J. Geophys. 43, 535–543, 1977

Journal of Geophysics

Precursors to P′P′ and Upper Mantle Discontinuities*

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Abstract. In this paper the origin of precursors to P′P′ with lead times greater than 50 s is investigated. Good NORSAR records of P′650P′ and P′400P′ for these arrivals as well as corresponding slowness estimates are presented. These phases are interpreted as done by others in terms of underside reflections from discontinuities or sharp transition zones in the upper mantle. An extensive search of 5 years of NORSAR records did not produce any significant evidence on P′P′ precursor arrivals with lead times greater than 50 s other than those mentioned above.

Key words: Precursor waves to P′P′ – Upper mantle structure – Array data.

Introduction

In a recent paper (Haddon et al., 1977) referred to subsequently as Paper 1, the consequences of postulating irregularities in layers at the top and bottom of the mantle were examined in respect of scattering associated with the usual P′P′ phases. Theoretical results were derived and compared with detailed observational evidence on P′P′ precursor wavetrains with lead times up to 50 s prior to the main P′P′ phases recorded at the NORSAR array. It was demonstrated that scattering in the crust and upper mantle and in the lowest mantle (region D″) could account adequately for all of the NORSAR data and, moreover, that these observations are generally inconsistent with the conventional P′dP′ interpretation i.e., the hypothesis of undersite reflections from upper mantle discontinuities at depths *d* in the 50 s lead time interval.

In the following we report results of an extension of our Paper 1 investigation, namely, to precursor wavetrains in the interval 150–50 s prior to P′P′. The question of their origin is also discussed, i.e., whether they arise from underside reflections from horizons in the upper mantle or have a scattering origin as inferred for P′P′-precursors having lead times less than 50 s.

* NTNF/NORSAR Contribution no. 214

Table 1. Events studied

Event no.	Date	Origin time (NOAA)	Lat (NOAA)
1	Aug 2 1971	07:24:56.8	41.4 N
2	Aug 21 1972	06:23:48.9	49.5 N
3	Jun 29 1975	10:37:41.4	38.8 N

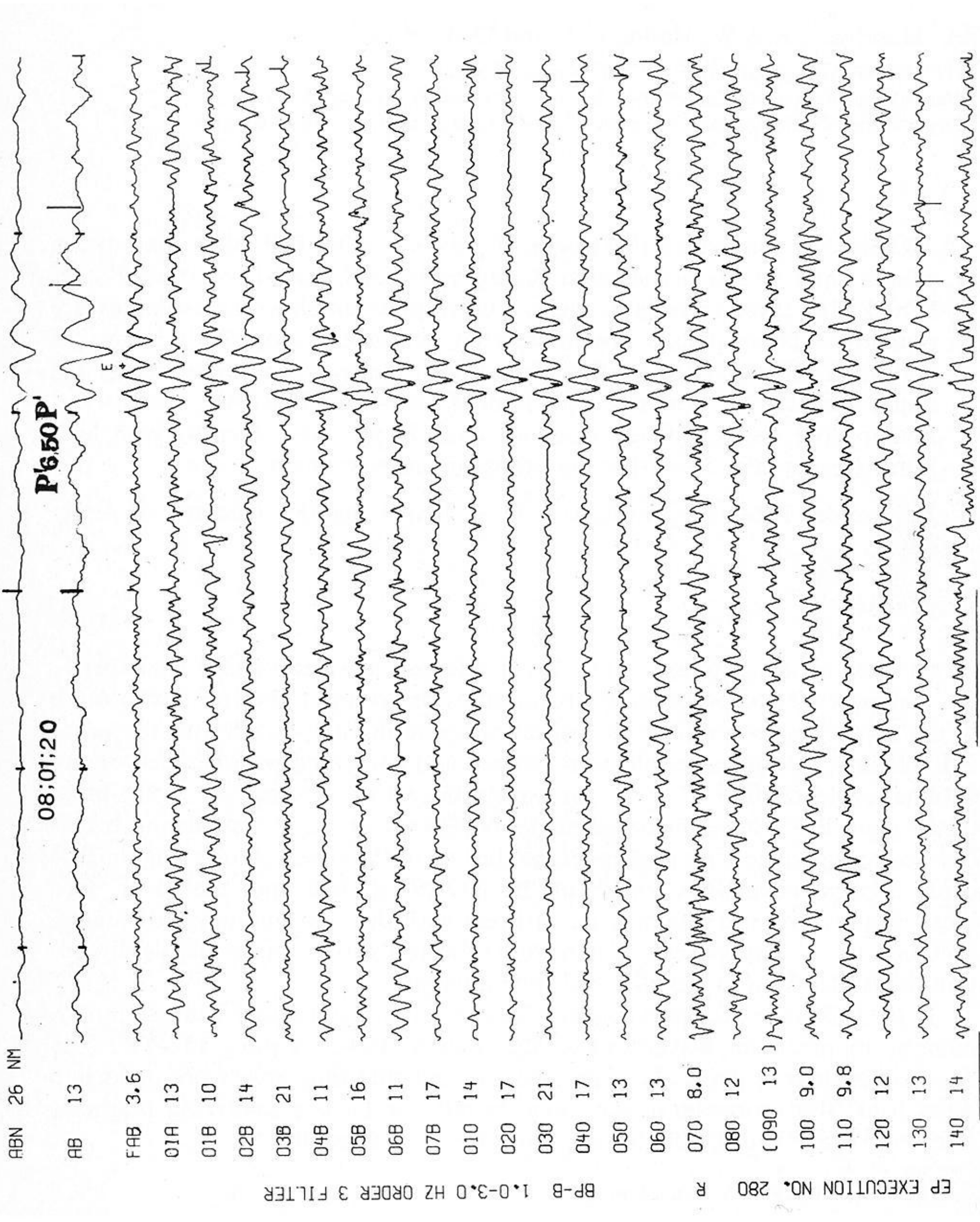


Fig. 1. Display of full-array beam and sub-array beam traces for Event 1 (Table 1). The left column gives the sub-array trace codes, while ABN and AB refer to full-array, unfiltered beam traces and FAB refers to 1.2–3.2 Hz bandpass filtered beam trace. Time marks for each 10 s

Long (NOAA)	Depth (NOAA)	M_b	Distance (deg)	Azimuth (deg)	Region	Depth corrected distance (deg)
143.5 E	51	6.6	71.1	35.8	Hokkaido, Japan	71.2
147.0 E	578	5.9	64.5	30.0	Sea of Okhotsk	66.0
130.0 E	560	6.2	69.1	47.0	Sea of Japan	70.6

Data

The flexibility of the NORSAR data library system (for details see Bungum et al., 1971) greatly facilitated an extensive search for P′P′ precursor arrivals in the distance range 40–75 deg with lead times greater than 50 s in the interval May 1971–December 1975. Out of many thousands of earthquake records available about fifty corresponding to the largest events in the appropriate distance range were inspected. Of these several exhibited clear arrivals at times corresponding to P′650P′, while only one reasonably clear P′400P′ phase was found. The conventional P′dP′ notation for P′P′ precursor arrivals is used to indicate lead times without regard to the question of the origin of the waves. Moreover, the associated *d*-values are given only to the nearest 50 km.

Full-array and sub-array beam seismograms for the best examples found (Table 1) are displayed in Figures 1, 2, and 3. Slowness and azimuth estimates for the corresponding observed maximum power arrivals obtained from BEAMAN analysis (King et al., 1976) are shown in Figures 4 and 5 for Event 3, the best event found. We note that in Figure 3 a weak arrival corresponding to P′550P′ may be seen on the full-array beam trace, but no reliable slowness and azimuth estimates could be obtained for this phase so its origin is uncertain.

Most of the NORSAR recordings bearing on P′dP′-phases are presented in Paper 1 and this study. It is here notable that this material is the result of an extensive search over 5 years of high quality array data, so good P′dP′-recordings are indeed scarce. In this respect we have found it necessary to supplement our own observations with results presented by other seismologists, notably Adams (1968, 1971), Engdahl and Flinn (1969), Whitcomb and Anderson (1970), Whitcomb (1973a, b). A summary of available evidence on preprecursors to P′P′ with lead times exceeding 50 s, in particular P′650P′ and P′400P′, is as follows:

a) The relatively few unambiguous reported P′650P′ and P′400P′ observations come mostly from the large arrays NORSAR (Paper 1, this study), Tonto Forest (Engdahl and Flinn, 1969) and LASA (Whitcomb, 1973).

b) These phases are most frequently observed for deep focus earthquakes or large nuclear explosions near the P′P′ caustic distance, i.e., in the approximate distance interval 69–73 deg. Reported slownesses are in the interval 2.7–3.1 s/deg, which is representative of the P′P′ (BC)-branch.

c) The main P′650P′ and P′400P′ arrivals exhibit features like sharp onsets, short duration and high spatial coherency which are characteristic of 'true'

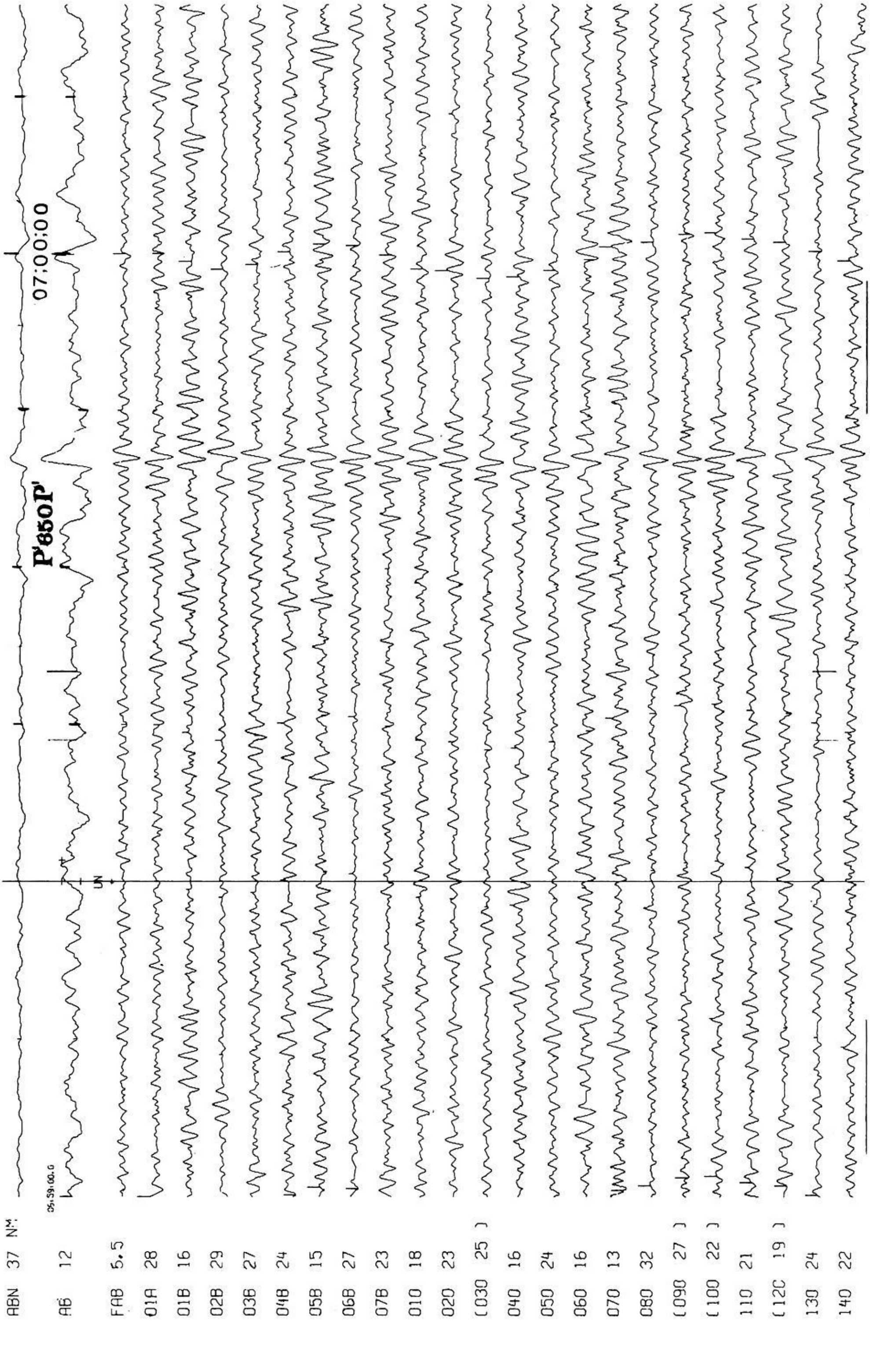


Fig. 2. Display of full-array beam and sub-array beam traces for Event 2. Other details as in caption for Figure 1. This event has been analyzed in detail in Paper 1

P-waves as compared to precursor waves having a scattering origin (Paper 1; Husebye et al., 1976; King et al., 1975). Relatively weak precursors to the main P′650P′ phase have also been reported and are consistent with having a scattering origin (for details, see Paper 1).

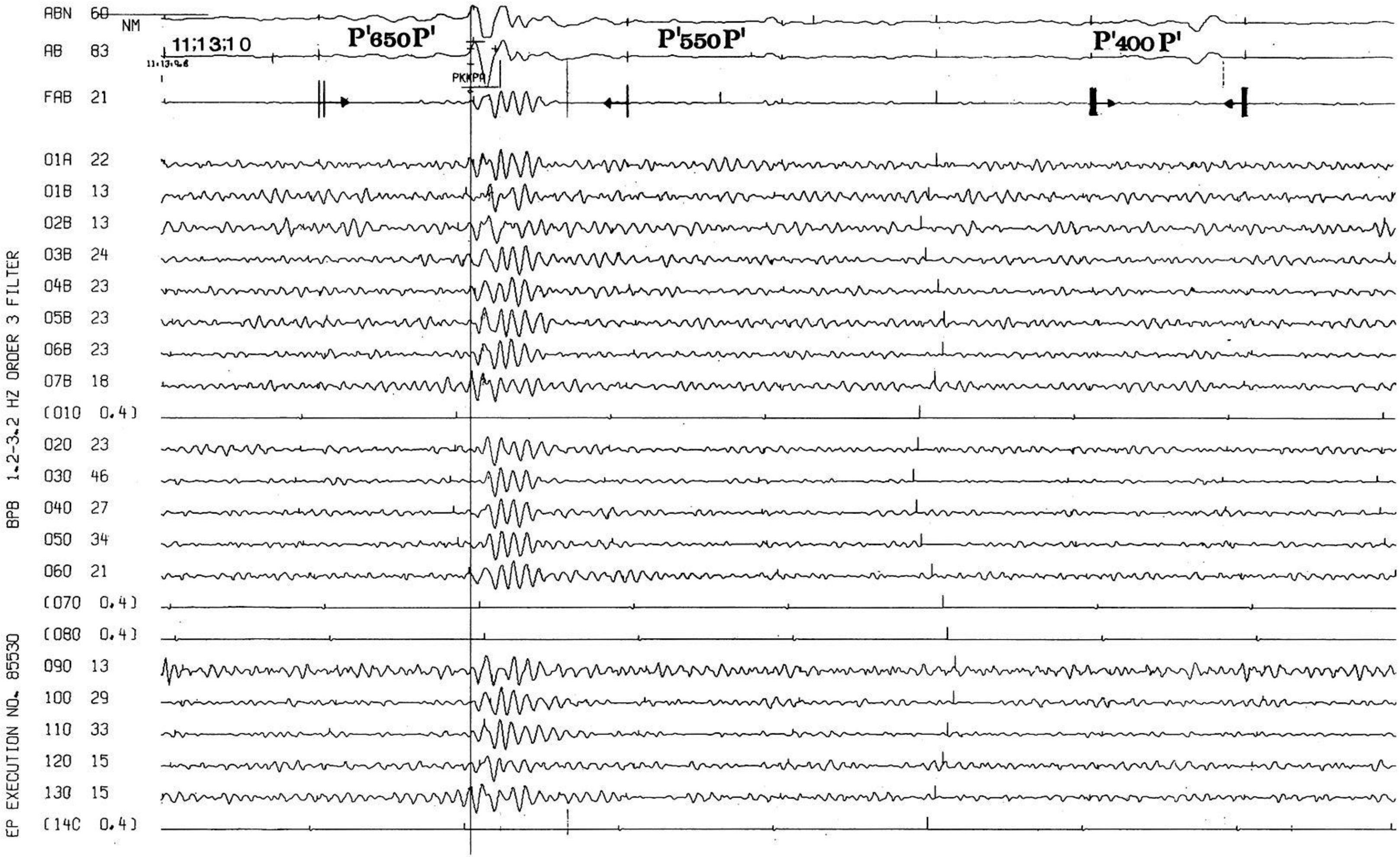
d) The lead times of P′400P′ and P′650P′ are around 100 and 140 s, and these precursors to P′P′ are the only ones with lead times greater than 50 s which have been reliably detected in the NORSAR records and we have identified these as phases of the P′dP′ type. The example of P′400P′ presented in Figures 3 and 5 is the only one observed at NORSAR. To our knowledge, no other array identification of this phase has been reported. Weak arrivals at lead times different from these of P′650P′ and P′400P′ have sometimes been reported by other authors.

Discussion

The topic of this paper is the origin or generating mechanism of observed precursors to P′P′ with lead times greater than 50 s. This problem will be discussed in the context of the results presented and quoted in the foregoing section. First of all, the observational evidence bearing on P′650P′ clearly indicates that this phase has been correctly attributed to underside reflections from the so-called 650 km discontinuity and does not have a scattering origin. Concerning available evidence on P′400P′, the amount of observational data is meager but the results presented in Figures 3 and 5 give significantly added weight to the corresponding interpretation of single station observations. In other words, these observations indicate that the 400 km discontinuity can be ‘sharp’ enough to give detectable reflections of short period waves.

As mentioned previously, weak onsets having P′P′-lead times different from those of P′650P′ and P′400P′ have been occasionally observed and subsequently ascribed to upper mantle reflection horizons. We consider, however, that good array recordings of such arrivals are a prerequisite for a reliable interpretation of these phases as single station observations in themselves cannot discriminate between a reflection or scattering origin.

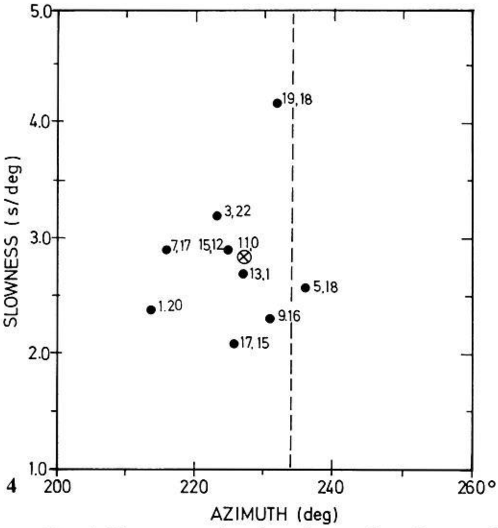
Finally, we would like to comment on the general lack of P′650P′ and P′400P′ observations. We have found that there is often no trace of P′dP′ phases 50–150 s prior to P′P′ even for large magnitude earthquakes even though such phases are observed for other earthquakes of similar magnitude having epicenters just a few degrees away. Engdahl (personal communication) has also experienced a similar elusiveness of P′dP′ phases in an extensive search of WWSSN-records. In this regard, several factors may be important including, for example, wave energy dissipation, focusing-defocusing effects and the relative sharpness of the reflection horizons. In particular, if the reflection horizons should actually be narrow transition zones, the reflection coefficients would be critically dependent on the thickness of these zones relative to the wavelength of the incoming waves (Richards, 1972). The above-mentioned elusiveness of P′dP′ precursors may thus result from local variations in the sharpness of the 400 and 650 km discontinuities. We note in passing that the majority of



3a

Fig. 3. a Display of full-array beam and sub-array beam traces for Event 3 in Table 1. Other details as in caption for Figure 1. **b** Display of full-array beam and subarray beam unfiltered traces for Event 3 in Table 1. In this case with no filtering the P′400P′ phase is observable on *individual* subarray beam traces while the arrival corresponding to P′550P′ is considered uncertain


ABN 230 NM
AB 59
11;13;10
FAB 120
01A 150
01B 160
02B 180
03B 220
04B 130
05B 170
06B 170
07B 160
[010 0.2]
020 170
030 220
040 190
050 210
060 150
[070 0.2]
[080 0.2]
090 150
100 180
110 200
120 130
130 160
[140 0.2]
ALL PASS FILTER
R
EP EXECUTION NO. 1
P'650P'
P'550P'
P'400P'
PKPA
3b



4

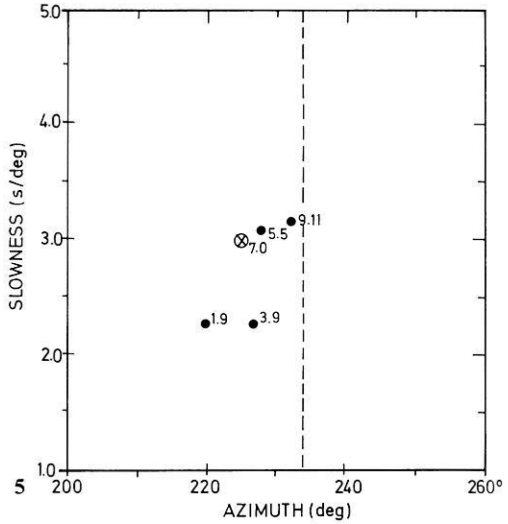


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Fig. 4. Slowness-azimuth estimates based on peak signal power locations average over 2 s intervals for the P′650P′ phase shown in Figure 3. The positioning of the 20 s time window is also shown in this figure. For each point estimate, the first number given refers to the mean time of the 2 s frame in s recorded from the start of the window, and the second the signal power in dB down from maximum observed within the wavetrain analyzed. For example, in case of P′650P′ the maximum power is observed at 11 s (the 10–12 s frame) after window start. The dashed line indicates the NORSAR-estimated back-azimuth

Fig. 5. Slowness-azimuth estimates based on peak signal power locations average over 2 s intervals for the P′400P′ phase shown in Figure 3. Other details as in Figure 4 caption

the reflection points (areas) of reported P′dP′ observations are Antarctica and adjacent seas.

Acknowledgements. The NORSAR project is supported by the Advanced Research Projects Agency of the U.S. Department of Defense and is monitored by AFTAC, Patrick AFB FL 32925, under contract no. F08606-77-C-0001.

Financial support for two of us (R.A.W. Haddon and D.W. King) from the Royal Norwegian Council for Scientific and Industrial Research is gratefully acknowledged.

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Received January 21, 1977