RUPTURE TRIGGERING, NUCLEATION, AND PREDICTABILITY IN FOAM RUBBER MODELS OF EARTHQUAKES

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Spontaneous stick-slip along the interface between stressed foam rubber blocks can be used as a simple analog of earthquake fault rupture, incorporating a steady buildup of tectonic strain, fault creep, characteristic earthquakes, rupture nucleation, nearly time and slip predictable sequences of tens of events, and event triggering by normal stress reduction. Results from this model are used to elucidate (1)problems associated with short term earthquake prediction based on premonitory nucleation phenomena, (2)long term prediction based on accurate measurement of strain build up, and (3)the possibility of earthquake triggering by reduction of normal stress by conjugate events. The model is compared with the various possibilities for predictable and non-predictable earthquake triggering models presented by Brune(1979).

No useful premonitory phenomena(short term) have been established for the model. The model may be stressed to very near the peak value for nucleation and it will remain stable indefinitely if no more stress is added. The critical nucleation patch radius and the critical nucleation premonitory slip are consistent with the results of Deitrich(1986) for laboratory blocks of granite, and are too small to be useful in short term prediction unless some at present unknown mechanism causes strong roughness on a scale much larger than the primary roughness scale.

Preliminary efforts to measure the velocity dependence of fault friction have not yielded any evidence of velocity weakening. Observations indicate that dynamic changes in normal stress may play an important role in controlling stick slip, as suggested by Tolstoi(1967) and by some seismological observations(e.g. Blandford, 1975).

Long term prediction based on the known rate of strain build up, or on long sequences of characteristic events, can be accurate to an uncertainty of less than 10% of the average earthquake recurrence interval. Sequences of several events often fit both the time predictable and slip predictable models quite well, but these sequences are often followed by a perturbation in which the expected characteristic event is replaced by two or three smaller events, disrupting the predictability. However,the sequence [redacted] evolves back into approximate agreement with the [redacted] slip predictable model. Sequences are often as regular as indicated by Bakun and McEvilly(1984) for Parkfield, but such sequences are often followed by a period of irregularity.

Event triggering by reduction in normal stresses has been suggested for recent earthquakes (e.g. Superstition Hills, 1988), and this is also an efficient method of triggering events in the foam rubber model. In principle it should be possible to stress the model arbitrarily close to incipient nucleation, so that an event may be triggered by an arbitrarily small reduction in normal stress. We have verified that we can stress the model to the point where less than 10% reduction of normal stress will trigger rupture. If similar conditions apply to real faults large earthquakes may be triggered by relatively small precursory events, making precise short term prediction very difficult, and forcing us to be content with relatively uncertain probabilistic statements about earthquake triggering.

1.0%

Offset Holocene Stream Channel and Rate of Slip Along the Northernmost Reach of the San Jacinto Fault

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The 3-dimensional geometry of a buried channel-fill deposit which crosses and is offset by a strand of the San Jacinto fault zone in San Bernardino, California is reconstructed from an extensive suite of trench logs. The age of the deposit is $\leq 1970 \pm 109$ years based on radiometric dating of carbon collected from the unit. Interpretation of the trench logs shows that the original and active course of the channel was, prior to crossing the fault zone, deflected for a short distance along strike of the fault, a geometry analogous to that observed for many streams which cross active strike-slip fault zones today. Total offset of the channel across the fault is about 11 m in a right-lateral sense, but only about 3.5 to 6 meters of the displacement may be attributed to fault slip subsequent to formation of the channel deposit. The fault strand studied is 1 of 2 or more parallel and active strands at this site and, in that respect, our study points to a minimum rate of slip of 1.7 to 3.2 mm/yr along the northernmost reach of the San Jacinto fault zone. Furthermore, reconstruction of the original channel geometry serves to illustrate the large uncertainties attendant to fault slip estimates when based on few observations between piercing points which are inferred to be offset by fault movement.

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PLATE MOTIONS AND SEISMIC SLIP ON PLATE BOUNDARIES

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The focal mechanisms, recurrence, and time-average moment release of earthquakes on a plate boundary segment reflect the direction and rate of motion between the two plates. Plate motion models thus provide quantitative constraints on the spatially and temporally integrated deformation across plate boundary zones.

For the western North American plate boundary zone, two independent approaches have been applied to estimate plate motions and hence slip rates along major faults. One uses geologic observations and geodetic measurements in the Basin and Range and along the San Andreas Fault and other faults in the plate boundary zone. The approach is based on plate motion models that incorporate spreading rates from marine magnetic anomalies, transform azimuths, and earthquake slip vectors. Several interesting differences are observed between their results.

It has long been recognized that the 50-60 mm/yr rate of Pacific-North America motion inferred from marine magnetic anomalies in the Gulf of California exceeds the geologically and geodetically determined San Andreas Fault slip rate of ~32-36 mm/yr [Prescott et al., 1981; Sieh and Jahns, 1984]. Estimates of the direction of Pacific-North America motion are also discordant: the San Andreas strikes counterclockwise of the direction predicted by plate motion models. The "San Andreas discrepancy," which measures how much Pacific-North America motion is taken up elsewhere in the plate boundary zone, has been attributed to a combination of right lateral strike-slip along faults parallel to the San Andreas and shortening normal to it [e.g. Minster and Jordan, 1984, 1987; Weldon and Humphreys, 1986]. This discrepancy should be manifested seismically as both strike-slip faulting (accommodating the component of the discrepancy parallel to the San Andreas Fault) and thrust faulting (accommodating the component of the discrepancy parallel to the San Andreas Fault).

Recent analysis of this problem [DeMets et al., 1987] gives results significantly different from prior studies. Analysis of marine magnetic profiles from the Gulf of California, the only data that directly measure the full relative motion between the Pacific and North American plates over a time scale greater than a few years, shows a slower rate of motion than the earlier models. Since 3 Ma, spreading has averaged 48 mm/yr, 10 mm/yr (or 20%) slower than estimated before [Minster and Jordan, 1978], a rate consistent with the 49 mm/yr predicted by a global plate motion model derived without any data along the Pacific-North America boundary. The slower rate of Pacific-North America motion is also consistent with displacements measured across the boundary zone using very long baseline radio interferometry [Clark et al., 1987; Kroeger et al., 1987; Ward, 1988].

Results from other plate boundaries offer additional interesting insights. The maximum depth of seismicity is presumably controlled by the variation in rock strength with depth, and hence reflects the thermal structure. This depth has important implications for the depth of locking between major plate boundary earthquakes, and for the estimation of fault slip from seismic moments.

Often the rate of motion from relative plate motion models, which average over several million years, differs from that inferred from historical seismicity. Comparison of island arcs illustrates these difficulties. For the Lesser Antilles arc, The slip rate predicted by plate motion models is about 2 cm/yr, whereas that estimated from historical seismicity is approximately 0.2 cm/yr, about 10% [Stein et al., 1986a]. Such a deficiency of seismic slip relative to long term average plate motion can indicate several effects: time variability between short (10^2–10^3 year) and long (10^6 year) term average motion, a fraction of the slip occurring aseismically, or seismic gaps: a short term slip deficiency. At the other extreme, the seismic slip rate at the Chilean subduction zone estimated from the slip in the great 1960 earthquake and historical records indicating that major earthquakes have occurred in this area about every 130 years in the last 400 years *exceeds* the convergence rate estimated by plate motion models [Stein et al., 1986b]. Such an excess of seismic slip relative to long term average plate motion *requires* time variability; known large earthquakes and their temporal spacing cannot fully reflect plate motion. One possibility is that the seismic slip is overestimated: either the earlier earthquakes were significantly smaller than the 1960 event or they in general occur less frequently than in the last 400 years. Alternatively, the rate of plate motion is nonuniform on various time scales. These examples bear out some of the difficulties in estimation of earthquake recurrence on a plate boundary, and identification of seismic gaps.

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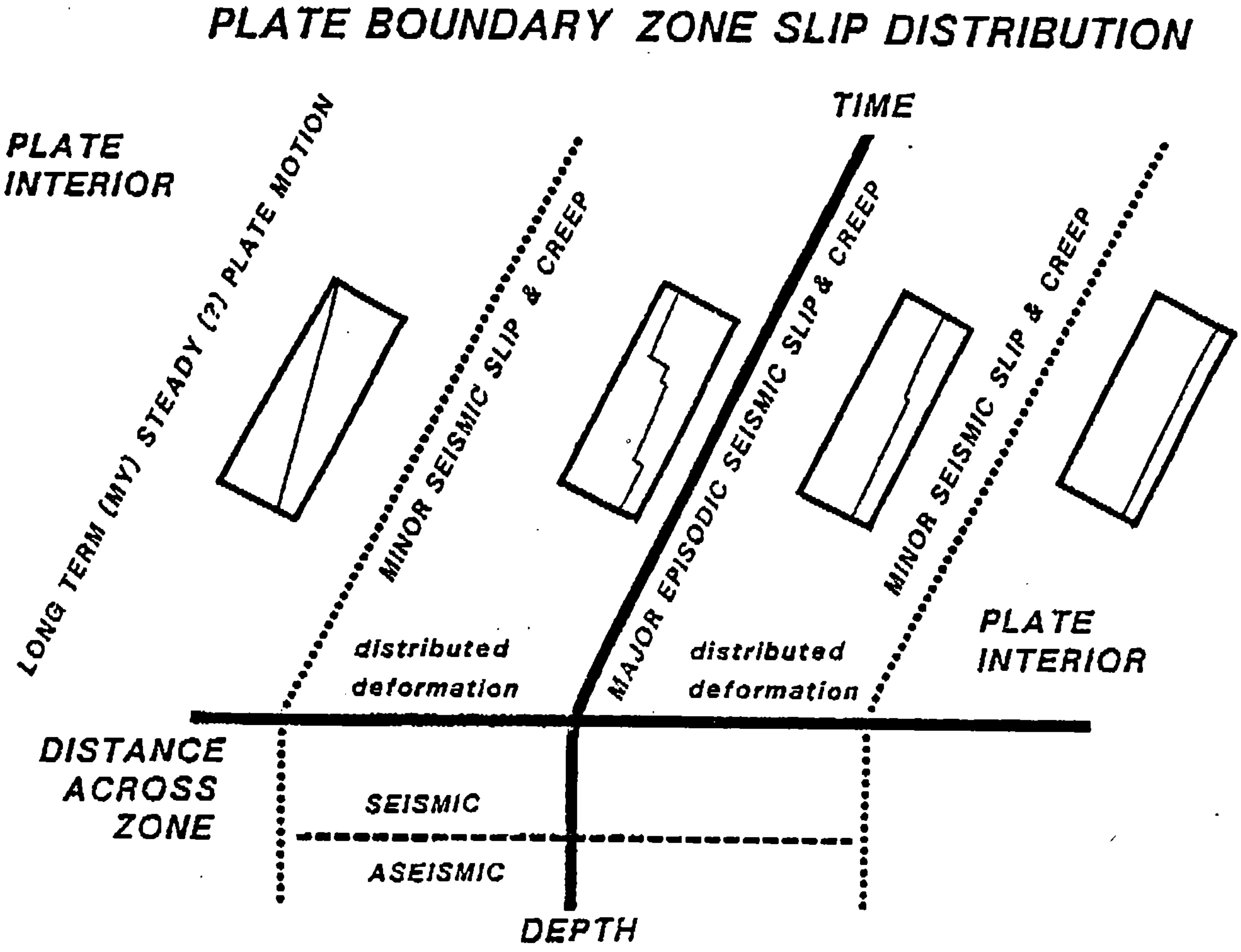
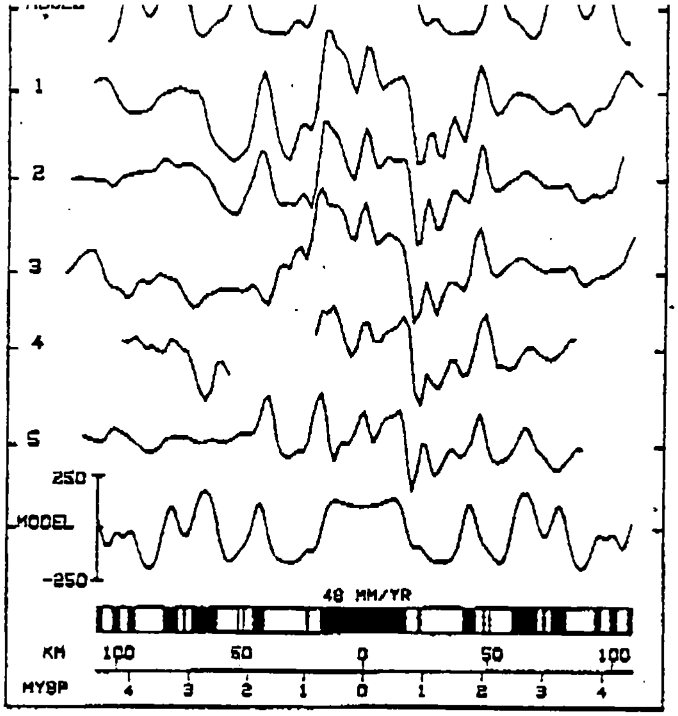
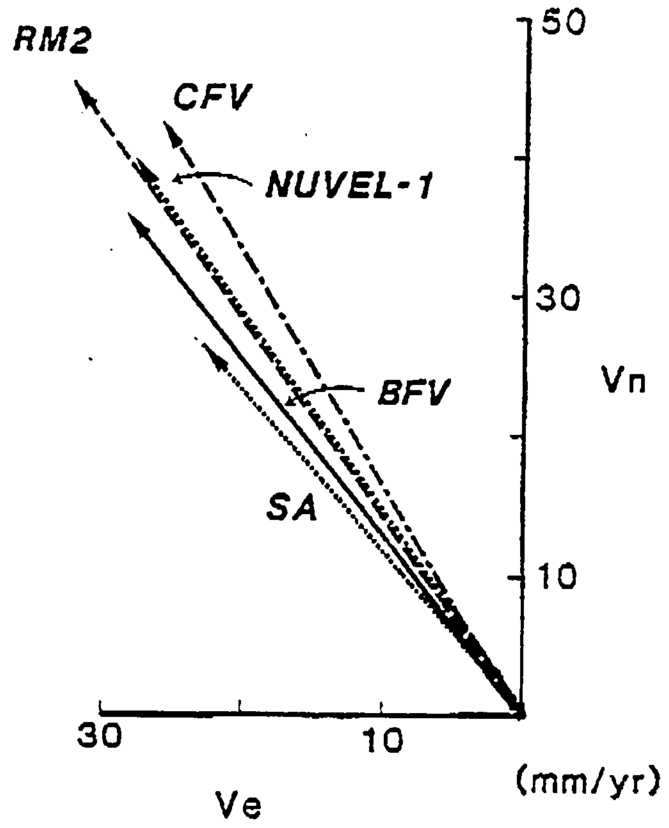


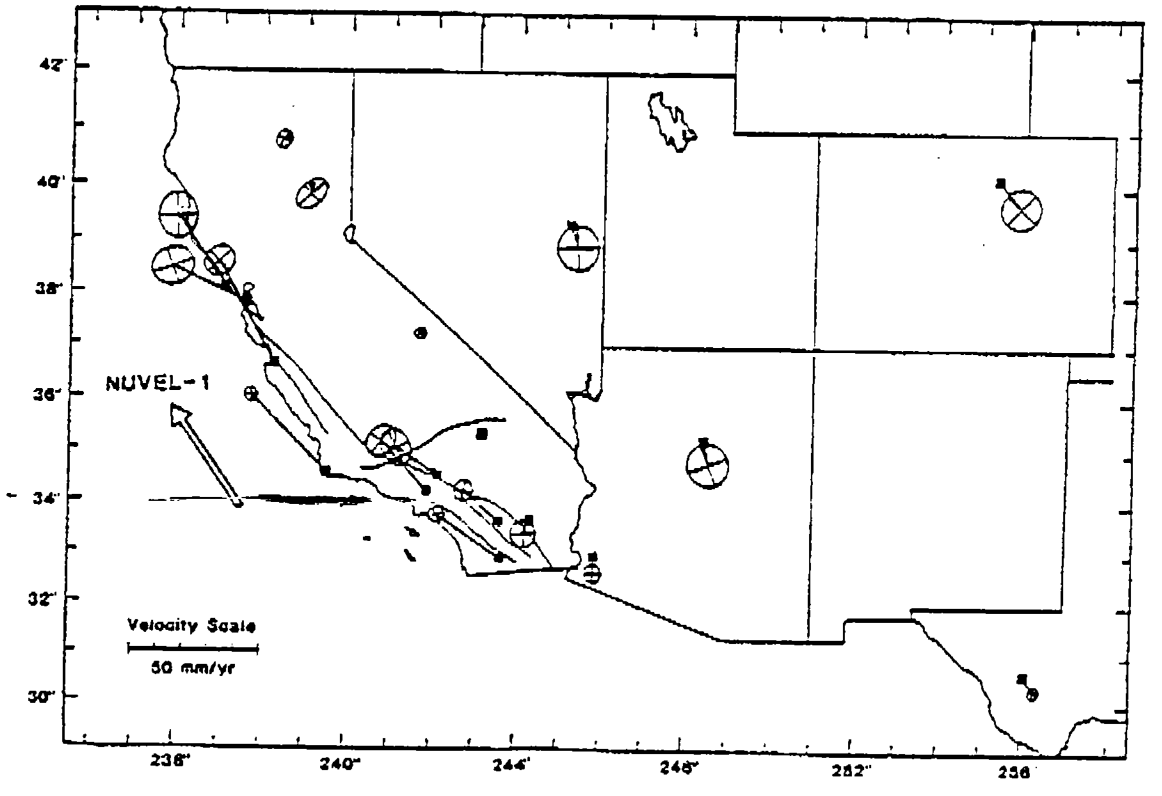
Schematic illustration of the variation across a plate boundary zone of the slip resulting from the motion between two major plates.



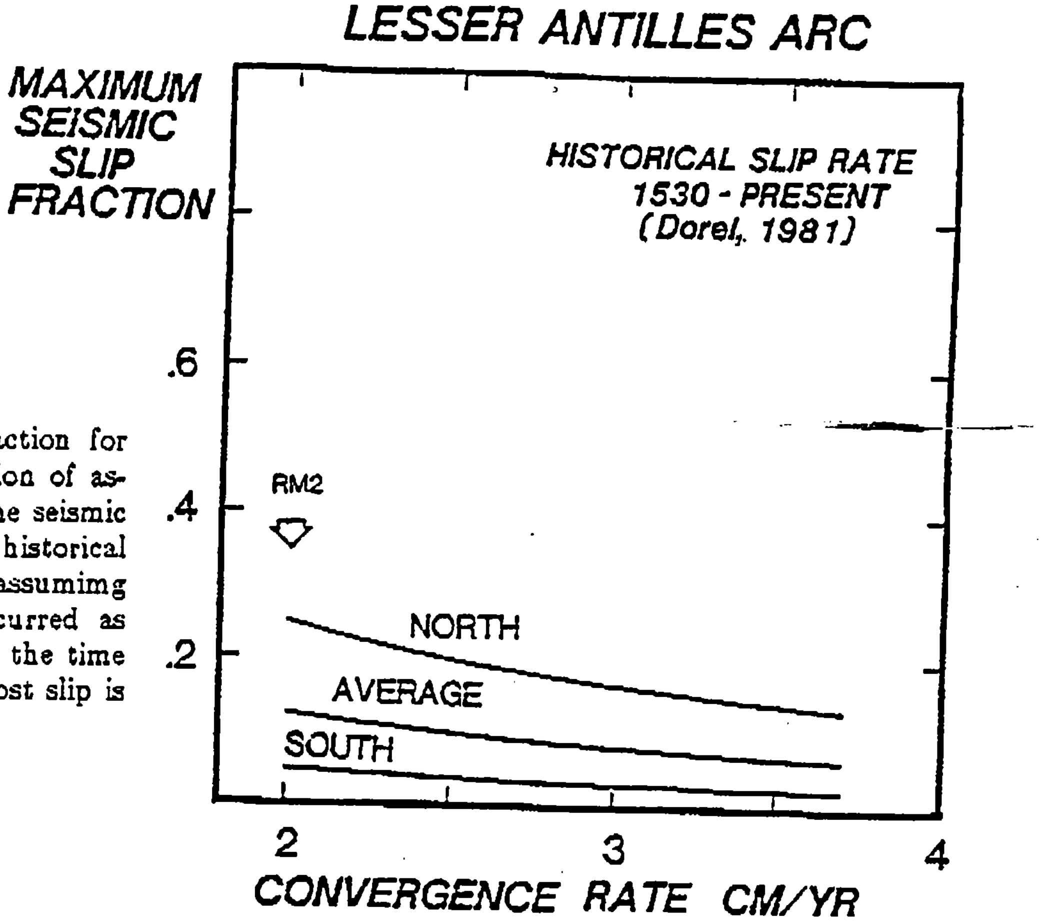
Along-track (GULFO-81, GAM-2, and MARSUR-78) and projected (HYPO, N60° W) magnetic profiles are compared to 48 mm/yr and 58 mm/yr synthetic profiles. Profile 1 is the GULFO-81 north, #2 is the GAM-2 north, #3 is the HYPO north, #4 is the MARSUR-78, and #5 is the GULFO-81 south. All profiles have been reduced to the pole by a phase shift of 83° determined from the 1976 ICRF for the present field and an axial geocentric dipole model for the remanent magnetization. The profile-to-profile correlation of short and long wavelength features is good for the 48 mm/yr synthetic, but poor for the 58 mm/yr synthetic.



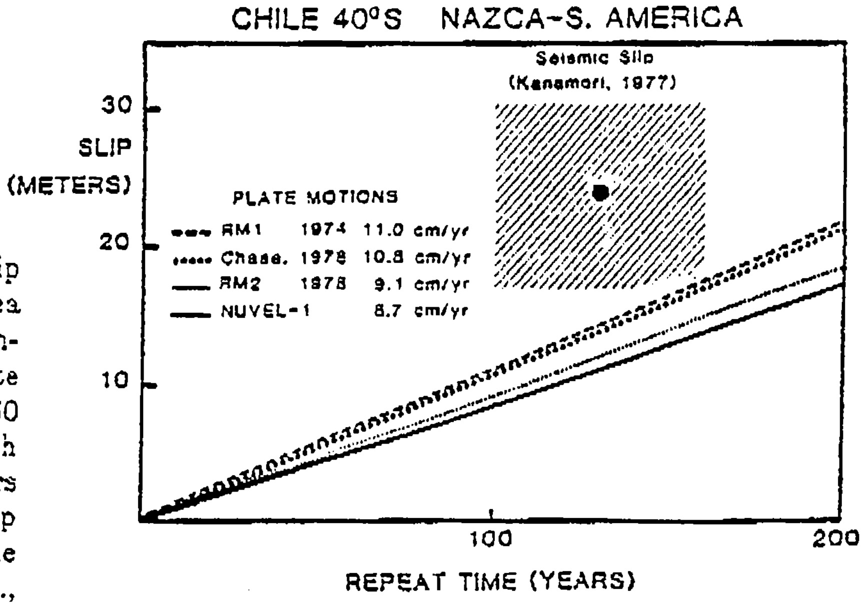
Linear velocity vectors representing the observed and predicted relative motions at 36°N along the San Andreas Fault in central California. The predictions of the NUVEL-1 Pacific-North America best-fitting (BFV, solid), closure-fitting (CFV, alternating dashed), and global vector (NUVEL-1, thin solid) differ from the summed San Andreas



Site motion vectors and three-sigma formal error ellipses determined for the sites in the western United States as given in Table 4. For reference, the trace of the San Andreas and several other faults and the NUVEL-1 velocity for the central California coast are also shown.



Seismic slip fraction for the Antilles arc as a function of assumed convergence rate. The seismic slip, estimated from historical records, is an upper bound assumimg all historical seismicity occurred as interplate thrust events. If the time sample is representative, most slip is aseismic. [Stein et al., 1986].



Comparison of seismic slip rate and plate motions for the area of the great 1960 Chilean earthquake. Shaded region gives slip rate estimated from slip in the 1960 event and recurrence of large trench earthquakes in the last 400 years [Kanamori, 1977]. The estimated slip rate exceeds that predicted by the plate motion models [Stein et al., 1986].

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A microplate model for tectonic deformation in California

by

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and

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Abstract

We use a combination of Very Long Baseline Interferometry (VLBI), trilateration, creep, and geological fault displacement data to infer the translation velocities and rotation rates of seven "microplates" in California. In our model the microplates are free to move parallel to their bounding faults below 10 km depth, but they are restricted by friction above 10 km depth. The friction near the surface causes deformation, which we model using elastic dislocation theory, near the microplate boundaries. The boundaries are formed by the San Andreas, San Jacinto, Hayward, Garlock, San Gregorio-Hosgri, Santa Monica, and an unspecified offshore fault. In our inversion we include prior estimates of the microplate velocities, chosen such that the San Andreas Fault (SAF) system is the boundary between the Pacific and North American plates, which move at relative velocities given by the NUVEL-1 model. The adjusted model, which fits the data vastly better than the prior model, is also consistent with the NUVEL-1 plate model and most of the geological estimates of long-term fault slip rates. But it differs from the prior model in the following respects: (1) it requires significant displacement at depth on all of the above-named faults except the Garlock, (2) it requires more than 15 mm/yr displacement on the San Gregorio-Hosgri and unspecified offshore faults, and (3) it requires 15 mm/yr compression across the western Transverse Ranges, decreasing to 5 mm/yr across the eastern Transverse Ranges. The model predicts seismic risk from offshore faults comparable to that of the southern San Andreas or San Jacinto faults.

A Microplate Model for Tectonic Deformation in California

by

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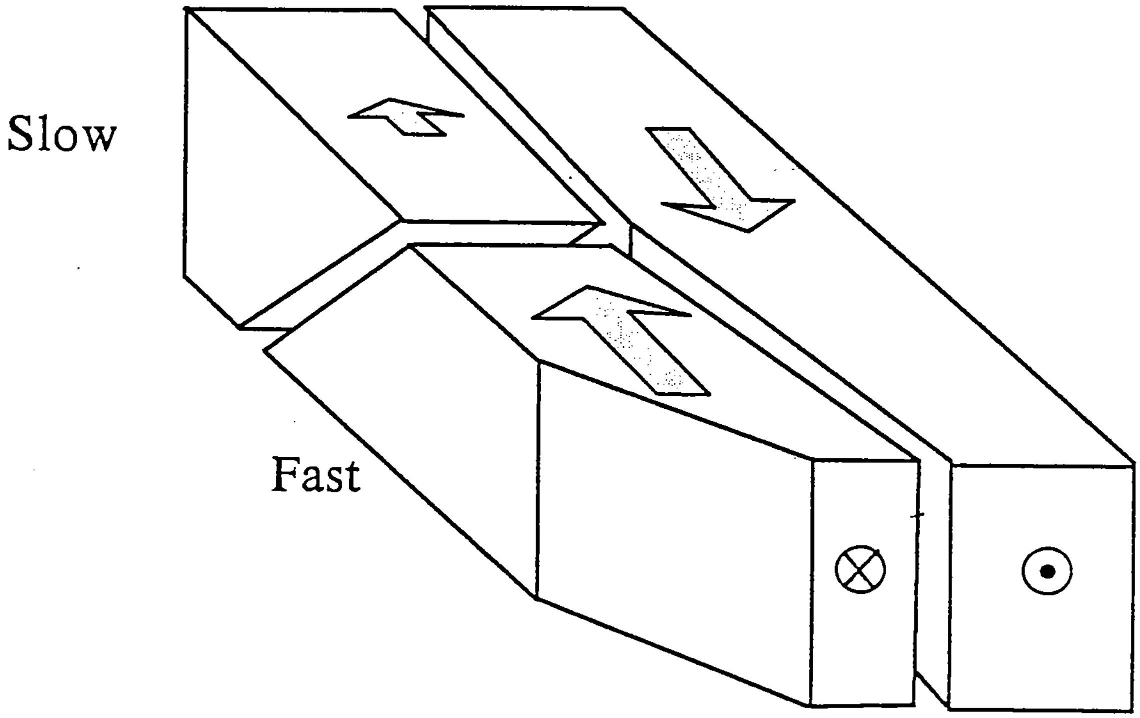
(Chiba Univ.) *(UCLA)*

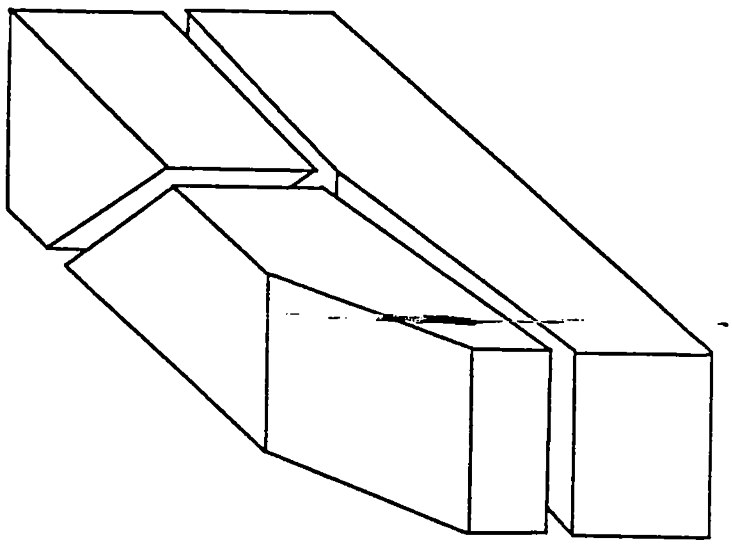
* Objective:

To relate geodetic observations (10 - 10^2 yr),
geological observations (10^3-10^5 yr),
and plate motion estimates (> 10^6 yr)
in California

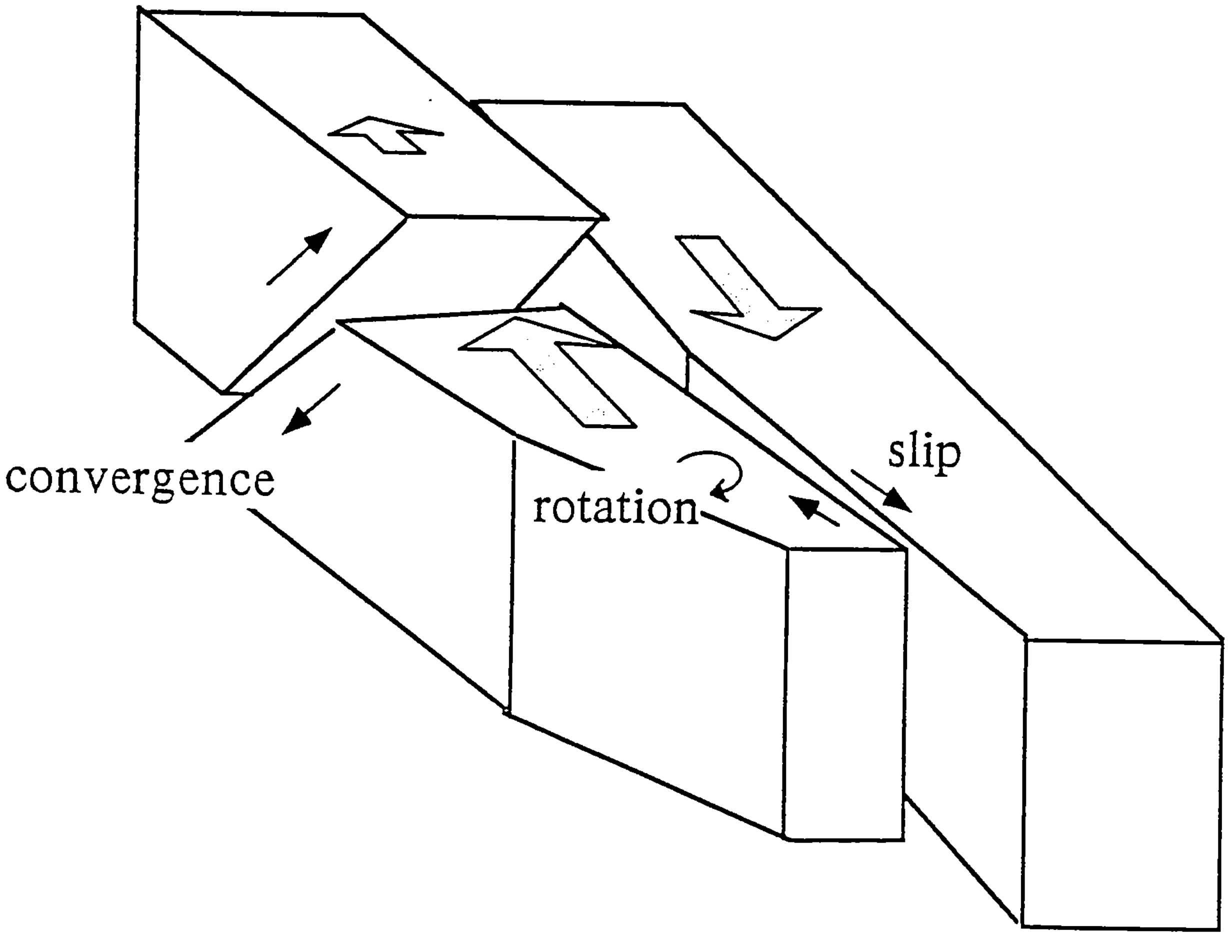
* San Andreas Discrepancy

Undeformed Blocks



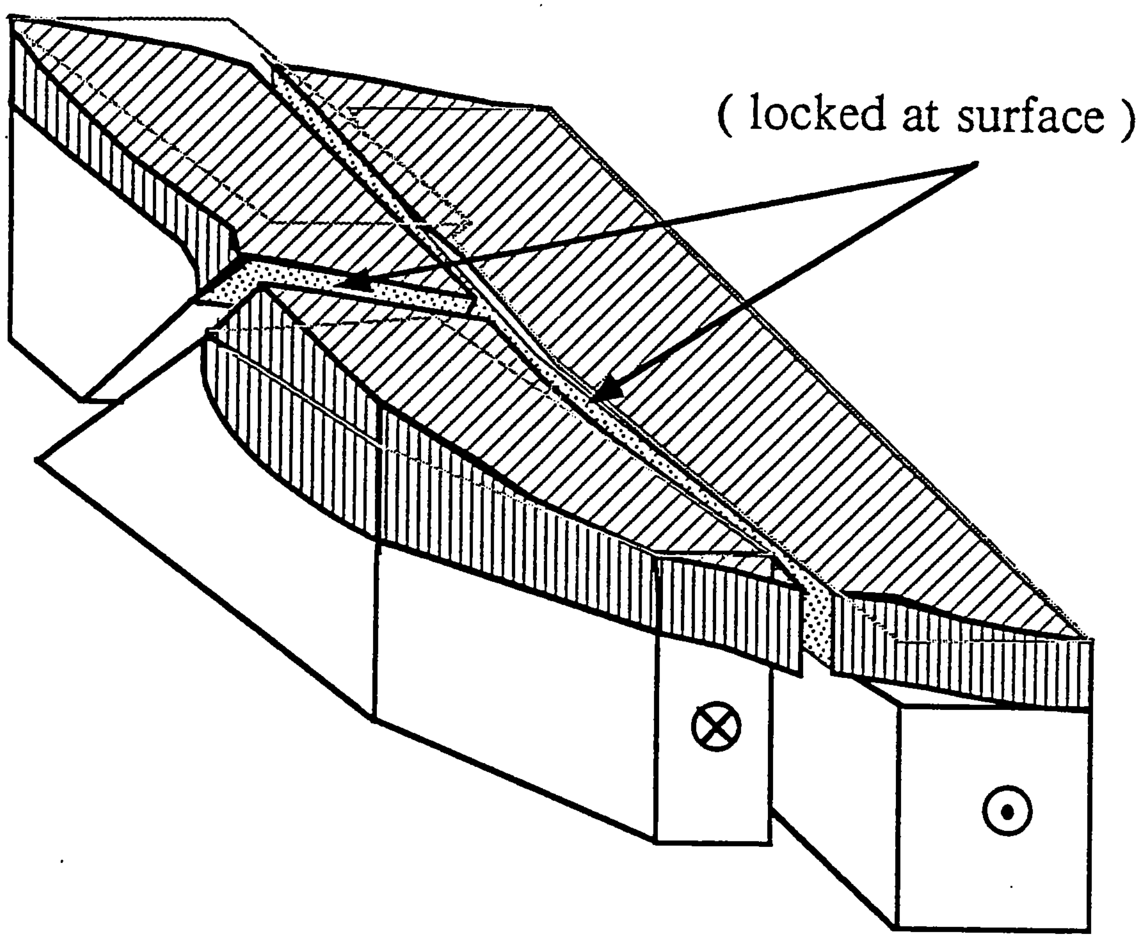


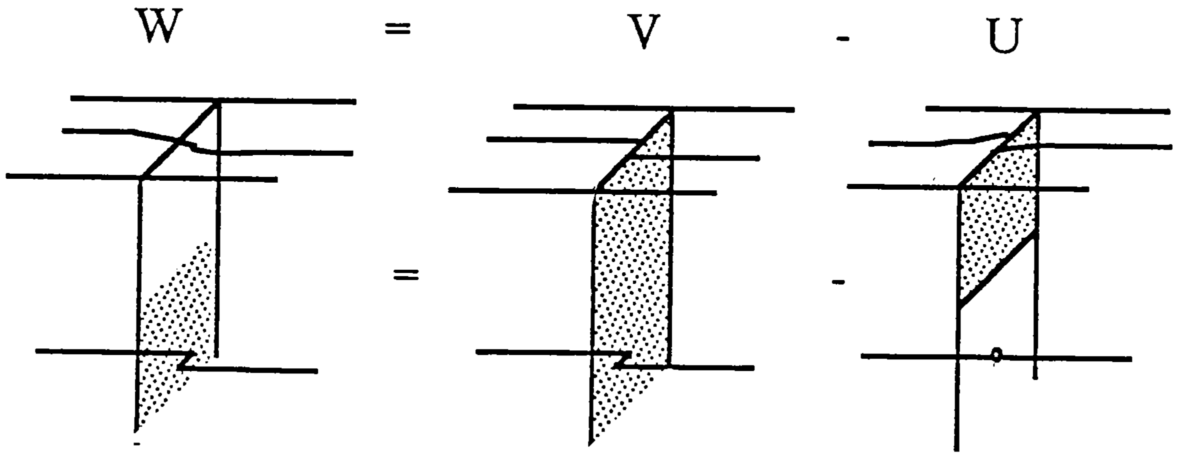
Rigid Block Motion
(creep at surface)



N.Hirata (1989)

Rigid Block Motion
+ Elastic Deformation





Aseismic deformation

Block motions

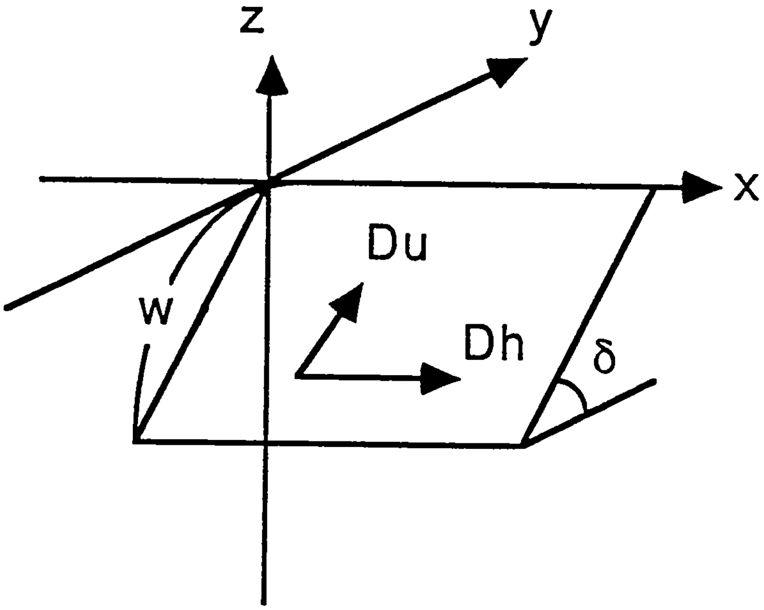
Dislocation deficit

Model

$$W = V - U$$

$$V = \omega \times r$$

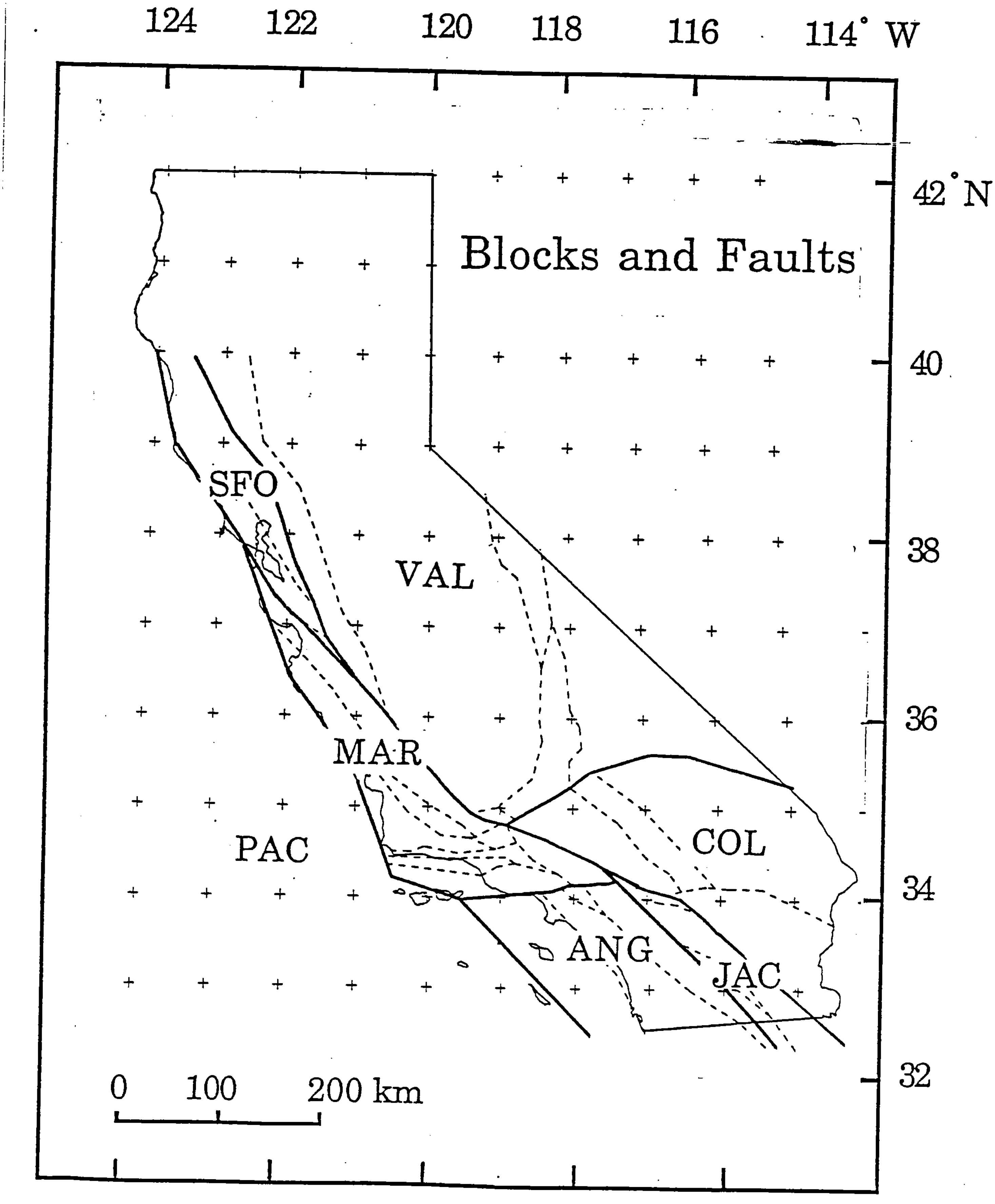
$$U = \sum_k u_k(D_u, D_h)$$

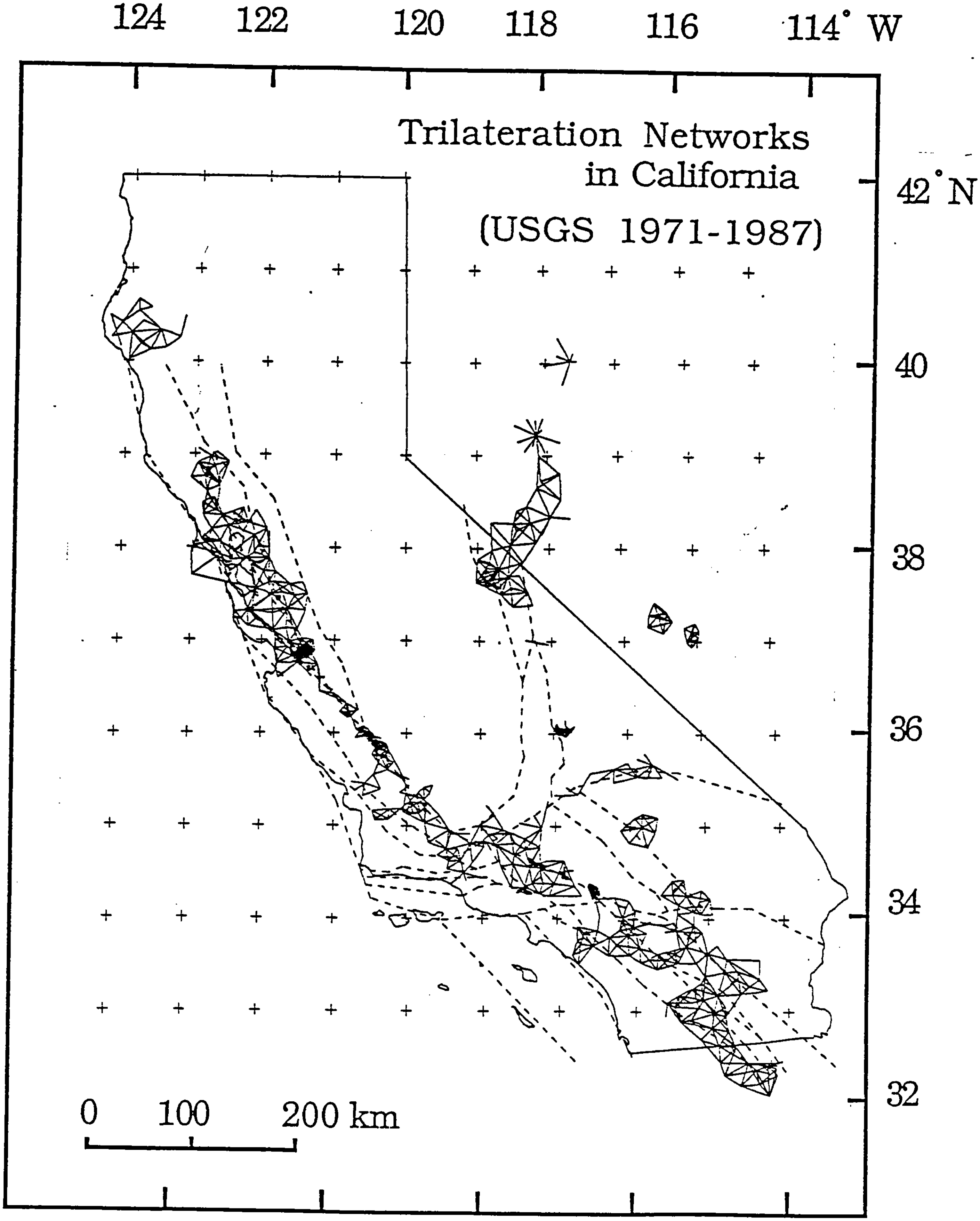


Fault model

Parameters

Fixed parameters	
microplate	(7)
fault patch	(71)
Model parameters	***163***
V_e, V_n, ω	(21)
D_u , D_h	(142)
Strict constraint	***68***
fixed block COL	(3)
$D_u = 0$ for vertical patches	(65)
Unknowns to be determined	***95***


124
122
120
118
116
114° W
42° N
40
38
36
34
32
Blocks and Faults
SFO
VAL
MAR
PAC
COL
ANG
JAC
0
100
200 km


124
122
120
118
116
114° W
Trilateration Networks
in California
(USGS 1971-1987)
42°N
40
38
36
34
32
0
100
200 km

Inversion

Method

Bayesian inversion
(*Jackson and Matsu'ura, 1986*)
Linear problem

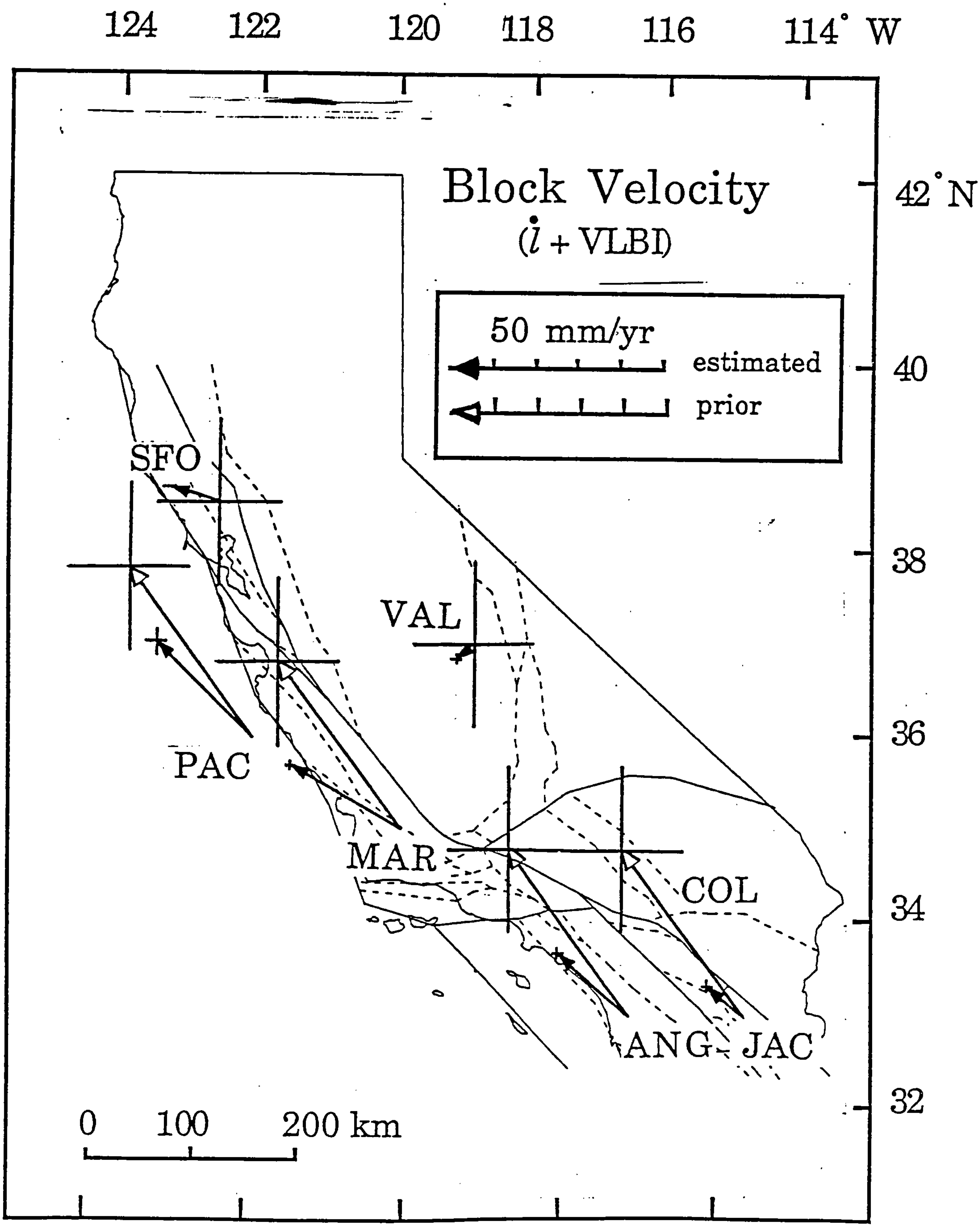
Prior data

Plate motion: NUVEL-1 (*DeMets et al.,1987*)
Du, Dh

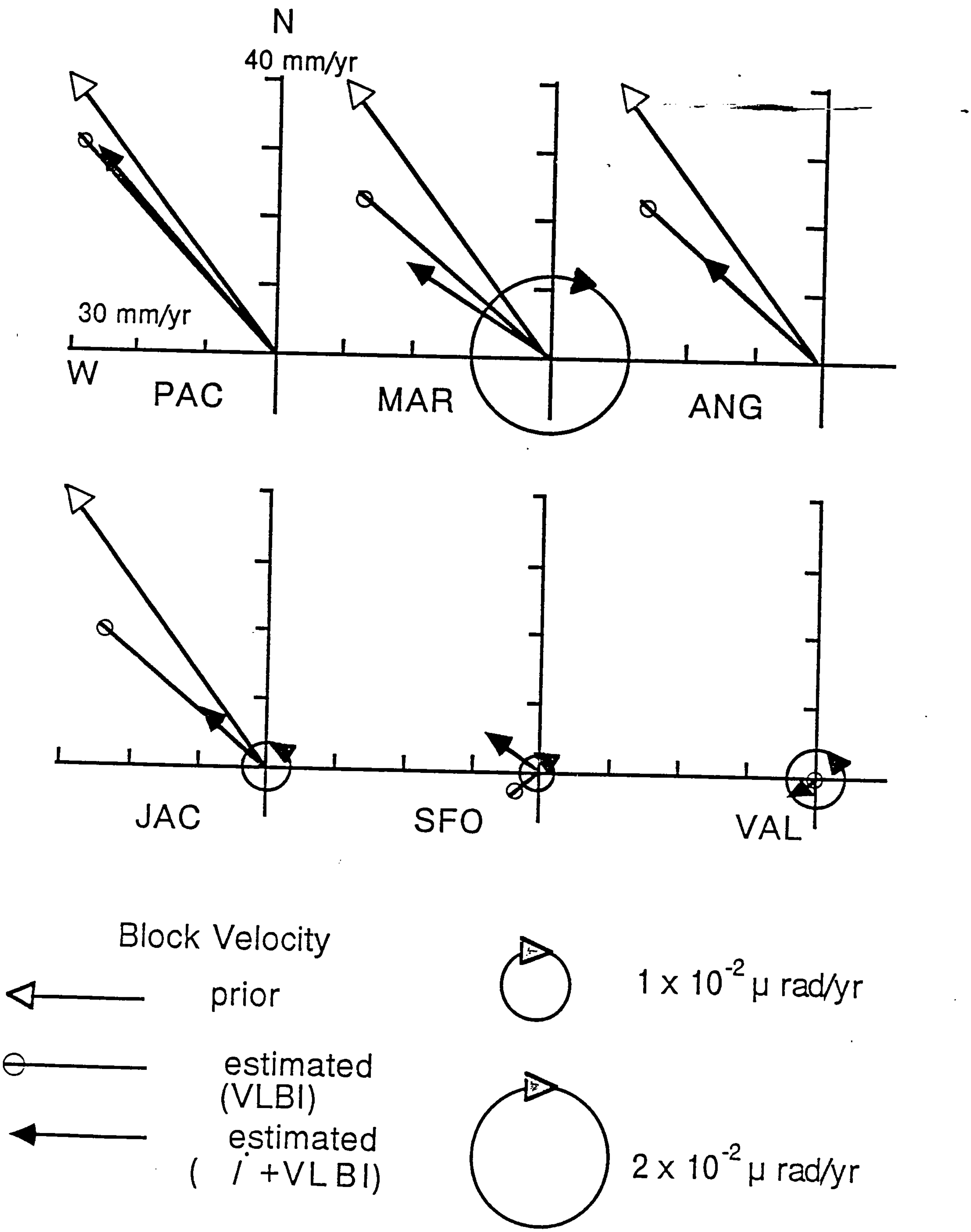
Observed data

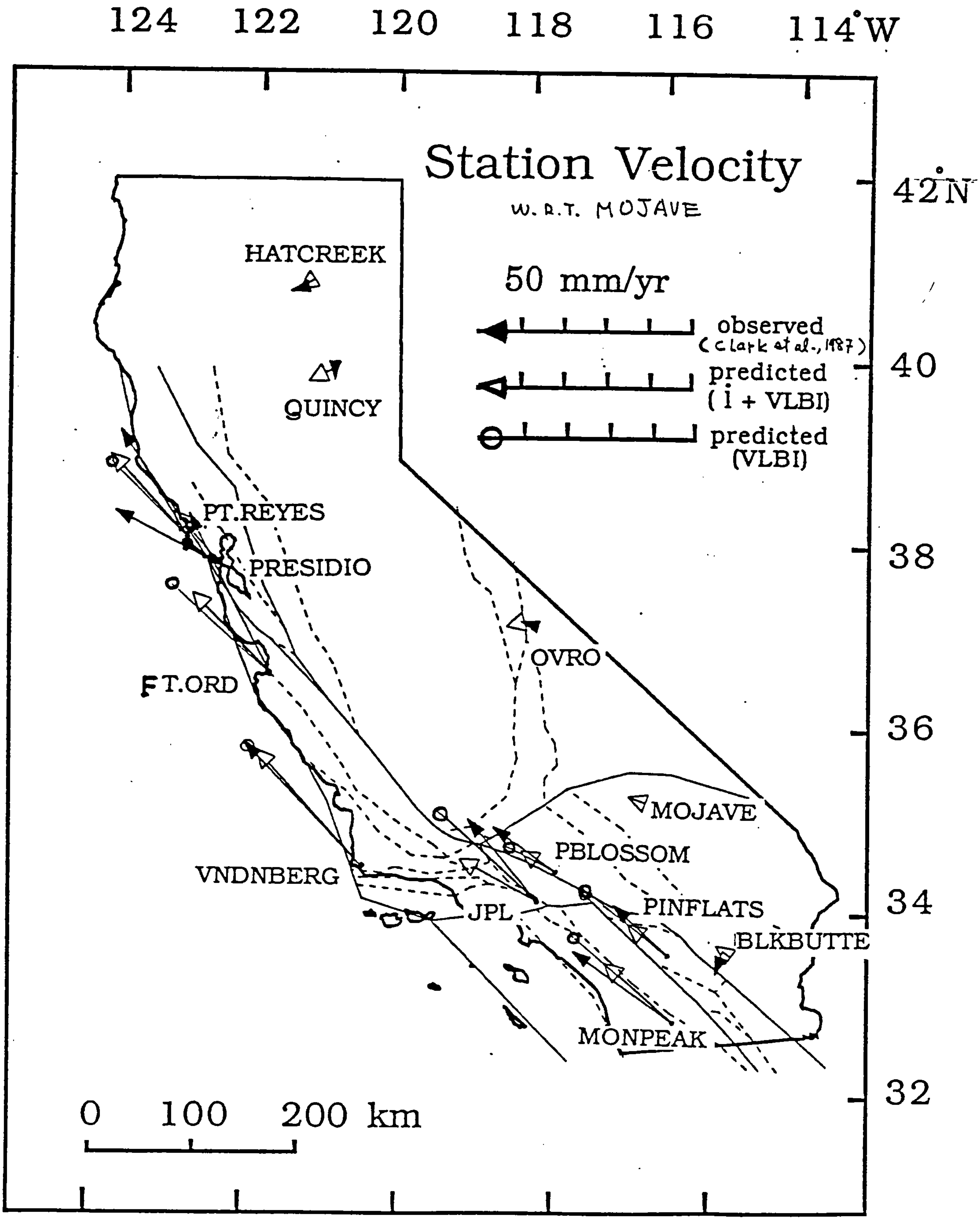
Trilateration	831	lines
VLBI	24	components

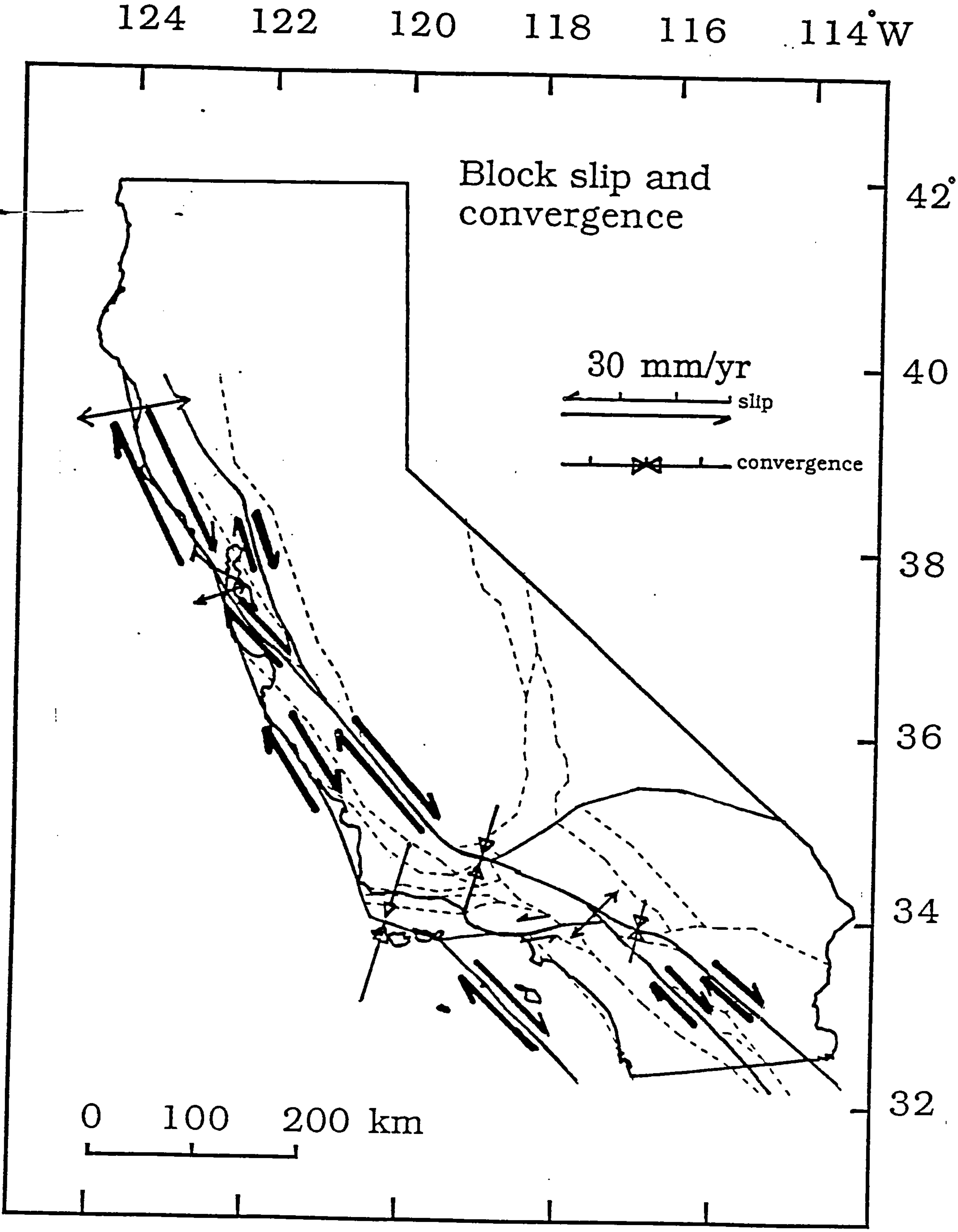
Creep rate & surface convergence rate


124
122
120
118
116
114° W
Block Velocity
($\dot{l}$ + VLBI)
50 mm/yr
estimated
prior
42°N
40
38
36
34
32
SFO
VAL
PAC
MAR
COL
ANG
JAC
0
100
200 km

Block Velocities




124
122
120
118
116
114°W
42°N
40
38
36
34
32
Station Velocity
W.R.T. MOJAVE
50 mm/yr
observed
(Clark et al., 1987)
predicted
(I + VLBI)
predicted
(VLBI)
HATCREEK
QUINCY
PT.REYES
PRESIDIO
OVRO
FT.ORD
MOJAVE
PBLOSSOM
VNDNBERG
JPL
PINFLATS
BLKBUTTE
MONPEAK
0 100 200 km


124
122
120
118
116
114°W
Block slip and convergence
42°N
40
38
36
34
32
30 mm/yr
slip
convergence
0 100 200 km

Conclusion

(1) Known onshore faults with geodetic data ***can not*** explain the plate motion.

(2) ***Our model*** adjusted by VLBI, trilateration, and creep data is ***consistent with*** the *NUVEL-1 model* and most of the *geological* estimates of long-term fault slip rate.

(3) But the model differs from the *NUVEL-1 model*:

  (a) significant displacement at depth on microplate boundaries.

  (b) more than 15 mm/yr displacement on unspecified offshore faults

  (c) 15 mm/yr compression across the western Transverse Ranges

NUCLEATION SIZE AND FAULT BEHAVIOR FOR MODERATE EARTHQUAKES IN CALIFORNIA FROM HIGH-RESOLUTION STRAIN MEASUREMENTS.

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Simple views of the earthquake rupture process in the late 1970's included poorly supported concepts of: 1) substantial ~~non-linear~~ deformation (dilatancy) and strain in the "preparation zone" of earthquakes prior to rupture, 2) scale for this "preparation zone" that exceeded the eventual earthquake rupture dimensions by large factors, and 3) properties of near-fault materials that vary with time and location. In contrast, recent high resolution borehole strain recordings near many moderate earthquakes in California and Japan indicate: 1) short-term non-linear precursive strains greater than 10^{10} have not been detected in the eventual epicentral region, 2) the size of fault patches that initiate failure are probably less than a few hundred meters in size while the eventual earthquake rupture dimensions are several tens of kilometers, and, 3) strains from regional strain field offsets resulting from earthquakes are transmitted largely elastically through the complex geology and fault geometry in these regions. The events in California for which near-field recordings were obtained and on which these conclusions are based include: the August 4, 1985, Kettleman Hills (M_L 5.5, Δ 34 km) earthquake, the April, 1984, Morgan Hill (M_L 6.1, Δ 55 km) earthquake, the November, 1984, Round Valley (M_L 5.8, Δ 58 km) earthquake, the July 8, 1986, North Palm Springs (M_L 5.9, Δ 44 km) earthquake, the July 21, 1986, Chalfant (M_L 6.0, Δ 40 km) earthquake, the January 26, 1986, and the February 20, 1988, Quiensabe (M_L 5.5, 5.0, Δ 23.7, 21.3 km, respectively) earthquakes, the March 31, 1986, Mount Lewis (M_L 5.7, Δ 67.6 km) earthquake, the October 1, 1987, Whittier Narrows (M_L 5.9, Δ 46 km) earthquake, and the December 3, 1988, Pasadena (M_L 5.0, Δ 41 km) earthquake, The best recorded event in Japan showing similar characteristics was the January 14, 1978, Izu (M_L 7.0, Δ 28 km) earthquake. Similar results regarding the absence of detectable short term strain changes have recently been obtained at Pinon Flat for several other moderate to large earthquakes. The concept of inhomogeneous faulting implied by the small size of rupture initiation compared with that of the final rupture zone, is consistent with recent inversions of 3-component seismic data that show non-uniform seismic moment release with time.

SLIP RATE ON THE SAN JACINTO FAULT ZONE IN THE ANZA SEISMIC GAP, SOUTHERN CALIFORNIA

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Trenching studies have resulted in two new slip-rate estimates for the Clark fault within the San Jacinto fault zone near Anza. This fault shows the most convincing geologic evidence of Holocene movement and the largest cumulative displacement of any in the San Jacinto fault zone. However, it has not experienced a ground-breaking earthquake in historic time.

Charcoal from sediments interpreted to have ponded behind a shutter ridge was dated at 28,650±980 years B.P. This date and the offset from the shutter ridge yield an estimated slip rate of 7-18 mm/yr. Charcoal from the upper part of the stream gravels in the abandoned channel was dated at 3860±110 years. This date and the minimum offset of the stream channel of 48 m yield a minimum slip rate of 12 mm/yr. Another previously reported radiocarbon date from offset ponded sediments provided a minimum slip rate for the last 9500 years of 9±1 mm/yr, but allows for a larger rate. Collectively, these estimates bracket the slip rate on the Clark fault north of Anza within 12-18 mm/yr for the last 30,000 years. At least one ground-breaking event has occurred in the last 730±60 years, as indicated by a radiocarbon date from sediments displaced by one of several strands of the Clark fault at Hog Lake.

SLIP-RATE AND PALEOSEISMIC STUDIES ON THE NORTHERN SAN ANDREAS FAULT NEAR POINT ARENA, CALIFORNIA

Carol Prentice and Kerry Sieh

ABSTRACT

The northern segment of the San Andreas fault last ruptured in 1906, producing the great San Francisco earthquake. Geologic slip-rate and paleoseismic data, important in the assessment of seismic hazard, are sparse for this segment of the fault. This study involves the collection and interpretation of geologic data from the segment of the northern San Andreas fault near Point Arena, California, to determine the recurrence interval and slip rate of this segment of the fault.

Holocene sediments deposited on an alluvial fan preserve a record of prehistoric earthquakes near Point Arena. Excavations into the fan exposed sediments deposited across the San Andreas fault zone. Evidence for at least five earthquakes exists in the section. All of these occurred after the deposition of a unit that is approximately 2000 years old. Because deposition in this setting was intermittent, it is possible that some earthquakes were not recorded at this site; therefore, the five events are a minimum number. Radiocarbon ages allow constraints to be placed on the dates of the earthquakes. A buried Holocene (2356-2709 years old) channel has been offset a maximum of 64 ± 2 meters. This implies a maximum slip rate of 25.5 ± 2.5 mm/yr. These data suggest that the average recurrence interval for great earthquakes on this segment of the San Andreas fault is long - between about 200 and 400 years.

Offset marine terrace risers near Point Arena allow estimation of the average slip rate across the San Andreas fault since Late Pleistocene time. Correlation of two marine terrace risers across the fault in this area suggests offsets of approximately 1.5 and 2.5 km. The U-series age of a solitary coral, altitudinal spacing and correlation with known global high-sea-level stands suggest ages of 83,000 and 133,000 years for these surfaces, indicating slip rates of about 18-19 mm/yr since Late Pleistocene time.

Marine deposits near Point Arena may have been offset from the Pliocene Ohlson Ranch Formation in northwestern Sonoma County, 50 km to the southeast. If correct, this correlation allows calculation of a Pliocene slip rate for the northern San Andreas fault. A fission-track age of 3.3 ± 0.8 Ma was determined for zircons separated from a tuff collected from the Ohlson Ranch Formation. The geomorphology of the region, especially of the two major river drainages, supports the proposed 50 km Pliocene offset. This implies a Pliocene slip rate of at least 12-20 mm/yr.

The similarity of the Holocene, Pleistocene and Pliocene rates implies that the slip rate of the northern San Andreas fault has not changed by more than a factor of two in the last several million years. The rates also imply that much of the Pacific-North American plate motion must be accommodated on other structures at this latitude.

STRUCTURE AND ACTIVITY OF THE OFFSHORE NEWPORT-INGLEWOOD - ROSE CANYON ZONE OF DEFORMATION

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The offshore Newport-Inglewood - Rose Canyon Zone of Deformation (NI-RC ZD) is a 106 km long, linear zone of complex folds and faults, which extends from Newport Beach to La Jolla. The offshore Zone was mapped at a scale of 1:24,000 using closely spaced high resolution seismic profiles and 20 digitally processed seismic reflection lines. At depth the Zone is both a complex wrench fault system and a positive flower structure which controls both width and trend of the shelf between Newport Beach and La Jolla.

Analysis of the Zone reveals three distinct fault zone segments: the right-stepping Newport Beach segment (Newport Beach to Dana Point), the left-stepping San Onofre segment (Dana Point to Oceanside) and the left-stepping La Jolla segment (Oceanside to La Jolla). A 10° asperity marks the northern boundary of the San Onofre segment while a 20° asperity marks the southern boundary. A fourth major segment, the San Diego segment, is suggested onland south of San Diego by a 25° asperity near La Jolla.

The onshore portion of the Newport Beach segment was probably responsible for the 1933 Long Beach (M=6.3) earthquake. Activity on this northern segment decreases progressively southward to Dana Point, where high resolution data indicate no deformation has occurred during the past 5,000 years. There is little or no seismicity along the Newport segment. Based upon the clustering of earthquake epicenters from 1971 to the present and surficial deformation shown by high resolution profiles, the middle of the central (San Onofre) segment is considered to be active. This activity decreases northwards towards Dana Point (segment boundary).

The southern segment is the most stucturally complex of the four mapped segments. Off Encinitas there is a major left-stepping break associated with a zone of shearing, folding and thrusting. A break in continuity of the Zone or perhaps distinct and overlapping NIZD and RCZD segments (?) is suggested at this point. The inner splay (RCZD) exhibits stream channels that are deflected by a compressional ridge documenting Late Quaternary or younger activity.

If this analysis is valid the active segments of the offshore Zone are 25 km to 44 km in length. The upper potential limit of earthquakes along the offshore NI-RC ZD may be significantly less than previously suggested.

THE PALOS VERDES FAULT ZONE: ONSHORE TO OFFSHORE

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ABSTRACT

The Palos Verdes fault is a northwest-trending wrench fault zone, which extends from the northern Santa Monica shelf, southward across the Palos Verdes peninsula and offshore over the San Pedro margin, a distance of over 100 km. Over the San Pedro Shelf the zone is 1 to 2 km wide and consists of a complex pattern of en echelon and anastomizing fault splays. Displacement along the zone is both right-slip and reverse (south-side-up). At the top of the Catalina Schist basement the vertical separation is about 1,800 m (south-side-up) across the Palos Verdes hills, and about 350m (south-side up) near the Beta field. Right-lateral separation, which cannot be quantified, is suggested by en echelon folds, facies changes in the Monterey Formation and the stepping or offset of individual fault segments over the San Pedro shelf. The fault plane is vertical at depth, but it becomes steeply south-dipping from about 1000 m above the basement to the ocean floor in the Beta area. A positive-flower structure, the Palos Verdes, uplift marks the southern flank of the fault zone.

Inception of a "proto-Palos Verdes fault zone" probably occurred during mid-Miocene time when Catalina Schist detritus was shed off a rising ridge. However, little or no evidence of vertical movement can be documented from late middle Miocene to early Pliocene time. For example, the producing late Miocene sands of the Beta field remain constant in thickness across the fault zone.

During the Quaternary, on land fault activity is dramatically shown by the 13 major elevated marine terraces of the Palos Verdes peninsula. Offshore the fault displaces late Pleistocene to Holocene age sediments, while the onshore trace of the fault is obscured by colluvium and urban development. On the San Pedro shelf high resolution seismic profiles and core hole data were used to define a Quaternary seismic stratigraphic sequence. The offshore data set provides abundant evidence for Holocene to modern activity, including; 3 m vertical offsets of the basal Holocene reflector, sea-floor scarps 1 to 1.5 m high in Holocene sediments and a series of positive en echelon topographic anomalies expressed in Holocene sediments. No piercing points necessary to quantify horizontal separation were found.

A virtual lack of recent seismicity and Holocene reflector offsets along the zone have been documented in the Santa Monica bay. On the San Pedro shelf, most of the seismic activity is along the Newport-Inglewood fault zone. The hypothesis that the Palos Verdes structural

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A virtual lack of recent seismicity and Holocene reflector offsets along the zone have been documented in the Santa Monica bay. On the San Pedro shelf, most of the seismic activity is along the Newport-Inglewood fault zone. The hypothesis that the Palos Verdes structural block is decoupled from the Santa Monica shelf along the Redondo Canyon and Palos Verdes faults is supported by a general northerly decrease in activity and evidence for Holocene displacements along the zone. If true, the active portion of the Palos Verdes fault zone is no more than 70 km long. If the major asperity at the Los Angeles harbor is used as a northern boundary of fault rupture for the San Pedro segment of the fault, the length of the fault is about 56 km.

Average vertical separation rates for segments of the Palos Verdes fault on the San Pedro shelf range from about 0.1 to 0.4 mm/yr. A reasonable estimate of an average Holocene to modern vertical separation rate is 0.3 mm/yr. (based on surface scarp heights of 1 to 1.5 m)

A number of methods and assumptions were used to estimate the potential upper level ("maximum credible") earthquake along the Palos Verdes fault. Earthquakes in the range of **M** 6.5 to 7.0 (moment magnitude) and local magnitude M_L 6.4 to 6.6 probably occurred on the Palos Verdes fault during the late Holocene. Using a variety of techniques, recurrence intervals of earthquakes of this size, range from 2000 to 8000 years. A larger earthquake is possible if the entire fault length (70 km) between the Redondo Canyon fault and the Lasuen Sea Knoll were to rupture.