greater than 250 cm^{-3} in this area and, during two periods, exceeded 1500 cm^{-3}. Concentrations similar to those measured north of 13°N were found when dry air was reentered at 3°N. On 30 October 1977, flight 50 passed over the ITCZ in the troposphere at 178 mbar and recorded similar increases in aerosol concentration while ozone concentrations again approached zero. Great fluctuations in larger (light-scattering) particles also occurred in this area.

Particles large enough to scatter visible light were rather uniformly distributed (1.0 ± 0.5 cm^{-3}) throughout the upper troposphere and lower stratosphere at all latitudes. The concentrations measured tended to be greater than 1 cm^{-3} over the Pacific Ocean and less than 1 cm^{-3} over North America, the Arctic ice fields, Europe, and Africa. This may be evidence that the "ocean hemisphere" (particularly the stormy regions at 50° to 60°S in the Pacific) and the strong convection along the ITCZ may be major sources and transport routes of particles to the layers above them near 200 mbar.

Smaller particles were rather symmetrically distributed around the globe at altitudes between 160 and 250 mbar. A maximum occurred over the ITCZ. Concentrations were nearly equal on the Greenwich and date-line sides of the world. Increased concentrations occurred over the boundaries between tropical and temperate air masses. Comparison of total particle and light-scattering particle data at several latitudes reinforces Junge's conclusion (*6*) that coagulation exceeds sedimentation as a sink mechanism for particles in the higher layers. Where fresh injections are rare and coagulation times long, as over the Arctic and Antarctic, small particles are few.

Generally, aerosol concentrations decrease with increasing latitude, but higher concentrations are sometimes found just above strong inversions in the vicinity of high winds, indicative of a possible transport route for particles from troposphere to stratosphere. The small interhemispheric differences in total aerosol concentration that do occur may be seasonal or even due to chance in a single observation.

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Earthquakes near Parkfield, California: Comparing the 1934 and 1966 Sequences

Abstract. *Moderate-sized earthquakes (Richter magnitude* M_L $5^1/_2$*) have occurred four times this century (1901, 1922, 1934, and 1966) on the San Andreas fault near Parkfield in central California. In many respects the June 1966 sequence was a remarkably detailed repetition of the June 1934 sequence, suggesting a recurring recognizable pattern of stress and fault zone behavior.*

Rupture of the San Andreas fault during the main shock of the 8 June 1934 earthquake near Parkfield, California, propagated toward the southeast. The main shock occurred at 0447 Greenwich mean time (G.M.T.); 17 minutes 25 seconds earlier, a foreshock of magnitude M_L 5.1 on the Richter scale occurred about 1 km to the northwest of the focus of the main shock. Rupture during the foreshock was toward the northwest. A nearly identical sequence of events occurred at Parkfield on 28 June 1966. The 1934 and 1966 events have been compared to obtain a basis for anticipating the characteristics of future Parkfield earthquakes as well as data needed in modeling fault dynamics. Finding a means for predicting future Parkfield earthquakes is especially significant in

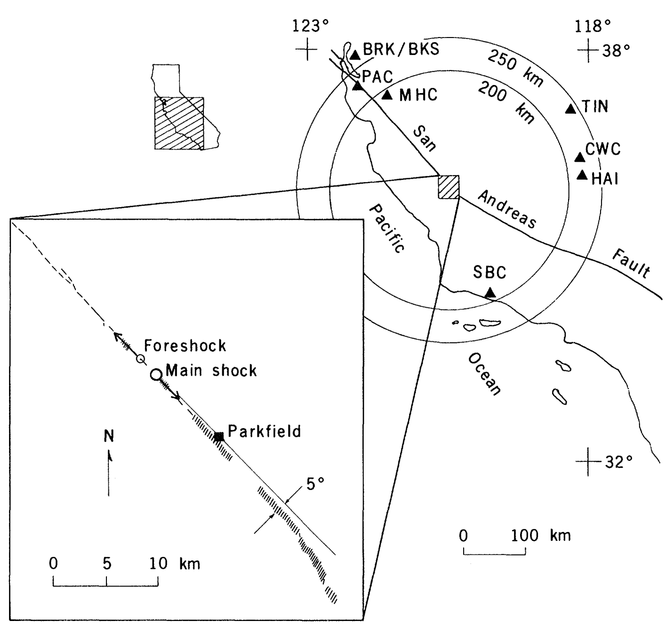

Fig. 1. Location of the Parkfield epicentral region and trace of the San Andreas fault relative to the W-A seismographic stations used (*2*). In the inset, the epicenter locations (open circles) of the 1934 (inferred) and 1966 main shocks and foreshocks together with the direction of rupture expansion for each event (heavy arrows) are shown, as is a 5° change in the strike of the fault trace (*6*). The dashed line represents the mapped trace of the fault, the solid line extends the trend of the fault from the northwest, and sections of the fault where surface displacement during the 1966 sequences was observed (*11*) are indicated by hatching.

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light of recent suggestions (*1*) that the great 1857 earthquake of southern California was preceded by foreshocks near Parkfield and that its epicenter may also have been located there.

We have examined Wood-Anderson (W-A) seismograms written at epicentral distances of 180 to 260 km (Fig. 1). Seismographs at stations BRK/BKS, MHC, TIN, and SBC (*2*) recorded both the 1934 and 1966 Parkfield sequences. Differences in travel times to these stations limit the permissible range of epicenter locations for the 1934 and 1966 Parkfield main shocks and foreshocks to at most 6 km along the fault (*3-5*). Wave-form similarities suggest even closer spacing. As shown in Fig. 2, the seismograms are remarkably similar at a particular station for the two foreshocks and for the two main shocks. For example, the similarity of ground motion at MHC persists for 10 seconds. The correlation between wave forms from corresponding events implies a common source location and a common initial source-displacement time history. The main shock and foreshock motions, however, are not well correlated with each other at a particular station. The epicenter of the 1966 main shock is accurately located immediately to the southeast of a 5° change in the strike of the trace of the San Andreas fault (*6*). The M_L 5.1 foreshock in 1966 is located 1 to 2 km to the northwest of and at a shallower depth than the 1966 main shock (*5, 7*). The identical character of the initial seconds of the wave forms for the two main shocks and the two foreshocks at a particular station thus implies a common hypocenter location for the 1934 and 1966 foreshocks, a short distance (~ 1 to 2 km) to the northwest of the common epicenter of the two main shocks. The foreshocks preceded their main shocks by 17 minutes 25 seconds and 17 minutes 17 seconds, respectively, in 1934 and 1966. Although the sizes of the main shocks are comparable ($M_L \sim 5^1/_2$), the seismic-wave amplitude radiation for the 1934 main shock varied with azimuth: $M_L = 6$ was assigned by CIT (*8*), using southern California stations, whereas $M_L = 5.2$, using the UCB stations to the northwest.

Fourier amplitude spectra of the first 3 seconds of the main shock signals in Fig. 2A are shown in Fig. 2C. First arrivals are P_n compressional waves, refracted along the upper mantle at about 7.8 km/sec, followed 5 to 10 seconds later by the P_g crustal phase at 6 km/sec. The low amplitudes of the *P* waves at MHC are expected theoretically, as this station lies near a node of *P*-wave radiation for Parkfield earthquakes (*9*). Relatively higher frequences are seen at SBC to the southeast than at MHC to the northwest. This azimuthal dependence of frequency content suggests that rupture during the main shocks was directed toward SBC and away from MHC (*10*). Although additional seismic data for the 1934 sequence are sparse, there is independent evidence for unilateral rupture propagation to the southeast along the fault trace for both the 1934 and 1966 Parkfield main shocks (*4, 9, 11-13*).

By virtue of the shorter rupture lengths of the smaller foreshocks, spectral evidence for their directivity would lie at higher frequencies (shorter wavelengths) than that for the main shocks (*14*). Lateral variations in crustal and upper mantle structure in California produce propagation-path effects that increasingly affect higher frequencies, effectively masking evidence for source differences at distant stations. However, station-by-station comparisons of the foreshock spectra with those of five reference events suggest that the foreshocks ruptured toward the northwest. Figure 2D compares P_n spectra for the 8 June 1934 foreshock and an earlier 1934 foreshock of M_L 5.0 that occurred nearby on 5 June at 2148 G.M.T. (*4*). Spectra are similar in shape at TIN, which is broad-

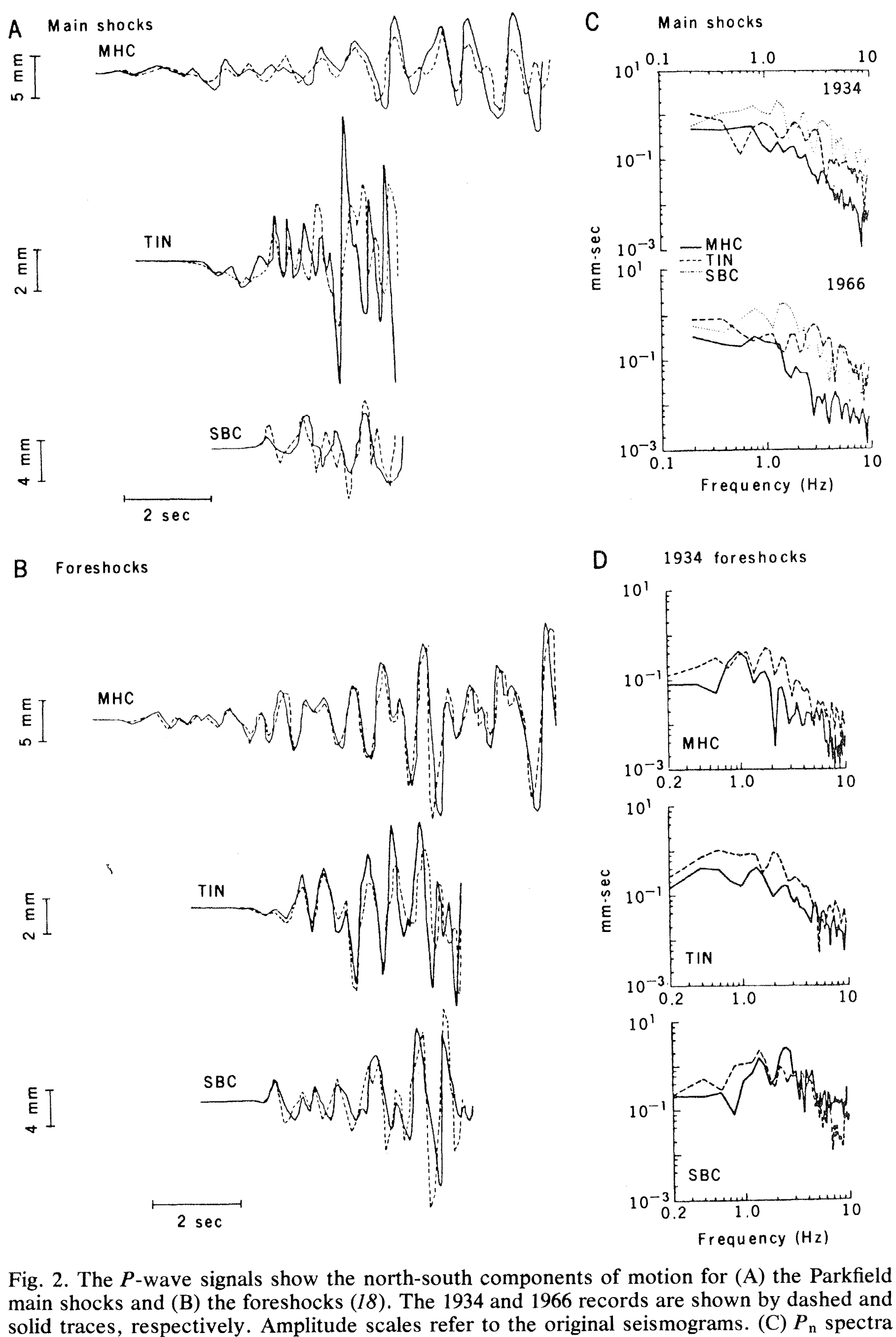

Fig. 2. The *P*-wave signals show the north-south components of motion for (A) the Parkfield main shocks and (B) the foreshocks (*18*). The 1934 and 1966 records are shown by dashed and solid traces, respectively. Amplitude scales refer to the original seismograms. (C) P_n spectra (*19*) for the two main shocks. (D) P_n spectra (*19*) for the 1934 foreshock (dashed traces) and an earlier 1934 foreshock (solid traces).

side to the fault to the northeast, an azimuth not sensitive to differences in directivity along the fault trace. However, the high-frequency portions of the spectra are dominant in opposite directions along the fault for the two events, indicating that the 5 June foreshock ruptured to the southeast while the later foreshock ruptured northwestward. The spectral differences illustrated in Fig. 2D are typical of the subtle but clear seismological evidence for differences in directivity of Parkfield earthquakes.

The similarities in fault behavior in the 1934 and 1966 sequences suggest a scenario for Parkfield earthquakes. An M_L 5.0 earthquake (the foreshock) occurs immediately northwest of the bend in the fault (the 5° change in the strike of the fault trace), which acts as a barrier to slip. The fault zone near the hypocenter of the main shock, southeast of the bend, is loaded by slip associated with the foreshock, even though that slip need not extend through the bend to the vicinity of the main shock hypocenter. The main shock does not occur immediately, but the loading is sufficient to initiate the inevitable failure of the fault zone southeast of the bend. The main shock occurs about 17 minutes later immediately southeast of the bend, which again acts as a barrier to slip, directing rupture growth toward the southeast. Note that breaking of the bend itself during the sequence is not necessary even though the loading stress is transmitted across it. The extent of rupture during the main shock may be controlled by physical discontinuities on the fault surface (*6*, *15*). Great earthquakes on the San Andreas fault, such as that in 1857, would thus initially resemble moderate-sized events and grow to full extent by breaking the barriers that arrest slip in the M_L $5^1/_2$ shocks. It may well be, then, that successful prediction of major earthquakes (that is, smaller ruptures that have "gotten away") will involve an assessment of the potential for rupture growth across barriers.

Although the initial stages of the 1934 and 1966 Parkfield sequences were similar, the 1934 sequence included an early M_L 5.0 foreshock (the reference event in Fig. 2D), whereas the 1966 sequence did not (*4*, *9*). Improved instrumental coverage in 1966 revealed southeastward migration of small earthquakes in the months preceding the main shock toward its epicenter (*9*), while fresh cracks on the fault southeast of Parkfield 2 weeks before the 1966 main shock (*16*) are consistent with substantial precursory aseismic slip on the fault. The migration of small shocks or precursory aseismic slip, or both, could serve as the 1966 loading counterpart to the early 1934 foreshock. The sparse instrumental data available for the 1922 Parkfield earthquake and the similar descriptions for the 1901 Parkfield shock strongly suggest that they occurred near and were comparable in size to the 1934 and 1966 main shocks; neither was preceded by felt foreshocks (*17*), so that the 1901 and 1922 Parkfield shocks do not conform precisely to the proposed scenario. However, the failure patterns in 1934 and 1966 suggest that future M_L $5^1/_2$ earthquakes at Parkfield will follow episodes of stress concentration at the bend in the fault trace.

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19. A cosine taper was applied to the final 5 percent (0.15 second) of the first seismic phase before computing the Fourier spectrum.
20. We thank A. Lindh and W. Stuart for suggestions and B. Raleigh and R. Archuleta for critical reading of the manuscript.

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Dinosaurs: A Jurassic Assemblage from Patagonia

Abstract. *The first Jurassic assemblage of carnosaurs and sauropods from South America has been recorded in the Callovian-Oxfordian beds of Patagonia. The new genus of carnosaur is related to* Allosaurus. *The two new genera of sauropods are cetiosaurids, comparable with but different from* Cetiosaurus, *and more primitive than* Haplocanthosaurus.

An important fossil locality with a Jurassic assemblage of dinosaurs has been discovered in the Argentine Patagonia. The new evidence consists of relatively well-preserved specimens of two genera of Sauropoda and of one genus of Carnosauria. The age of the fossiliferous beds is Callovian-Oxfordian (*1*), some 15 million years older than the well-known dinosaur faunas from the Morrison formation and the Tendaguru beds, both assigned to or considered the top of the Jurassic.

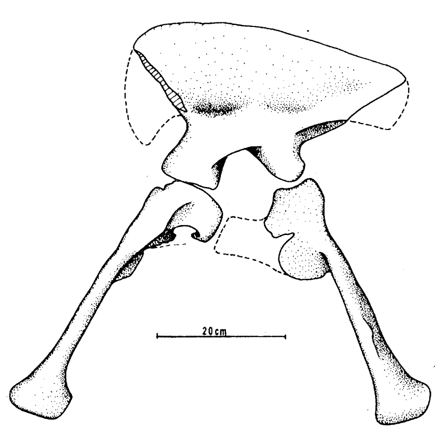

Fig. 1. Lateral view of the pelvis of *Piatnitzkysaurus floresi* n.g.n.sp. (new genus, new species), a megalosaurid carnosaur from the Jurassic of Patagonia (specimen PVL. 4073).

As would be expected, the anatomical characteristics of the species recently discovered in Patagonia are more primitive than those of comparable species of the cited dinosaur faunas. Knowledge of the Jurassic assemblages of dinosaurs is largely based on the rich information from the end of that period (Morrison and Tendaguru); only relatively poor information is available for the rest of the