardino section at intersection of north branch (Mill Creek fault). Slip rate reduced from San Bernardino North section to accommodate slip transfer to San Jacinto fault and San Gorgonio knot zone of distributed shear.
San Andreas (San Gorgonio Pass - Garnet Hill) [1i, 250*]		WGCEP 2007	180	58	N	10	6	0	0	16.4	Slip rate reported by Weldon and Sieh (1985). Slip reduced from Coachella section by 10 mm/yr total slip in Eastern California Shear Zone.
San Andreas (Coachella) [1j]		2002	180	90	n/a	20	6	0.1	0	11.1	Slip rate based on Sieh and Williams (1990); Sieh (1986); Keller et al. (1982); Bronkowski (1981) Section modified from 2002 by moving northern end point to intersection of North Branch (Mill Creek fault) with Banning section. Aseismic slip factor of 0.1 applied due to documented creep and triggered slip.
Imperial [132]		CFM-R	180	82	NE	20	5	0.1	0	14.6	Slip rate based on study by Thomas and Rockwell (1996). Aseismic slip factor of 0.1 applied due to documented creep and triggered slip (Sharp and others, 1982)
San Jacinto (San Bernardino) [125a]		WGCEP 2007	180	90	n/a	6	4	0	0	16.1	Slip rate reported by WGCEP (1995). Southern end of section moved to south margin of San Bernardino valley, inferred

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseismic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
											change from compressional to extensional component of motion.
San Jacinto (San Jacinto Valley) [125b]		WGCEP 2007	180	90	n/a	18	6	0	0	18.5	Slip rate reported by WGCEP (1995). Slip rate changed to high end of range from geologic studies for consistency with geodetic studies.
San Jacinto (San Jacinto Valley, stepover) [126b]		WGCEP 2007	180	90	n/a	9	4	0	0	16.8	Slip rate reported by WGCEP (1995). Slip rate on zone distributed equally between parallel faults on either side of stepover.
San Jacinto (Anza, stepover) [125c]		WGCEP 2007	180	90	n/a	9	4	0	0	16.8	Slip rate reported by WGCEP (1995). Slip rate on zone distributed equally between parallel faults on either side of stepover.
San Jacinto (Anza) [125c]		WGCEP 2007	180	90	n/a	18	6	0	0	16.8	Slip rate reported by WGCEP (1995). Slip rate changed to high end of range from geologic studies for consistency with geodetic studies.
San Jacinto (Clark) [125c]		WGCEP 2007	180	90	n/a	14	6	0	0	16.8	Slip rate reported by WGCEP (1995). Slip rate changed to high end of range from geologic studies for consistency with geodetic studies, then reduced by slip on parallel Coyote Creek section.
San Jacinto (Coyote Creek) [125d]		CFM-R	180	90	n/a	4	6	0	0	15.9	Slip rate reported by WGCEP (1995).
San Jacinto (Borrego) [125e]		CFM-R	180	90	n/a	4	6	0.1	0	13.1	Slip rate reported by WGCEP (1995). Aseismic slip factor of 0.1 applied due to documented triggered slip and afterslp (Clark, 1972)
Superstition Hills [125f]		CFM-R	180	90	n/a	4	2	0.1	0	12.6	Slip rate reported by WGCEP (1995). Aseismic slip factor of 0.1 applied due to documented triggered slip and afterslip (Kahle and others, 1988).
Superstition Mountain [125g]		CFM-R	180	90	n/a	5	3	0.1	0	12.4	Slip rate based on Gurrola and Rockwell (1996)
Whittier (FM 2.1) [126a]	Whittier extends to base of seismicity	CFM-R	150	75	NE	2.5	1	0	0	14.1	Slip rate based on Rockwell et al. (1990); Gath et al. (1992) description of offset drainage.
Whittier (FM 2.2) [126a]	Chino extends to base of seismicity	CFM-R	150	70	NE	2.5	1	0	0	12.4	Slip rate based on Rockwell et al. (1990); Gath et al. (1992) description of offset drainage.
Elsinore (Glen Ivy) [126c]		CFM-R	180	80	SW	5	2	0	0	13.3	Reported slip rates vary from 3.0-7.2 (Millman and Rockwell, 1986)
Elsinore (Glen Ivy stepover) [126c]		WGCEP 2006	180	80	SW	2.5	2	0	0	13.3	Reported slip rates vary from 3.0-7.2 (Millman and Rockwell, 1986) Slip rate on zone distributed equally between parallel faults on either side of stepover.
Elsinore (Temecula stepover) [126d]		WGCEP 2006	180	80	NE	2.5	2	0	0	13.3	Reported slip rates vary from 3.0-7.2 (Millman and Rockwell, 1986) Slip rate on zone distributed equally between parallel faults on either side of stepover.
Elsinore (Temecula) [126d]		WGCEP 2006	180	88	NE	5	2	0	0	14.2	Slip rate reported by WGCEP (1995). Trace modified to follow trace of Wildomar faullt
Elsinore (Julian) [126e]		CFM-R	180	84	NE	3	1	0	0	18.8	Slip rate reported by WGCEP (1995). Slip rate reduced by slip on parallel Earthquake Valley fault.
Elsinore (Coyote Mountain) [126f]		CFM-R	180	82	NE	3	1	0	0	13.2	Slip rate reported by WGCEP (1995). Slip rate from Rockwell, 1990.
Laguna Salada [126g]		CFM-R	180	90	n/a	3.5	1.5	0	0	13.3	Slip rate reported by Mueller and Rockwell (1995).

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Hayward (Northern) [55a]		2002	180	90	n/a	9	2	0.4	0	12	Well constrained slip rate for southern segment reported by Lienkaemper, et al. (1995) and Lienkaemper and Borchardt (1996). WG99/WG02 source parameters used in 2002.
Hayward (Southern) [55b]		2002	180	90	n/a	9	2	0.4	0	12	Well constrained slip rate for southern segment reported by Lienkaemper, et al. (1995) and Lienkaemper and Borchardt (1996). WG99/WG02 source parameters used in 2002.
Rodgers Creek [32]		2002	180	90	n/a	9	2	0	0	12	Slip rate is composite of slip rate reported by Schwartz, et al. (1992) and slip rate from Hayward fault (Lienkaemper and Borchardt, 1996) WG99/WG02 source parameters used in 2002.
Calaveras (Northern) [54a]		2002	180	90	n/a	6	2	0.2	0	13	Slip rate based on composite of 5mm/yr rate reported by Kelson, et. al. (1996) and 6mm/yr creep rate from small geodetic net reported by Prescott and Lisowski (1983). WG99/WG02 source parameters used in 2002.
Calaveras (Central) [54b]		2002	180	90	n/a	15	3	0.7	0	11	Slip rate is composite based on slip rate for a branch of Calaveras fault reported by Perkins & Sims (1988) and slip rate of Paicines fault reported by Harms, et al. (1987). Creep rate for fault zone approximately 15 mm/yr. Maximum earthquake assumed to about 6.2 (Oppenheimer, et al. 1990). WG99/WG02 source parameters used in 2002.
Calaveras (Southern) [54c]		2002	180	90	n/a	15	3	0.8	0	11	Includes Paicines fault south of Hollister. Slip rate is composite based on slip rate for a branch of Calaveras fault reported by Perkins & Sims (1988) and slip rate of Paicines fault reported by Harms, et al. (1987). Creep rate for fault zone approximately 15 mm/yr. Maximum earthquake assumed to about 6.2 (Oppenheimer, et al. 1990). WG99/WG02 source parameters used in 2002.

Fault revised since 2002 model   Fault added since 2002 model   Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006

Other significant faults where slip-rate data are available

Peninsular Ranges

Fault Name	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseismic slip	top depth km	bottom depth km	Details of slip rate
Chino (FM 2.1) [126b]	Whittier extends to base of seismicity	CFM-R	150	50	SW	1	1	0	0	9	Unconstrained slip rate based on assumptions of slip transfer between Elsinore and Whittier faults
Chino (FM 2.2) [126b]	Chino extends to base of seismicity	CFM-R	150	65	SW	1	1	0	0	13.4	Unconstrained slip rate based on assumptions of slip transfer between Elsinore and Whittier faults
Coronado Bank [131a, 131b]		CFM-R	180	90	n/a	3	1	0	0	8.6	Slip rate for Palos Verdes fault assummed to extend to SE along Coronado Bank flt.
Earthquake Valley [126e]		CFM-R	180	90	n/a	2	1	0	0	18.8	Slip rate based on Rockwell (p.c. 1996).
Earthquake Valley N extension		CFM-R	180	90	n/a			0	0	18.8	Extension of fault based on CFM-R, slip rate not known
Earthquake Valley S extension		CFM-R	180	90	n/a			0	0	18.8	Extension of fault based on CFM-R, slip rate not known
Elmore Ranch [125f]		2002	0	90	n/a	1	0.5	0	0	11.4	Late Holocene slip rate based on Hudnut, et al. (1989)
Newport Inglewood [127a, 127b]	NI not offset, subdivided in splays	CFM-R	180	88	E	1	0.5	0	0	15	based on WGCEP (1995)
Newport-Inglewood [127a, 127b]	NI simplified, offset by Compton	2002,	180	90	n/a	1	0.5	0	0	15.1	based on WGCEP (1995)
Newport-Inglewood (offshore) [127c, 127d]		2002	180	90	n/a	1.5	0.5	0	0	10.2	Slip rate based on assumption that slip from Rose Canyon zone transfers to offshore Newport-Inglewood (WGCEP, 1995).
Palos Verdes [128a, 128c, 128c]		CFM-R	180	90	n/a	3	1	0	0	13.6	Slip rate is based on rl offset of ancestral channel of Los Angeles River (Stephenson et al. 1995).
Rose Canyon [127e, 127f, 127g]		2002	180	90	n/a	1.5	0.5	0	0	7.7	Mininum slip rate reported by Lindvall and Rockwell (1995). 2002 Fault length extended to the south to include the Silver Strand fault.

Los Angeles Basin and Central Transverse Ranges

Fault Name	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseismic slip	top depth km	bottom depth km	Details of slip rate
Anacapa-Dume, (FM 2.1) [100]	Anacapa Dume extends to base of seismicity	CFM-R	60	45	N	3	2	0	0	15.5	Unconstrained slip rate, based on assumption by authors that fault carries 1 mm/yr sinstral slip rate from Santa Monica flt and 3.0 mm/yr dextral slip rate from Palos Verdes fault is carried as contractional slip rate.
Anacapa-Dume, (FM 2.2) [100]	Malibu Coast extends to base of seismicity	CFM-R	60	41	N	3	2	0	1.2	11.4	Unconstrained slip rate, based on assumption by authors that fault carries 1 mm/yr sinstral slip rate from Santa Monica flt and 3.0 mm/yr dextral slip rate from Palos Verdes fault is carried as contractional slip rate.
Clamshell-Sawpit [105e]		2002	90	50	NW	0.5	0.5	0	0	14	Unconstrained slip rate reported by Dolan, et al. (1995), based on geomorphic expression of fault.
Cucamonga [105h]		2002	90	45	N	5	2	0	0	7.8	Slip rate based on cumulative vertical displacement across three strands reported by Morton and Matti (1987, 1991).
Elysian Park (Upper) [218*]		2002	90	50	NE	1.3	0.4	0	3	15	Slip rate and fault geometry from Oskin, et al. (2000).
Hollywood [102]		2002	30	70	N	1	0.5	0	0	17.3	Slip rate estimated by authors, based on similar rationale for Santa Monica fault zone. Dolan, et al. (1995) reported a slip rate of 1.0-

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
											1.5 mm/yr.
Holser, (FM 2.1) [96*]	Santa Susana extends to base of seismicity	2002	90	58	S	0.4	0.4	0	0	18.6	Slip rate estimated by authors based on offset of base of Plio-Pleistocene Saugus Fm. reported by Stitt (1986).
Holser, (FM 2.2) [96*]	Holser and Del Valle extend to base of seismicity	CFM-R	90	58	S	0.4	0.4	0	0	18.5	Slip rate estimated by authors based on offset of base of Plio-Pleistocene Saugus Fm. reported by Stitt (1986).
Malibu Coast, (FM 2.1) [99]	Anacapa Dume extends to base of seismicity	CFM-R	30	75	N	0.3	0.2	0	0	7.8	Slip rate is horizontal component of slip based on left-laterally deflected drainages incised in terrace surface (Stage 7? or 9?) reported by Treiman (1994).
Malibu Coast, (FM 2.2) [99]	Malibu Coast extends to base of seismicity	CFM-R	30	74	N	0.3	0.2	0	0	16.6	Slip rate is horizontal component of slip based on left-laterally deflected drainages incised in terrace surface (Stage 7? or 9?) reported by Treiman (1994).
Malibu Coast Extension, (FM 2.1)	Anacapa Dume extends to base of seismicity	CFM-R	30	74	N			0	0	16.6	Extension of fault based on CFM-R, slip rate not known
Malibu Coast Extension, (FM 2.2)	Malibu Coast extends to base of seismicity	CFM-R	30	74	N			0	0	16.6	Extension of fault based on CFM-R, slip rate not known
Northridge [135*]		CFM-R	90	35	S	1.5	1	0	7.4	16.8	
Oak Ridge (onshore) [94*]		2002	90	65	S	4	2	0	1	19.4	Dip-slip rate estimated by authors is composite of several published rates (Yeats, 1988; Levi & Yeats, 1993; Huftile, 1992; Yeats, et al. 1994; WGCEP, 1995).
Pleito [75a, 76b]		2002	90	46	S	2	1	0	0	13.6	Holocene slip rate based on offset Tecuya alluvial fan reported by Hall (1984).
Puente Hills (FM 2.1) [185a, 185b, 185c]	Puente Hills simplified 2002 single trace	2002	90	25	N	0.7	0.4	0	5	13	Source parameters from Shaw and Shearer (1999), Shaw, et al. (2000), and Christofferson, et al. (2001)
Puente Hills, Coyote Hills section (FM 2.2) [185c]	Puente Hills CFM 3 sections	CFM-R	90	26	N	0.7	0.4	0	2.8	14.6	
Puente Hills, LA section (FM 2.2) [185a]	Puente Hills CFM 3 sections	CFM-R	90	27	N	0.7	0.4	0	2.1	15	
Puente Hills, Santa Fe Springs section (FM 2.2) [185b]	Puente Hills CFM 3 sections	CFM-R	90	29	N	0.7	0.4	0	2.8	15	
Raymond [103]		2002	60	79	N	1.5	1	0	0	15.6	Slip rate estimated by authors is poorly constrained, based on focal mechanism of 1988 Pasadena earthquake and assumed vertical component of offset reported by Crook et al. (1987). 2002 Slip rate increased from 0.5 mm/yr, based on slip rate study by Marin, et al. (2000).
San Cayetano [95*]		2002	90	42	N	6	3	0	0	16	Dip-slip rate estimated by authors is composite of several published rates (Rodkwell, 1983, 1988; Yeats, 1983; Molnar, 1991; Levi & Yeats, 1993; Huftile, 1992; WGCEP, 1995).
San Gabriel [89a, 89b, 89c, 89d, 89e]		CFM-R	180	61	N	1	0.5	0	0	14.7	Poorly constrained long term slip rate reported by Yeats, et al. (1994). Slip rates range from 1-3 mm/yr but Holocene slip rates are

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
											thought to be closer to the lower value.
San Gabriel extension		CFM-R	180	61	N			0	0	14.7	Extension of fault based on CFM-R, slip rate not known
San Joaquin Hills [186]		2002	90	23	SW	0.5	0.2	0	2	8.0	Model by Grant, et al. (1999) and Grant and Runnerstrom (written communication, 11-01)
San Jose [107*]		2002	30	74	NW	0.5	0.5	0	0	15.8	Unconstrained slip rate reported by Dolan, et al. (1995), based on geomorphic expression of fault.
Santa Monica, (FM 2.1) [101]	Santa Monica high angle	CFM-R	30	75	n	1	0.5	0	0	17.9	Published slip rate (0.3mm/yr; Clark et al. 1984) is for Potrero Canyon fault, a branch of Santa Monica fault zone. Slip rate of 1mm/yr is based on 2 assumptions: 1). H:V is 1:1 and 2). slip rate for Potrero Canyon is half of entire Santa Monica fault.
Santa Monica, (FM 2.2)	Santa Monica low angle	CFM-R	30	50	N	1	0.5	0	0	11.6	Published slip rate (0.3mm/yr; Clark et al. 1984) is for Potrero Canyon fault, a branch of Santa Monica fault zone. Slip rate of 1mm/yr is based on 2 assumptions: 1). H:V is 1:1 and 2). slip rate for Potrero Canyon is half of entire Santa Monica fault.
Santa Susana, (FM 2.1) [105a]	Santa Susana extends to base of seismicity	2002	90	55	N	5	2	0	0	16.3	
Santa Susana, (FM 2.2) [105a]	Holser and Del Valle extend to base of seismicity	CFM-R	90	53	N	5	2	0	0	10.6	
Sierra Madre [105c, 105d, 105f, 105g]		2002	90	53	N	2	1	0	0	14.2	Dip-slip rate is combination of slip rate reported by Clark et al. (1984), estimate by authors for the Dunsmore alluvial fan (of age 2-10 ka) reported in Crook et al. (1987), and slip rate reported in WGCEP (1995). 2002 slip rate reduced from 3 to 2 mm/yr (Cao et al. 2003)
Sierra Madre (San Fernando) [105b]		2002	90	45	N	2	1	0	0	13	Dip-slip rate is combination of rate reported by Clark et al. (1984) and estimate by authors for the Dunsmore alluvial fan (of age 2-10 ka) reported in Crook et al. (1987).
Simi-Santa Rosa [98a, 98b, 98c]		CFM-R	30	60	N	1	0.5	0	1	12.1	Slip rate reported by Gonzalez and Rockwell (1991) is for Springville fault, a branch of Simi-Santa Rosa fault. Slip rate of 1mm/yr assumed in order to account for entire fault zone.
Verdugo [104*]		2002	90	55	NE	0.5	0.5	0	0	14.5	Unconstrained slip rate based on report of scarps in alluvial fans (Weber, et al. 1980).
White Wolf [74*]		CFM-R	60	75	S	2	2	0	0	14.6	Poorly constrained long term slip rate, based on Stein and Thatcher (1981), is suggestive of about 5mm/yr. WGCEP (1995) used slip rate of 2 mm/yr.
White Wolf extension		CFM-R	60	75	S			0	0	14.6	Extension of fault based on CFM-R, slip rate not known
Western Transverse Ranges and Santa Barbara Channel											
Channel Islands Thrust [139]		CFM-R	90	21	N	1.5	1	0	7.4	14.7	
Channel Islands Western Deep Ramp		CFM-R	90	21	SW			0	4.8	12.5	Fault based on CFM-R, slip rate not known
Mission Ridge fault system [88[a], 88b, 88c, 88d]		2002	90	70	S	0.4	0.2	0	0	7.6	Minimum dip-slip rate based on Rockwell, et al. (1984). Assumption that half of 65 km length ruptures. Total length includes More Ranch fault. Includes Mission Ridge, Arroyo Parida and

Fault revised since 2002 model [yellow] Fault added since 2002 model [orange] Alternate slip rates in deformation models [pink]

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
											Santa Ana faults, renamed based on Séller and Gurrola, (2000)
North Channel (FM 2.2) [180]	CFM Santa Barbara alt 2	CFM-R	90	26	N	1	1	0	1.1	4.2	(replaces 2002 North Channel Slope fault in alt 2)
North Channel Slope [137*]		2002	90	26	N	2	2	0	10	20	Replaced by North Channel and Pitas Point (upper)
Oak Ridge (blind thrust offshore) [136]		2002	90	30	S	3	3	0	0	7.8	Replaced by Oak Ridge offshore and Oak Ridge offshore, west extension, or Pitas Point (Lower) Montalvo and Pitas Point (Lower), west
Oak Ridge offshore (FM 2.2)	CFM Santa Barbara alt 2	CFM-R	90	32	S	3	3	0	0	7.9	(replaces 2002 Oak Ridge (blind thrust offshore) in alt 2)
Oak Ridge offshore, west extension (FM 2.2)	CFM Santa Barbara alt 2	CFM-R	90	78	S	3	3	0	0.4	3.1	(replaces 2002 Oak Ridge (blind thrust offshore) in alt 2)
Pitas Point (Lower) Montalvo (FM 2.1)	CFM Santa Barbara alt 1	CFM-R	90	16	N	3	3	0	0.4	12.7	(replaces 2002 Oak Ridge (blind thrust offshore) in alt 1)
Pitas Point (Lower), west (FM 2.1)	CFM Santa Barbara alt 1	CFM-R	90	13	N	3	3	0	1.5	8.8	(replaces 2005 Oak Ridge (blind thrust offshore) in alt 1)
Pitas Point (Upper) (FM 2.2)	CFM Santa Barbara alt 2	CFM-R	90	42	N	1	1	0	1.4	10	(replaces 2002 North Channel Slope fault in alt 2)
Red Mountain [90]		CFM-R	90	56	N	2	1	0	0	14.1	Slip rate based on summation of two strands of Red Mtn. flt at Punta Gorda reported in Clark, et al. 1984).
Santa Cruz Island [93]		CFM-R	30	90	n/a	1	0.5	0	0	13.3	Moderately constrained Qt. slip rate (0.75mm/yr) based on offset streams incised into Stage 11 (?) terrace (Pinter, et al. 1995).
Santa Rosa Island [92*]		CFM-R	30	90	n/a	1	0.5	0	0	8.7	Moderately constrained Qt. slip rate (1mm/yr) based on offset incised stream channels (Colson et al. 1995).
Santa Ynez (East) [87d]		CFM-R	0	70	S	2	1	0	0	13.3	Slip rate is preferred left-lateral, based on offset stream channel reported by Darrow and Sylvester (1984).
Santa Ynez (West) [87a, 87b, 87c, 87d]		CFM-R	0	70	S	2	1	0	0	9.2	Slip rate is preferred left-lateral, based on offset stream channel reported by Darrow and Sylvester (1984).
Ventura-Pitas Point [91, 180]		CFM-R	60	64	N	1	0.5	0	1	15	Slip rate is estimated by authors based on height of scarp across Harmon alluvial fan mapped by Sarna-Wojcicki, et al. (1976) and assumed slip components.
Southern Coast Ranges											
Casmalia (Orcutt Frontal fault) [84*]		2002	90	75	SW	0.25	0.2	0	0	10	Poorly constrained slip rate based on deformation of terraces (Clark, 1990).
Great Valley 7 [28g*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 8 [28h*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 9 [28i*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 10 [28j*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 11 [28k*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 12 [28l*]		2002	90	15	W	1.5	1	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).

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Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Great Valley 13 (Coalinga) [28m*]		CFM-R	90	15	W	1.5	1	0	9.1	15.2	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 14 (Kettleman Hills) [28n]		CFM-R	90	22	W	1.5	1	0	8.1	22.5	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Hosgri [81a, 81b, 81c, 81d]		CFM-R	180	80	E	2.5	1	0	0	6.8	Slip rate based on San Simeon fault slip rate reported in Hanson and Lettis (1994).
Hosgri extension		CFM-R		80	E			0	0	7.5	Extension of fault based on CFM-R, slip rate not known
Lions Head [83*]		2002	90	75	NE	0.02	0.02	0	0	10	Poorly constrained slip rate based on offset marine terraces (Clark, 1990).
Los Alamos-W. Baseline [85*]		2002	90	30	S	0.7	0.7	0	0	10	Poorly constrained slip rate based in part on dip slip displacement of A soil horizon (Guptil, et al. 1981).
Los Osos [79a, 79b, 79c, 79d]		2002	90	45	SW	0.5	0.4	0	0	10	Poorly constrained late Quaternary slip rate based on uplift of marine terraces and assumed flt. dip of 30-60 degrees (Lettis & Hall, 1994).
Ortigalita [59a. 59b, 59c, 59d]		2002	180	90	n/a	1	0.5	0	0	11	Poorly constrained slip rate based on vertical slip rate reported by Clark, et al. (1984) (0.01-0.04 mm/yr), assumptions regarding H:V ratio, and geomorphic expression of flt. consistent with about 1 mm/yr.
Rinconada [63a, 63b, 63c]		CFM-R	180	90	n/a	1	1	0	0	10	Long term slip rate of about 3mm/yr based on Hart (1985). Lacks obvious Holocene offset.
San Juan [77*]		2002	180	90	n/a	1	1	0	0	13	Poorly constrained slip rate based on Anderson (1984).
San Luis Range (S margin) [82*]		2002	90	45	N	0.2	0.1	0	0	10	3Fault system with composite slip rate of about 0.2mm/yr. Includes San Luis Obispo Bay, Oceano, Wilmar Ave., Olson, and Santa Maria River flts (Lettis, et al. 1994).
San Francisco Bay Area and Central Coast Ranges											
Bartlett Springs fault system [29a, 29b, 29c]		2002	180	90	n/a	6	3	0.5	0	15	Slip rate based on assumption that slip carried from Concord-Green Valley system (WGNCEP, 1996). Taylor and Swan (1986) and Swan and Taylor (1991) reported minimum slip rate of 1-2mm/yr for segment at Lk. Pillsbury, based on apparent vertical separation and plunge of slickensides. Aseismic slip factor of 0.5 applied based on factor calculated for Concord-Green Valley fault.
Collayomi [34]		2002	180	90	n/a	0.6	0.3	0	0	10	Slip rate based on (Clark, et al. 1984)
Concord [38a, 38b, 38c]		2002	180	90	n/a	4	2	0.5	0	16	WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
Great Valley 1 [28a*]		2002	90	15	W	0.1	0.05	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley [28b*]		2002	90	15	W	0.1	0.05	0	7	9.6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994).
Great Valley 3, Mysterious Ridge [28c*]		2002	90	15	W	1.25	0.75	0	9	14	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994). Revised trace and slip rate based onO'Connell, and Unruh (2000)
Great Valley3a, Dunnigan Hills [28c*, 234]		2002	90	20	E			0	3	6	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994). Revised trace based on O'Connell, and Unruh (2000)
Great Valley 4a, Trout Creek [28d*]		2002	90	20	W	1.25	0.75	0	9	14	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994). Revised trace and slip rate based on O'Connell, and

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											Unruh (2000)
Great Valley 4b, Gordon Valley [28d*]	2002		90	30	W	1.25	0.75	0	8	14	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994). Revised trace and slip rate based on O'Connell, and Unruh (2000)
Great Valley 5, Pittsburg – Kirby Hills [28e*]	2002		180	90	W	1.5	1	0	8	14	Slip rate and sections from WGNCEP (1996) and Wakabayshi and Smith (1994). Revised trace, dip and sense of displacement based on O'Connell, and Unruh (2000)
Green Valley [37]	2002		180	90	n/a	5	3	0.5	.050	14	WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
Greenville [53b, 53c]	2002		180	90	n/a	2	1	0.1	0	15	WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
Hunting Creek-Berryessa [35a, 35b, 35c]	2002		180	90	n/a	6	3	0	0	12	Slip rate based on assumption that slip is carried from Concord-Green Valley system (WGNCEP, 1996).
Maacama-Garberville [30a, 30b, 19*]	2002		180	90	n/a	9	2	0.4	0	12	Slip rate of 9 mm/yr based on assumption that dextral slip from Hayward - Rodgers Crk. flt carried NW along Maacama zone (WGNCEP, 1996). Flt. has creep rate of 6.9 mm/yr in Ukiah (Galehouse, 1995). Aseismic slip factor of 0.4 applied based on factor calculated for Hayward fault.
Monterey Bay-Tularcitos [62a, 62b, 62c]	2002		150	90	n/a	0.5	0.4	0	0	14	Slip rate is composite of flts in Monterey area (Tularcitos, Chupines, Navy, flts in Monterey Bay). Rates of individual flts. estimated to be about 0.1mm/yr (Rosenberg & Clark, 1995).
Mount Diablo Thrust [353*]	2002		90	38	NE	2	1	0	8	16	WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
Monte Vista-Shannon [56]	2002		90	45	W	0.4	0.3	0	0	9	Poorly constrained slip rate based on vertical separation of late Pleistocene terrace and assumptions of age of terrace (23-120ka) and flt. dip reported by Hitchcock, et al. (1994). Actual dip and fault width is variable. 15 km width approximates average.
Point Reyes [61*]	2002		90	50	NE	0.3	0.2	0	0	9	Poorly constrained long term (post-Miocene) slip rate based on vertical offset of crystalline basement (McCulloch, 1987).
Quien Sabe [64]	2002		180	90	n/a	1	1	0	0	10	Poorly constrained slip rate estimated by authors based on vertically offset alluvial fan (Bryant, 1985) and assumptions regarding H:V ratio (6:1 to 14:1) based on 26JAN86 M5.8 earthquake (Hill et al. 1990) and age of fan surface based on soil profile development.
San Gregorio (North) [60a]	2002		180	90	n/a	7	3	0.1	0	12	Weber and Nolan (1995) reported Holocene slip rate of 3-9mm/yr; latest Pleistocene slip rate of 5 mm/yr (min) and lt. Qt. slip rate of about 4.5mm/yr reported by Simpson, et al. (written communication to J. Lienkaemper, 1995). WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
San Gregorio (South) [60b]	2002		180	90	n/a	3	2	0.1	0	12	Late Qt. slip rate of 1-3 mm/yr based on assumed transfer of slip from Hosgri flt. Slip rate from San Simeon flt. (Hanson and Lettis (1994) and Hall et al. (1994). WG99/WG02 source parameters used in 2002, which effectively results in fault being treated as an "A fault".
West Napa [36a, 36b]	2002		180	90	n/a	1	1	0	0	10	Unconstrained slip rate based on assumption that geomorphic expression of fault is consistent with about 1mm/yr slip rate (WGNCEP, 1996).
Zayante-Vergeles [59]	2002		150	90	n/a	0.1	0.1	0	0	12	Slip rates reported by Clark, et al. (1984).

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Northwestern California											
Big Lagoon-Bald Mtn flt zone [12]		2002	90	35	NE	0.5	0.5	0	0	13	Long term slip rate, based on vertical offset of Pliocene "Klamath sapprolite" and assumption that age of offset began about 1ma (McCrory, 1996).
Fickle Hill [13]		2002	90	35	NE	0.6	0.4	0	0	13	Slip rate based on Carver & Burke (1992) and McCrory (1996).
Little Salmon (offshore) 14]		2002	90	30	NE	1	1	0	0	13	Poorly constrained slip rate based on vertical separation of Rio Dell equivalent strata (1 my) and base and top of Hookton Fm. (about 0.5 my) reported by McCrory (1996).
Little Salmon (onshore) [15]		2002	90	30	NE	5	3	0	0	13	Slip rate based on Carver & Burke (1988, 1992) and assumption by authors that main trace has slip rate of 4 mm/yr and 1 mm/yr for eastern strand.
Mad River [13]		2002	90	35	NE	0.7	0.6	0	0	13	Slip rate based on Carver & Burke (1992) and assummed dip of 30 degrees.
McKinleyville [13]		2002	90	35	NE	0.6	0.2	0	0	13	Slip rate based on recalulation of rate by Carver & Burke (1992), with assumption that lowest terrace age is 80ka.
Mendocino fault zone [18]		2002	150	90	NE	35	5	0	15	30	Slip rate based on relative plate motion (McCrory, et al. 1995).
Table Bluff [16]		2002	90	45	NE	0.6	0.6	0	0	13	Poorly constrained slip rate based on 700 m vertical offset of basement rocks. Age of deformation assumed to have begun about 1ma (McCrory, 1996).
Trinidad [13]		2002	90	35	NE	2.5	1.5	0	0	13	Slip rate based on recalulation of slip rate reported by Carver & Burke (1992), with assumption that lowest terrace age is 80ka. Dip slip rate includes horizontal shortening rate from Trinidad anticline, resolved for 35 degree dipping fault (P. McCrory, p.c., 1996).
Northeastern California											
Battle Creek [20*]		2002	-90	75	S	0.5	0.4	0	0	11	Slip rate based on Clark, et al. (1984) and Page and Renne (1994).
Cedar Mtn-Mahogany Mtn [2a, 2b, 2c, 2d]		2002	-90	60	E	1	0.5	0	0	10	Poorly constrained slip rate of 0.2mm/yr based on vertical offset of late Tioga gravels along E. Cedar Mtn. flt. reported by Bryant and Wills (1991). 1mm/yr slip rate assumed for entire fault zone, including Mahogany Mtn. flt. zone.
Gillem-Big Crack [3]		2002	-90	60	E	1	0.5	0	0	11	Poorly constrained slip rate based on vertical separation of late Pleistocene (about 40ka) Mammoth Crater basalt (Donnelly-Nolan and Champion (1987).
Goose Lake [828]		2002	-90	50	W	0.1	0.05	0	0	10	Slip rate based on Pezzopane (1993). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Hat Creek-McArthur-Mayfield [6, 8, 9]		2002	-90	60	W	1.5	1	0	0	10	Hat Creek flt. has poorly to moderately constrained slip rate based on offset of Tioga lateral moraine reported by Muffler et al. (1994) and Sawyer (p.c. 1995). McArthur flt. has poorly constrained slip rate based on offset of 'Popcorn Cave basalt' (Page, 1995). Mayfield flt. has moderate to well-constrained slip rate based on vertical offset of 10.6ka basalt and surveyed scarp profiles (Donnelly-Nolan, et al. 1990).
Honey Lake [22]		2002	180	90	n/a	2.5	1	0	0	11	Slip rate based on dextral offset of Holocene fluvial terrace reported by Wills and Borchardt (1993) (1.9 +/- 0.8mm/yr)
Likely [5]		2002	180	90	n/a	0.3	0.3	0	0	11	Unconstrained slip rate based on assumption by authors that up to 5 m of dextral offset of latest Pleistocene shorelines at

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											northern Madeline Plains (Bryant, 1991) may go unobserved and also overall geomorphic expression of fault zone.
Surprise Valley [4]		2002	-90	50	E	1.3	0.5	0	0	10	Slip rate base on vertical offset of Holocene alluvial fans and assumptions of fan ages based on relationship to Pleistocene Lk. Surprise (Hedel, 1980, 1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Sierra Nevada and western Great Basin											
Antelope Valley [39]		2002	-90	50	E	0.8	0.5	0	0	13	Dip slip offset of Holocene alluvial fan reported by Bryant (1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Birch Creek [65a]		2002	-90	50	E	0.7	0.5	0	0	13	Slip rate based on Beanland and Clark (1994). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Carson Range (Genoa) [1285d, 1285e]		2002	-90	50	E	2	1.3	0	0	13	Also referred to as Carson Range fault zone. Slip rate increased from 1.0 mm/yr to 2.0 mm/yr based on Ramelli, et al. (1999). Included in Nevada model. Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Death Valley (Black Mts Frontal fault) [142a, 142b, 142c, 142d]		2002	-150	60	w	4	3	0	0	13	Slip rate based on vertically offset alluvial fan surface reported in Klinger and Piety (1994).
Death Valley (N of Cucamongo) [49a, 49b, 49c, 49d]		2002	180	90	n/a	5	3	0	0	13	Late Qt. slip rate based on offset Pleistocene shutter ridge in Fish Lake Valley reported in Reheis (1994). Reheis and Dixon (1996) suggest lt. Qt. slip rate of about 5 mm/yr in the Fish Lake Valley area
Death Valley (Northern) [49d, 141a, 141b, 141c]		CFM-R	180	90	n/a	5	3	0	0	13	Late Pleistocene slip rate based on offset alluvial fan near Redwall Canyon. Rate of about 4.5mm/yr estimated from 46m rl offset reported by Reynolds (1969) and estimated age of incision of fan surface (5-20ka) based on geomorphic expression of alluvial deposits and correlation of rock varnish ages in southern Death Valley by Dorn (1988). Slip rate of 5-12mm/yr reported by Klinger and Piety (1994) may be too high because of their assumption that Redwall Canyon alluvial fan surface is 40-70ka. Cation-ratio dates of rock varnish in southern Death Valley reported by Dorn (1988) suggest age of 100-170ka, which would reduce mean rate from 8.5mm/yr to .5mm/yr.
Death Valley (South) [143a, 143b]		CFM-R	180	90	n/a	4	3	0	0	13	Long term slip rate based on 35km rl. offset of Miocene volcanic rks. reported by Butler, et al. (1988).
Deep Springs [50]		2002	-90	50	NW	0.8	0.6	0	0	13	Dip slip rates based on offset Holocene alluvial fans reported by Bryant (1989). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Fish Slough [48]		2002	-90	50	E	0.2	0.1	0	0	13	Poorly constrained dip slip rate based on offset of Bishop Ash reported in Bateman (1965). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Hartley Springs [43]		2002	-90	50	E	0.5	0.3	0	0	13	Slip rate (0.15mm/yr) based on dip-slip offset of late Tioga lateral moraine reported in Clark, et al. (1984). Slip rate is for

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											small branch fault; unconstrained slip rate of 0.5mm/yr assumed for entire fault zone. Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Hilton Creek [44]		2002	-90	50	E	2.5	0.6	0	0	13	Slip rate based on dip-slip offset of late Tioga lateral moraine reported in Clark, et al. (1984).
Hunter Mountain-Saline Valley [66a, 66b]		2002	-150	90	n/a	2.5	1	0	0	12.4	Long term slip rate (Pliocene) of 2.0-2.7mm/yr for Hunter Mtn. fault (Burchfiel, et al. 1987), and association with Panamint Vly flt.
Independence [65a]		CFM-R	-90	50	E	0.2	0.1	0	0	14.6	Slip rate based on offset Tioga outwash deposits reported in Clark, et al. (1994). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Little Lake [72*]		2002	180	90	n/a	0.7	0.4	0	0	13	Minimum slip rate basd on offset channel cut in basalt (Roquemore, 1981).
Mono Lake [41]		2002	-90	50	E	2.5	1.25	0	0	13	Slip rate based on offset of late Tioga lateral moraine reported in Clark, et al. (1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
North Tahoe [1649]		WGCEP 2007	-90	50	E	0.43	0.03	0	0	13	Minimum dip slip rate based on 21-25 m vertical offset of McKinney Bay debris complex thought to be 60 ka, and assumption of 60° fault dip (Kent et al. 2005). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Owens Valley [51a, 51b]		CFM-R	180	90	n/a	1.5	0.8	0	0	13.5	Slip rate reported in Beanland and Clark (1994) is composite based on Lone Pine fault and assumption that horizontal component similar to 1872 earthquake.
Panamint Valley [67a, 67b, 67c, 67d]		2002	-150	90	W	2.5	1	0	0	13	Moderately constrained slip rate based on offset drainages developed on Holocene alluvial fans reported in Zhang, et al. 1990.
Robinson Creek [40]		2002	-90	50	SE	0.5	0.3	0	0	13	Dip slip offset of late Tioga outwash in Buckeye Crk. reported in Clark, et al. (1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Round Valley [45]		2002	-90	50	E	1	0.5	0	0	13	Slip rate based on dip-slip offset of late Tioga lateral moraine reported in Clark, et al. (1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
S Sierra Nevada [65b]		CFM-R	-90	50	E	0.1	0.1	0	0	13.6	Unconstrained dip slip rate estimated by authors based on association with Independence fault. Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
Sierra Nevada n extension		CFM-R		50	E			0	0	13.8	Extension of fault based on CFM-R, slip rate not known
Tank Canyon [71*]		2002	-90	50	W	1	0.5	0	0	8.3	Moderately constrained slip rate based on vertically offset Holocene alluvial fan (Clark, et al. 1984). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
West Tahoe [216*]		WGCEP 2007	-90	50	E	0.6	+ 0.4/	0	0	13	Minimum dip slip rate based on 10-15 m vertical offset of 19.2 ka paleo shoreline and assumption of 60° fault dip (Kent et al.

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							- 0.1				2005). Dip changed to 50 degrees in 2007 based on recommendation of WSSPC for basin and range faults.
White Mountains [47a, 47b, 47c, 47d]		2002	180	90	n/a	1	0.5	0	0	13	Preferred rl slip rate reported by dePolo, 1989.
Eastern Transverse Ranges and Mojave Desert											
Blackwater [113*]		CFM-R	180	90	n/a	0.5	0.3	0	0	12.1	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993), Slip rate revised in 2007 based on Oskin (2007)
Burnt Mtn [119*]		CFM-R	180	67	W	0.6	0.4	0	0	15.9	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),
Calico-Hidalgo [121a, 121b, 121c]		CFM-R	180	90	n/a	1.8	0.4	0	0	13.9	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993), Slip rate revised in 2007 based on Oskin (2007)
Cleghorn [108a, 108b]		2002	0	90	n/a	3	2	0	0	15.5	Slip rate based on Meisling (1984).
Eureka Peak [120*]		2002	180	90	n/a	0.6	0.4	0	0	15	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),
Garlock (East) [69c]		2002	0	90	n/a	3	2	0	0	11.5	Section split from Eastern Garlock fault in 2002 model. Unconstrained slip rate reduced from slip rate on Central Garlock fault east of the junction of the Owl Lake fault. Designated as an A fault in 2006.
Garlock (Central) [69b]		2002	0	90	n/a	7	2	0	0	11.5	Section split from Eastern Garlock fault in 2002 model. 1996 slip rate based on offset late Qt. stream channel (McGill, 1994; p.c.1996). Designated as an A fault in 2006.
Garlock (West) [69a]		2002	0	90	n/a	6	3	0	0	14.7	1996 slip rate based on offset late Qt. stream channel (McGill, 1994; p.c.1996). Designated as an A fault in 2006.
Gravel Hills-Harper Lk [112*]		2002	180	90	n/a	0.7	0.4	0	0	11.4	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),
Helendale-S Lockhart [110a, 110b, 110c]		CFM-R	180	90	n/a	0.6	0.4	0	0	12.8	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),
Johnson Valley (Northern) [115a]		2002	180	90	n/a	0.6	0.4	0	0	15.9	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),
Landers [114a, 114b, 115b, 116]		CFM-R	180	90	n/a	0.6	0.4	0	0	15.1	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993),

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate mm/yr	slip rate error	Aseis-mic slip	top depth km	bottom depth km	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Lenwood-Lockhart-Old Woman Springs [111a, 111b]		CFM-R	180	90	n/a	0.9	0.4	0	0	13.2	Mojave slip rates based on Holocene rates reported for Homestead Vlly., Emerson, and Johnson Vlly. flts (Hecker, et al. 1993; Rubin and Sieh, 1993; Herzberg and Rockwell, 1993), Slip rate revised in 2007 based on Oskin (2007)
Mill Creek -San Andreas, north branch [1i]		WGCEP 2006	180	76	S			0	0	18.3	Slip included in estimate for San Gorgonio knot zone (C zones below)
Mission Creek [1i]		CFM-R	180	65	N			0	0	17.7	Slip included in estimate for San Gorgonio knot zone (C zones below)
North Frontal Fault zone (Eastern) [109b]		2002	90	41	S	0.5	0.25	0	0	16.6	Flt. zone east of intersection with Helendale flt. Unconstrained slip rate based on assumption that some slip transferred to NW-striking flts.
North Frontal Fault zone (Western) [109a]		2002	90	49	S	1	0.5	0	0	15.7	Reported slip rate of 1.2 mm/yr for Sky High Ranch fault, a RLSS segment of fault zone (Meisling, 1984). Other reported slip rates range between 0.1 and 1.3 mm/yr.
Owl Lake [70]		2002	0	90	n/a	2	1	0	0	12	Slip rate based on offset stream channel. Timing of offset based on radio-carbon and rock varnish dating of alluviual fan surface reported by McGill (1993).
Pinto Mountain [118]		2002	0	90	n/a	2.5	2	0	0	15.5	Long term slip rate based on Anderson (1979). Reported slip rates range from 0.3-5.3.
Pisgah-Bullion Mtn-Mesquite Lk [122a, 122b, 122c, 123]		2002	180	90	n/a	0.8	0.4	0	0	13.1	Slip rate based on rl offset of drainage developed on Sunshine lava flow (Hart, 1987). Slip rate revised in 2007 based on Oskin (2007)
S Emerson-Copper Mtn [114b, 114c]		2002	180	90	n/a	0.6	0.4	0	0	14.1	Slip rate based on Rubin and Sieh (1993).

Fault revised since 2002 model (yellow) Fault added since 2002 model (orange) Alternate slip rates in deformation models (pink)

Table 1, Fault parameters, including source of trace and slip rate information

Fault Name [ID # in Quaternary Fault and Fold Database- * indicates Q-faults compilation not yet completed]	model	Source of fault trace	rake	dip	dip direction	slip rate	slip rate error	top depth	bottom depth	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Zones of distributed shear										
Foothills Fault System		2002	-150	75		0.1	0.6	0	12	Poorly constrained composite late Quaternary slip rate across Bear Mtn. and Melones flt zones (Woodward-Clyde Consultants, 1978; Clark, et al. 1984; PG&E, 1994).
Mohawk-Honey Lake Zone		2002	180	90		4	2	0	15	Distributed dextral shear zone carried from Western Nevada Zone.
Northeastern California		2002	180	90		8	4	0	15	Distributed dextral shear of Sierra Nevada-Great Basin shear zone, based on VLBI data (Argus & Gordon, 1991; Argus (p.c. to J. Lienkaemper, 1995). Model weighted 50%.
Western Nevada		2002	180	90		8	4	0	15	Distributed dextral shear of Sierra Nevada-Great Basin shear zone, based on VLBI data (Argus & Gordon, 1991; Argus (p.c. to J. Lienkaemper, 1995). Model weighted 50%.
Eastern California Shear Zone		WGCEP 2006	180	90		4	2	0	14	Distributed dextral shear across Mojave desert to be consistent with geodetic and plate tectonic constraints, reduced by 6 mm/yr for slip already accommodated by existing faults
Imperial Valley		WGCEP 2006	180	90				0	12.6	Distributed dextral shear south of end of San Andreas fault and San Jacinto fault, Clark section. Assumed to be accommodated in background earthquakes and aseismic slip.
San Gorgonio Knot		WGCEP 2006	180	90		6	1	0	6	Distributed dextral shear with about half of the overall slip on the San Andreas through the San Gorgonio Pass (Yule and Sieh, 2003)

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 2, Fault parameters for faults being considered for development of deformation models

Fault Name	model	Source of fault trace	rake	dip	dip direction	slip rate	slip rate error	top depth	bottom depth	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Faults being considered for development of deformation models										
Peninsular Ranges										
Brawley Seismic Zone (FM 2.1)	Western edge of zone	CFM-R		90				0	13.2	New geometry for CFM-R, not modeled as fault source in 2002 model, so no slip rate available
Brawley Seismic Zone (FM 2.2)	Eastern edge of zone	CFM-R		90				0	13.2	New geometry for CFM-R, not modeled as fault source in 2002 model, so no slip rate available
Canada David detachment		CFM-R		37	W			0	15.3	Fault from CFM-R, slip rate not known
Carlsbad		CFM-R		37	E			1.6	7.3	Fault from CFM-R, slip rate not known
Cerro Prieto		CFM-R		90				0	14.3	Fault from CFM-R, slip rate not known
Oceanside		CFM-R		23	NE			1	8.3	Fault from CFM-R, slip rate not known
San Clemente		CFM-R		88	NE			1.3	9	Fault from CFM-R, slip rate not known
San Diego Trough, north		CFM-R		90				0	8.3	Fault from CFM-R, slip rate not known
San Diego Trough, south		CFM-R		90				0	8.3	Fault from CFM-R, slip rate not known
San Pedro Basin		CFM-R		88	NE			0.8	12.3	Fault from CFM-R, slip rate not known
San Pedro Escarpment		CFM-R		17	NE			1	16	Fault from CFM-R, slip rate not known
Santa Cruz Catalina Ridge		CFM-R		90				0	11	Fault from CFM-R, slip rate not known
Thirty Mile Rivero		CFM-R		24	NE			0.3	9.6	Fault from CFM-R, slip rate not known
Los Angeles Basin and Central Transverse Ranges										
Anaheim		CFM-R		71	NE			3.8	14.2	Fault from CFM-R, slip rate not known
Big Pine East		CFM-R		73	NW			0	14.3	Poorly constrained Plio-Pleistocene slip rate > 0.8 mm/yr from Kahle (1966). 1996 slip rate no longer used because that rate assumed left-lateral slip, which is not compatible with current geometry of fault from CFM.
Big Pine Central		CFM-R		76	SE			0	6.6	Poorly constrained Plio-Pleistocene slip rate > 0.8 mm/yr from Kahle (1966). 1996 slip rate no longer used because that rate assumed left-lateral slip, which is not compatible with current geometry of fault from CFM.
Big Pine West		CFM-R			N			0	11	Fault from CFM-R, slip rate not known
Compton		CFM-R	90	20	NE			5.2	15.6	Fault from CFM-R, slip rate not known
Del Valle (FM 2.2)	Holser and Del Valle extend to base of seismicity	CFM-R	90	73	S			0	18.8	Fault from CFM-R, slip rate not known
Elysian Park (Lower) CFM		CFM-R		22	N			10	14.7	Fault from CFM-R, slip rate not known
Fontana seismicity		CFM-R		80	NW			0	16.3	Fault from CFM-R, slip rate not known
Morales (East)		CFM-R		32	NE			0	8.6	Fault from CFM-R, slip rate not known

Fault revised since 2002 model — Fault added since 2002 model

Table 2, Fault parameters for faults being considered for development of deformation models

Fault Name	model	Source of fault trace	rake	dip	dip direction	slip rate	slip rate error	top depth	bottom depth	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Morales (West)		CFM-R		32	NE			0	8.6	Fault from CFM-R, slip rate not known
North Salt Lake		CFM-R		54	N			0.5	16.7	Fault from CFM-R, slip rate not known
Northridge Hills		CFM-R	90	31	N			0	14.9	Fault from CFM-R, slip rate not known
Peralta Hills		CFM-R		50	N			0.3	14	Fault from CFM-R, slip rate not known
Pine Mountain		CFM-R		45	N			0	16.3	Fault from CFM-R, slip rate not known
Redondo Canyon, (FM 2.1)	Redondo Canyon Ziony	CFM-R		90				0	13.3	Fault from CFM-R, slip rate not known
Redondo Canyon, (FM 2.2)	Redondo Canyon Bohannon	CFM-R		80	S			0.5	12.9	Fault from CFM-R, slip rate not known
Richfield		CFM-R		28	N			2.5	12.9	Fault from CFM-R, slip rate not known
San Gorgonio Pass		CFM-R		60	N			0	18.5	Fault from CFM-R, slip rate not known
San Vicente		CFM-R		66	NE			1.6	17	Fault from CFM-R, slip rate not known
Santa Monica Bay april		CFM-R		20	NE			2.3	18	Fault from CFM-R, slip rate not known
Shelf projection		CFM-R		17	NE			2	18.1	Fault from CFM-R, slip rate not known
Sisar		CFM-R		29	S			0	17.4	Fault from CFM-R, slip rate not known
Yorba Linda		CFM-R		90				0	13.3	Fault from CFM-R, slip rate not known
Western Transverse Ranges and Santa Barbara Channel										
South Cuyama		CFM-R		33	SW			0	5.6	Fault from CFM-R, slip rate not known
Southern Coast Ranges										
Lost Hills		CFM-R		29	SW			4.2	12	Fault from CFM-R, slip rate not known
Nacimiento		CFM-R		66	NE			0	7.2	Fault from CFM-R, slip rate not known
Sierra Nevada and western Great Basin										
Lake Isabella seismicity		CFM-R		90				0	15.2	Fault from CFM-R, slip rate not known
Scodie Lineament		CFM-R		68	NW			7	12.9	Fault from CFM-R, slip rate not known
Eastern Transverse Ranges and Mojave Desert										
Bicycle Lake		CFM-R		90				0	12.3	Fault from CFM-R, slip rate not known
Blue Cut		CFM-R		90				0	13.1	Fault from CFM-R, slip rate not known
Cady		CFM-R		90				0	13.9	Fault from CFM-R, slip rate not known
Coyote Canyon		CFM-R		90				0	12.3	Fault from CFM-R, slip rate not known
Coyote Lake		CFM-R		90				0	13.4	Fault from CFM-R, slip rate not known
Hector Mine		CFM-R		90				0	14.6	Fault from CFM-R, slip rate not known

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 2, Fault parameters for faults being considered for development of deformation models

Fault Name	model	Source of fault trace	rake	dip	dip direction	slip rate	slip rate error	top depth	bottom depth	Details of slip rate, black from 1996 model, red from 2002 model, blue from 2006
Garlic Springs		CFM-R		90				0	12.7	Fault from CFM-R, slip rate not known
Goldstone Lake		CFM-R		90				0	12.4	Fault from CFM-R, slip rate not known
Joshua Tree seismicity		CFM-R		90				0	13.3	Fault from CFM-R, slip rate not known
Ludlow		CFM-R		90				0	11.1	Fault from CFM-R, slip rate not known
Manix Afton Hills		CFM-R		90				0	13.2	Fault from CFM-R, slip rate not known
McLean Lake		CFM-R		90				0	11.1	Fault from CFM-R, slip rate not known
Nelson Lake		CFM-R		90				0	11.7	Fault from CFM-R, slip rate not known
Paradise		CFM-R		90				0	13.4	Fault from CFM-R, slip rate not known
Red Pass		CFM-R		90				0	11.7	Fault from CFM-R, slip rate not known

Fault revised since 2002 model | Fault added since 2002 model | Alternate slip rates in deformation models

Table 3, Alternative deformation models for southern California. Preliminary weights for the alternative deformation models are based on consistency with geologic slip rate studies, and geodetic deformation of the region. Slip rate error is estimated 95% error bounds, as in Table 1

2.1 Best Estimate San Andreas and San Jacinto	**Slip Rate**	**Slip Rate Error**	**2.2 High San Jacinto & Low San Andreas**	**Slip Rate**	**Slip Rate Error**	**2.3 High San Andreas & Low San Jacinto**	**Slip Rate**	**Slip Rate Error**
Preliminary Weight		50%	**Preliminary Weight**		20%	**Preliminary Weight**		30%
SA Mojave S	29	7	SA Mojave S	29	7	SA Mojave S	29	7
SA San Bernardino N	22	6	SA San Bernardino N	18	5	SA San Bernardino N	25	10
SA San Bernardino S (including San Gorgonio Pass Knot*)	18	6	SA San Bernardino S (including San Gorgonio Pass Knot*)	12	6	SA San Bernardino S (including San Gorgonio Pass Knot*)	18	8
SA San Gorgonio Pass-Garnet Hill (including San Gorgonio Pass Knot*)	12	6	SA San Gorgonio Pass-Garnet Hill (including San Gorgonio Pass Knot*)	7	2	SA San Gorgonio Pass-Garnet Hill (including San Gorgonio Pass Knot*)	13	6
SA Coachella	20	6	SA Coachella	16	6	SA Coachella	24	6
SJ San Bernardino Valley	6	4	SJ San Bernardino Valley	10	8	SJ San Bernardino Valley	3	2
SJ San Jacinto Valley & Anza	18	6	SJ San Jacinto Valley & Anza	22	6	SJ San Jacinto Valley & Anza	14	6

* Slip in San Gorgonio Pass Knot C-zone (figure 5) is modeled as 6 mm/yr in a zone from the surface to 6 km depth. For balancing moment rates, this is equivalent to 2 mm/yr spread over the entire 18 km depth of the San Andreas fault in this area.

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