from Eq. 8 are within a factor of about 2 of the observed central uplift rates obtained from the raised beachlines and survey measurements (*15*). While agreement as close as this must be fortuitous, considering the number of assumptions involved in predicting the uplift rates, the experimental and geophysical data appear consistent with each other, and support the contention that the mantle, at least beneath shield areas, is non-Newtonian (*19*).

In conclusion, recent evidence indicates a non-Newtonian mantle with $n \simeq 3$, at least under Fennoscandia. This suggests that all studies of mantle motion, notably the search for the driving force for plate tectonics, and all inferences about the viscosity of the earth should endeavor to incorporate non-Newtonian flow of this kind.

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8. The proof of Eq. 2 reduces to proving that $\langle\tau^n\rangle = k\langle\tau\rangle^n$, where k is a constant. The definition of proportional stress relaxation is: $\tau = \tau(r,t) = \tau(r,0)f(t)$, where r is a vector defining position and $f(t)$ is the appropriate function of time, invariant with position. Consequently
$$\frac{\langle\tau^n\rangle}{\langle\tau\rangle^n} = \frac{\langle[\tau(r,t)]^n\rangle}{\langle\tau(r,t)\rangle^n} = \frac{\langle[\tau(r,0)]^n\rangle[f(t)]^n}{\langle\tau(r,0)\rangle^n[f(t)]^n} = k$$
9. The inclusion of an elastic component into a model of a non-Newtonian mantle is definitely a complicating factor. When the elastic component is taken into account, the viscosity values calculated from the 6000- to 9000-year-old raised beachlines (for an assumed Newtonian mantle) are about half the values that result when the elastic component is ignored [D. P. McKenzie, *Geophys. J. Roy. Astron. Soc.* **14**, 297 (1967)]. The main reasons for concluding that the elastic component should not seriously affect the validity of Eq. 3 are that (i) the stress distribution resulting from a surface load on an elastic half-space is generally quite similar to that resulting from the same load on a nonelastic half-space [H. Jeffreys, *The Earth* (Cambridge Univ. Press, Cambridge, England, ed. 2, 1952), chapter 6]; (ii) the stress distribution in the elastic case keeps a constant shape if the surface load keeps a constant shape, as in the purely viscous case; and (iii) the stress distribution in a viscoelastic mantle should be intermediate between the purely elastic and purely viscous (both Newtonian and non-Newtonian) cases.
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19. B. Gjevik [*Phys. Earth Planet. Interiors* **5**, 403 (1972); *ibid.*, in press] has considered the possibility that mantle transitions might govern the rate of return to isostatic equilibrium. To first order, a mantle transition does not affect the shape of the flow field, but can exert a "back pressure" if the transition is significantly displaced from its equilibrium level by the flow. We believe that in this circumstance the back pressure would be proportional to the surface displacement, so that the conditions of proportional relaxation would be maintained. We estimate that the maximum back pressure would reduce the flow velocity by about 30 percent. As Gjevik points out, however, the dynamics of such transitions are difficult to analyze except in certain simple cases, so this effect will bear more examination.
20. The simple proof of Eq. 2 given in (*8*) was suggested by W. G. McMillan. N. L. Carter, B. Gjevik, and R. I. Walcott critically read the manuscript. We thank R. K. McConnell for permitting reproduction of his figures. Discussions with R. L. Shreve were stimulating and helpful. Publication No. 1191 of the Institute of Geophysics and Planetary Physics, University of California at Los Angeles. Supported by NSF grants GA-1394, GA-26027, and GA-36077x.

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Response of the Equatorial Countercurrent to the Subtropical Atmosphere

Abstract. *The strength of the equatorial countercurrent of the North Pacific and associated variations in sea surface temperatures at its eastern extremity off Central America are related to the zonal wind flow in the remote subtropical atmosphere with lags of as much as 8 months between wind and temperature.*

Wyrtki (*1*) showed that an index of transport of the equatorial countercurrent is the difference in sea level between islands situated north and south of the countercurrent. Constructing a time series of this index for 21 years, he demonstrated a dramatic relationship between this index and sea surface temperatures off Central America, indicated a time lag of 3 months, and suggested that increased countercurrent transport leads to the El Niño, or anomalously warm water mass, off Peru. Wyrtki cautions, "One should not, however, disregard the possibility that extremes in both the sea surface temperature and the countercurrent transport are simultaneously associated with an anomaly of oceanic and atmospheric circulation over a much larger part of the Pacific." In this report I attempt to amplify this suggestion and extend Wyrtki's "teleconnections" into the subtropical midtroposphere.

The north equatorial countercurrent, flowing in a narrow zone between 4°N and 10°N, is influenced by the stress of the northeast trade winds. Accurate, long-range measurements of the trade winds are lacking in these latitudes, but we may assume that these tropical trade winds are related to those in the subtropics farther north. The index used is from the 700-mbar level (~ 10,000 feet or 3 km) rather than the surface. This contains less of the "noise" introduced by smaller-scale features such as cyclones and anticyclones, and experience has shown it to be a more reliable indicator than surface indices for many purposes. Its

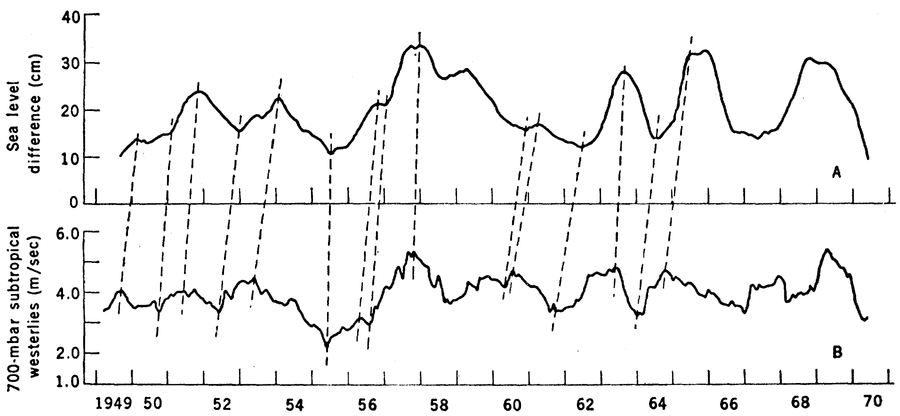

Fig. 1. (A) Annual running means of the sea level difference across the equatorial countercurrent. [After Wyrtki (1)] (B) Corresponding values of the strength of the subtropical 700-mbar westerlies as measured between 150°E to 110°W between 20°N 35°N.

correlation with the sea level zonal wind index immediately below is .85 (2).

Figure 1A reproduces Wyrtki's graph of the sea level difference across the countercurrent. Figure 1B shows the 700-mbar zonal index (zonal component of the geostrophic mean air flow at 700 mbar between 20°N and 35°N averaged from 150°E to 110°W). To conform to Wyrtki's procedure, the zonal index has been smoothed by taking a running annual mean centered on the indicated month. The correlation coefficient between these two series is .48. Inspection suggests that there is a lag between the two graphs, such that certain singular features in the zonal winds show up later in the countercurrent transport index. The broken lines in Fig. 1 indicate some of these possible connections before 1965, after which time such connections are less prominent or lacking. Lag correlations between the curves yield a maximum of .54 at a 4-month lag with a drop off to .40 at 9 months and .48 at no lag.

Since the strength of the trade winds seems to influence the future strength of the countercurrent and since the countercurrent, in turn, influences the sea surface temperatures off Central America (Wyrtki suggests a 3-month lag for the latter), it is of interest to check the total lag relationship between winds and water temperature. In this case, only the annual means of sea surface temperature centered on January have been examined—this is in accordance with the usual time of emergence of El Niño and the definition of an El Niño year. The best lag correlation, .55, was between these 22 annual means of sea surface temperature and the mean annual subtropical zonal index at 700 mbar centered on May, 8 months earlier. This agrees with the average lag suggested by the broken lines in Fig. 1, about 5 months, plus Wyrtki's 3-month lag. This peak value drops off to .48 at lag 0 and .35 at lag 12.

The significance of these statistics is that the east-to-west wind stress on the equatorial countercurrent, implied by the upper-level westerlies in the subtropics, causes variations in the east-west sea level difference and the countercurrent flow, variations which are reflected in the north-south sea level difference (used by Wyrtki) and at a later time in the surface temperatures in the extreme eastern portion of the countercurrent off Central America. When the subtropical upper westerlies are strong, the trade winds are weak and the countercurrent starts to flow more strongly eastward bringing warm water about 8 months later off Central America. When the subtropical upper westerlies are weak (the trades strong) the countercurrent is slowed down or possibly annihilated. In this case colder water, often associated with upwelling, appears off Central America. These findings, along with Wyrtki's, suggest that when more refined researches are completed the life history of the El Niño may be predictable.

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18 June 1973

N-Nitrosation by Nitrite Ion in Neutral and Basic Medium

Abstract. *Formaldehyde catalyzed the conversion of various secondary amines to nitrosamines in the* pH *range 6.4 to 11.0. Chloral was also an effective catalyst. The reaction proceeds easily enough to have potential synthetic applications; the proposed mechanism could explain some reported anomalies regarding the synthesis of carcinogenic* N-*nitroso compounds in vivo and in vitro.*

There is considerable debate at present concerning the public health significance of amine-nitrite interactions in the human environment (*1*), but there has been little disagreement regarding the *p*H requirements of such interactions. Investigations on mechanisms have suggested that "the protonation of nitrous acid appears necessary for initiating all nitrosation reactions" (*2, 3*), and it is generally assumed that potentially hazardous quantities of carcinogenic *N*-nitroso compounds cannot be produced unless the interaction of nitrite and amine occurs in acidic medium (*3*).

We describe experiments here that reveal a new dimension to the controversy by showing that nonenzymatic nitrosation occurs smoothly under neutral and basic conditions in the presence of appropriate catalysts. Aqueous buffer solutions of diethylamine, sodium nitrite, and formaldehyde led to significant yields (*4*) of diethylnitrosamine at room temperature over the entire *p*H range studied (*p*H 6.4 to 11.0) (Fig. 1). In the absence of formaldehyde, no nitrosamine could be detected above *p*H 7.5 under these conditions (*5*). The yield is almost independent of hydrogen ion concentration in basic medium, the quantity of product at *p*H 11.0 being 40 percent of that found at *p*H 7.5 (Fig. 1).

Except for diisopropylamine, all secondary amines we have studied have been easily nitrosated in alkaline formaldehyde solution. Nitrosamine yields varied roughly according to steric accessibility of the nitrogen atom toward