## General Disclaimer

## One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

(NASA-TM-85064) A COMPARISON OF CORONAL AND INTERPLANETARY CURRENT SHEET INCLINATIONS (NASA) 22 p HC A03/MF A01 CSCL 03B

N83-31566

Unclas
G3/92 28424

NASA

# Technical Memorandum 85064

# A Comparison of Coronal and Interplanetary Current Sheet Inclinations

K. W. Behannon, L. F. Burlaga and A. J. Hundhausen

JULY 1983

National Aeronautics and
Space Administration

**Goddard Space Flight Center**
Greenbelt, Maryland 20771

# A COMPARISON OF CORONAL AND INTERPLANETARY CURRENT SHEET INCLINATIONS

K. W. Behannon and L. F. Burlaga
NASA/Goddard Space Flight Center
Laboratory for Extraterrestrial Physics
Greenbelt, MD 20771

and

A. J. Hundhausen
High Altitude Observatory
National Center for Atmospheric Research
Boulder, CO 80307

JULY 1983

SUBMITTED TO: The Journal of Geophysical Research

## ABSTRACT

HAO white light K-coronameter observations show that the inclination of the heliospheric current sheet at the base of the corona can be both large (nearly vertical with respect to the solar equator) or small during Carrington Rotations 1660 - 1666 and even on a single solar rotation. We discuss Voyager 1 and 2 magnetic field observations of crossings of the heliospheric current sheet at distances from the sun of 1.4 and 2.8 AU. Two cases are considered, one in which the corresponding coronameter data indicate a nearly vertical (north-south) current sheet and another in which a nearly horizontal, near equatorial current sheet is indicated. For the crossings of the vertical current sheet, a variance analysis based on hour averages of the magnetic field data gave a minimum variance direction consistent with a steep inclination. The horizontal current sheet was observed by Voyager as a region of mixed polarity and low speeds lasting several days, consistent with multiple crossings of a horizontal but irregular and fluctuating current sheet at 1.4 AU. However, variance analysis of individual current sheet crossings in this interval using 1.92 sec averages did not give minimum variance directions consistent with a horizontal current sheet. We conclude that one cannot assume that the minimum variance direction will be the same as the normal to the current sheet when the analysis results are likely to be influenced by small-scale variations or curvatures within or near the sheet proper. This influence may be more pronounced when the sheet is locally nearly horizontal.

## Introduction

Theoretical considerations have suggested that at large distances from the sun the global heliospheric current sheet may be a near-equatorial, warped surface separating regions of oppositely directed interplanetary magnetic fields (IMF) which originate in opposite solar hemispheres (Schatten, 1972; Schulz, 1973; Alfvén, 1977). The study of coronal holes observed during the Skylab mission of 1973-1974 (see Zirker, 1977) led to the recognition that a similar concept helped to explain the observed brightness structure of the outer corona and the relationship between that structure and solar wind streams and magnetic sectors (Hundhausen, 1977; Levine, 1977). Pioneer 11 observations of the magnetic sector structure of the IMF as a function of solar latitude between 1 AU and 4.3 AU (Smith et al., 1978) and Helios observations between 0.3 and 1 AU (Villante et al., 1979; Burlaga et al., 1982 and Bruno et al., 1982) were interpreted as being generally consistent with this picture. A study which included both Pioneer 10 and 11 and data out to 8.5 AU provided additional experimental support for this view (Thomas and Smith, 1981).

The inclination of the current sheet with respect to the solar equator is a basic parameter, and estimates of it have been varied and controversial. Part of the confusion arises because of a failure to distinguish between local and global inclinations and between inclination and amplitude. Wilcox and Svalgaard (1974) suggested that the inclination of the neutral line might be large at times and extend to high latitudes, while Burlaga et al. (1978) showed that locally the inclination might be large even though the sector boundary does not extend to large latitudes. Intermediate situations were discussed by Svalgaard et al. (1975). We shall show that the inclination can even be large at one longitude but small at another. Various efforts to deduce the sheet orientation in interplanetary space using either multispacecraft measurements, two-point single spacecraft observations or single-point techniques, such as minimum variance analysis (Sonnerup and Cahill, 1967), have yielded a variety of estimates of the inclination, ranging from $\sim 10^{\circ}$ to $> 60^{\circ}$ (Rosenberg and Coleman, 1969; Neubauer, 1978; Villante et al., 1979; Klein and Burlaga, 1980; Behannon et al., 1981; Thomas and Smith, 1981; Villante and Bruno, 1982).

Some of the differences between individual results from direct interplanetary measurements may result from the different techniques used: some methods estimate the global sheet tilt and some estimate the local orientation, with a range of local inclinations possible within the warp structure. These efforts have not yet answered satisfactorily the following questions: 1) To what extent is the shape of the current sheet at a particular longitude near the sun preserved out to large distances from the sun? 2) How does the shape (inclination and amplitude) of the current sheet change with solar activity? and 3) Can the inclination of the current sheet be determined from measurements by one spacecraft using a minimum variance analysis? The principal aim of this paper is to provide an answer to the third question, but we shall also address the other two questions.

Our approach is based on the identification of the band of bright corona (or streamer belt) that surrounds the sun at times away from the maximum of the sunspot cycle as the base of the interplanetary neutral or current sheet. This is an extension of the long-held belief that individual coronal streamers are associated with neutral sheets (e.g., Newkirk, 1972, Pneuman, 1972) and sector boundaries (Howard and Koomen, 1974, Svalgaard et al., 1974) to the global context sugggested by coronal hole studies (Hundhausen, 1977, 1979; Svalgaard and Wilcox, 1978). Comparison of the coronal neutral sheet inferred from a maximum brightness line drawn on synoptic maps of the observed polarization brightness with the magnetic polarity observed in interplanetary space (Burlage et al., 1978; Bruno et al. 1982) has lent considerable credence to this identification. Here we will examine the structure and inferred orientation of the interplanetary neutral sheet with reference to the orientation implied by the coronal maximum brightness line.

The Voyager data studied were taken during 1977-78 over the heliocentric distance range 1.3 - 2.9 AU and included 1.92s, 48s and hourly averages. The solar data used were HAO white-light K-coronameter data for the same time period (Carrington rotations 1660-1666). To correlate the solar and spacecraft sheet observations in time, the Voyager position and

IMF sector polarities were projected back to the sun (to 1.75 $R_\odot$) using a constant solar wind speed of 375 km/sec, the value which gave the best overall consistency for this study, and we shall show that contrary to the assumption made in some previous publications, the minimum variance normal may not always be a reliable indicator of the steepness of the heliospheric current sheet.

Using the white-light data, we selected cases in which the sheet inclination at the sun was near one of the two extremes, i.e., $\sim 0°$ or $\sim 90°$. Both types were available within the epoch studied. This is significant in itself, for it implies that the local inclination is not either small or large in a given epoch of the solar cycle, but it can be both large and small. In fact, there were examples of both types occurring on a single solar rotation, but lack of sufficiently complete data during the relevant time intervals from one or the other of the Voyager spacecraft precluded use of such cases here. Only one example of each type of inclination will be presented in this brief note; however, multiple recurrences of each type were observed during the period of the study, and preliminary investigation suggests that the properties of interest here were usually maintained over several successive rotations.

For the interplanetary observations, a rough inference of the steepness of the sheet relative to the equatorial plane could be drawn from the sharpness of the sector polarity transition. Multiple sheet crossings over a few days or more implies a sheet nearly parallel to the orbital paths of the spacecraft, which were within a few degrees of being in the solar equator plane. The minimum variance analysis of Sonnerup and Cahill (1967) was also applied to estimate the current sheet orientation for each sheet crossing.

## Observations

Current sheet highly inclined to the solar equator. Figure 1 shows K-corona white light contours and projected Voyager IMF polarity data for a portion of CR 1666 (central meridian days March 25 - April 9, 1978), together with an estimated maximum brightness curve (dashed curve). Two

successive crossings of the equator by the maximum brightness curve occur, and the longitudes of those crossing points correspond to those at which the IMF magnetic sector polarity changed signs from negative (toward the sun) to positive (outward) to negative again. The crossings of the current sheet by the Voyagers occurred on April 3 and April 13, 1978 at a mean heliocentric radial distance of 2.8 AU. The longitude separation of the spacecraft was $\sim 1^\circ$, the latitude separation was $\sim 2^\circ$, and there was a separation in heliocentric distance of $\sim$ 0.1 AU.

The first current sheet crossing was not unusual, being followed by a small, corotating stream and preceded by a slow cold, high density flow. However, it was thick in the sense of Klein and Burlaga (1980) because the field changed polarity by rotating southward for more than a day.

The full crossing took 31 hours for Voyager 1 and 42 hours for Voyager 2. This was too long in each case to apply the minimum variance analysis to the 48s average data; instead, the hourly averages were used. This resulted in the estimates given for the sheet normal direction (latitude, longitude) angles $\delta_N$, $\lambda_N$ that are listed in the first two lines of Table 1. As the data show, nearly identical normal directions were determined at the two different locations, with a latitude angle of 6° at both. This represents a sheet inclination of 84° if the minimum variance method is a valid way of determining the normal. This is consistent with the steep inclination implied by the white-light observations in Figure 1.

Further details of this April 3 current sheet crossing are given in Table 1, viz., the angle $\omega$ through which the magnetic field rotated in the plane of the sheet; the magnitude of the normal component of the field relative to the total field, $B_z/B$; the number of averages N used in the analysis; and the type of average. The magnetic field vector tended to rotate in a single plane throughout the sheet traversal by Voyager 2. Thus an analysis of 48s averages for only a portion of the time interval (the final third) yielded essentially the same direction for the normal as obtained from the whole interval (third line of the table). In contrast, the directional variation observed by Voyager 1 during the crossing did not take place in a single plane, so that analysis of various subsets of the

total crossing data produced orientations inconsistent with that derived from the total interval, which effectively averaged over the separate intermediate, partial changes in direction.

The second current sheet crossing, on April 13, is not typical, for at Voyager 2 it was preceded by a magnetic cloud (see e.g., Burlaga et al., 1981; Behannon and Burlaga, 1982; and references therein), which was interposed between two sectors. The "sector boundary" that we shall now describe is actually the boundary between the rear of the cloud and the negative sector. In this case the crossing took less than two hours for Voyager 1 and therefore 48s data were analyzed. The crossing by Voyager 2 took considerably longer ($\sim$ 16 hours), but the time interval was still short enough for analysis of the 48s averages. Those results are shown in the next to last line of the table, and in the last line are the results obtained using Voyager 2 hourly averages for a slightly longer period.

Figure 2 illustrates the 48s data for the Voyager 2 traversal on the left and the hodogram plots for this case on the right. BZ is the component in the minimum variance direction; it was $\sim$ 2 nT on average throughout the crossing. BX and BY are the maximum and intermediate variance directions, respectively (bottom right); although considerable fluctuation of the field occurred during the analysis interval, the change in direction of $\underset{\sim}{B}$ tended to occur predominantly in the BX-BY plane, and an acceptable minimum variance result was obtained. The relatively large normal component in this case indicates that the field direction change across the current sheet was more like a rotational discontinuity (RD) than a tangential discontinuity (TD), in contrast to the other crossings given in Table 1, which showed the sheet to have been more like a TD at those times, i.e., $B_z/B \lesssim 0.1$ (Lepping and Behannon, 1980). This may be related to the fact that this represents a transition between a cloud and a sector rather than the transition between two sectors. The $|\delta_N|$ values in Table 1 show that the Voyager observations of this crossing, giving an inclination of 85° (90° - $|\delta_N|$) at Voyager 2 (79° from the hourly data) and 58° at Voyager 1. The latter value is not consistent with an almost vertical sheet, but because of the nature of the transition it may be inappropriate to compare these results with the coronal data.

Nearly horizontal current sheet. White-light coronagraph data indicating a current sheet close to the equatorial plane near the sun are shown in Figure 3, which has the same format as Figure 1. Once again the Voyager 1 and 2 orbital tracks and observed IMF polarities are projected on the sun in the near-equatorial region. Only part of a solar rotation is depicted, in this case bridging across portions of two successive Carrington rotations, CR 1660-1661 (central meridan days October 21 - November 5, 1977). The maximum brightness curve suggests that, near the sun at least, the current sheet was approximately horizontal over a longitudinal sector nearly 120° in width.

The corresponding interplanetary observations were made by Voyagers 1 and 2 during November 1-7, 1977 at ∿ 1.4 AU. The longitudinal and radial separations of the spacecraft were $\Delta\lambda \sim 1°-2°$ and $\Delta r \sim 0.02$ AU, respectively, and Voyager 1 was ∿ 2° south of Voyager 2 in latitude. Voyagers 1 and 2 at ∿ 1.4 AU observed a state of mixed IMF polarity throughout much of the interval, consistent with the interpretation of a nearly horizontal current sheet also at large distances from the sun at that time. The speed measured by Voyager 2 was low (< 350 km/s) throughout this period, again suggesting close proximity to the current sheet, for it is well-known that the speed is low at the current sheet at 1 AU (Hundhausen, 1972, p. 131, and references therein). Voyager 1 measured somewhat higher speeds in this period, and a dominance of negative polarities, suggesting that it was just below the current sheet some of the time. Since the spacecraft were close to the equatorial plane throughout the interval, these speed observations also suggest a nearly horizontal current sheet.

As the alternations in polarity imply, there were multiple crossings of the sheet over the ∿ 6 day period, with more traversals by Voyager 2 than by Voyager 1, where Voyager 2 was higher in latitude by a few degrees. These results suggest an orientation of the sheet in the solar wind at these longitudes that is not very different from the near-equatorial orbital planes of the spacecraft. The mixed polarities might be due to 1) a fluctuating meridional motion over a few degrees of a single thin current

sheet past the spacecraft, 2) passage through a filamentary current sheet, or 3) a combination of these two effects. The first of these alternatives is favored by the differences between Voyager 1 and 2 speed and polarity patterns, but the other alternatives cannot be excluded. This single observation of mixed polarities and low speeds associated with a horizontal current sheet suggests the hypothesis that mixed polarities in general are a signature of horizontal current sheets.

Let us now turn to the question of whether the minimum variance normal for this event gives a current sheet orientation consistent with that suggested by the white-light data. Minimum variance analysis was applied to all sheet traversals within the period of interest. Since the time required for these crossings was generally short (< 1 hour), 1.92s averages were used. Not all of the crossings yielded acceptable results (see criteria of Lepping and Behannon, 1980); those that were deemed acceptable are tabulated in Table 2 for the two spacecraft. To make it easier to visualize these results, the latitude angles $\delta_N$ of the individual minimum variance normals are illustrated in Figure 4. None of the normal directions was consistent with a sheet of very low inclination ($|\delta_N| \gtrsim 90°$). The values of $|\delta_N|$ were distributed between $\lesssim 10°$ and $\sim 50°$ in each case, corresponding to a range of sheet inclinations between 40° and 80°, with a mean of 62°. If we accept that a horizontal maximum brightness curve in the corona, an extended interval of mixed polarity and an extended interval of low speeds are indicative of a nearly horizontal current sheet between the sun and 1.4 AU, then we must conclude that one cannot use the minimum variance method to determine the normal to a nearly horizontal current sheet. Some of the possible reasons for this are discussed in the following section.

## Discussion and Conclusions

The minimum variance results for the case of the current sheet segment that was inferred to be nearly horizontal do not provide support for the idea that one can determine the orientation of the heliospheric current sheet by means of a minimum variance analysis of the high resolution data inside the sheet. On the other hand, the inclinations derived for one of

the "vertical" current sheets are consistent with a steep inclination. (The results for the other "vertical" current sheet are inconclusive because of the presence of a magnetic cloud.) This suggests that there may be additional structures in the horizontal sheet which act as noise in our computation of the current sheet normal.

The minimum variance analysis (MVA) can only respond to the observed "local" variation or curvature of $\underset{\sim}{B}$. It is possible that in cases where a heliospheric current sheet traversal is sampled at low resolution because of an intrinsically low sampling rate (or equivalently an effectively low rate because of averaging) and/or because of rapid motion of the sheet past the spacecraft, as may happen with a highly inclined sheet moving past at the resultant of the solar wind flow and corotation speeds, then only the gross field structure surrounding the sheet is observed. This structure may resemble the sheered-field structure associated with directional discontinuities.

On the other hand, when there is high-resolution sampling and low relative motion, as results from the low-frequency flapping or undulation of a nearly horizontal sheet, then actual internal structure may be observed, and this finer-scale, more locally resolved curvature of $\underset{\sim}{B}$ can give minimum variance directions that are quite different from the orientation of the true normal to the large-scale sheet. In a "stationary" system, in which the spacecraft remains in or near the current sheet for extended periods of time and the only relative motion is a slow drift of the spacecraft across the sheet, MVA can yield an estimate of the orientation of the plane in which the field lines close across the sheet, possibly at right angles to the sheet surface, or of the plane containing magnetic field "loops" in plasma "bubbles" within the sheet. A variety of such internal geometries were observed on Voyager crossings of the Jovian magnetotail current sheet (Behannon, 1983). They were not, in general, coplanar with the sheet itself.

In the solar wind, the influence on the MVA results of the convection of a nearly horizontal heliospheric current sheet past the spacecraft at solar wind speeds depends on the scale size of the fine-scale structures in

the sheet, their relative alignment, and the speed at which vertical motions of the sheet occur. The internal structures may appear as a succession of highly-inclined, nearly parallel features, as quasi-periodic, wavelike variations, or as a randomly-oriented set of perturbations if there is turbulence in the sheet (Behannon et al., 1981). In any case, it is clear that the MVA technique is of limited utility for studying the large-scale orientation of the heliospheric current sheet. Results from its application must always be tested by comparison with those obtained by independent means.

To the question of how representative the results of this study are, we have looked at both earlier and later cases of near-vertical and near-horizontal sheet orientations at the sun and, by association the corresponding sheet segments seen by the Voyagers, and similar analysis results were obtained. In some cases these were earlier and later appearances of the same sheet segment on different solar rotations. In total, these results suggest that sheet orientations near the sun are maintained to large distances and that these orientations may be maintained over several successive rotations of the sun.

## Acknowledgments

We thank L. Klein for assistance in the data analysis and R. P. Lepping for helpful discussions. The Mauna Loa K-coronameter data used in the study were obtained by R. Hansen. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

ORIGINAL PAGE IS
OF POOR QUALITY



## References

Alfvén, H., Electric currents in cosmic plasmas, Rev. Geophys. Space Phys., 15, 271, 1977.

Behannon, K. W., Fine-scale structure of the Jovian magnetotail current sheet, J. Geophys. Res., submitted, 1983.

Behannon, K. W., F. M. Neubauer, and H. Barnstorf, Fine-scale characteristics of interplanetary sector boundaries, J. Geophys. Res., 86, 3273, 1981.

Bruno, R., L. F. Burlaga, and A. J. Hundhausen, Quadrupole distortions of the heliospheric current sheet in 1976 and 1977, J. Geophys. Res., 87, 10339, 1982.

Burlaga, L. F. and K. W. Behannon, Magnetic clouds: Voyager observations between 2-4 AU, Solar Phys., 81, 181, 1982.

Burlaga, L. F., K. W. Behannon, S. Hanson, J. Pneuman, and W. Feldman, Sources of magnetic fields in interplanetary streams, J. Geophys. Res., 83, 4177, 1978.

Burlaga, L. F., R. P. Lepping, K. W. Behannon, L. W. Klein, and F. M. Neubauer, Large-scale variations of the interplanetary magnetic field: Voyager 1 and 2 observations between 1-5 AU, J. Geophys. Res., 87, 4345, 1982.

Howard, R. A., and M. J. Koomen, Observation of sectored structure in the outer solar corona: Correlation with interplanetary magnetic field, Solar Phys., 37, 469, 1974.

Hundhausen, A. J., Coronal Expansion and Solar Wind, Springer-Verlag, New York, 1972.

Hundhausen, A. J., An interplanetary view of coronal holes, in Coronal Holes and High Speed Wind Streams, edited by J. B. Zirker, p. 225, Colorado Associated University Press, Boulder, Colorado, 1977.

Hundhausen, A. J., Solar activity and the solar wind, Rev. Geophys. Space Phys., 17, 2034, 1979.

Klein, L., and L. F. Burlaga, Interplanetary sector boundaries 1971-1973, J. Geophys. Res., 85, 2269, 1980.

Lepping, R. P., and K. W. Behannon, Magnetic field directional discontinuities: 1. Minimum variance errors, J. Geophys. Res., 85, 4695, 1980.

ORIGINAL PAGE IS
OF POOR QUALITY



Levine, R. H., Large-scale solar magnetic fields and coronal holes, in Coronal Holes and High Speed Wind Streams, edited by J. B. Zirker, p. 103, Colorado Associated University Press, Boulder, Colorado, 1977.

Neubauer, F. M., Recent results on the sector structure of the interplanetary magnetic field, paper presented at Second European Solar Meeting, 'Highlights of Solar Physics,' Solar Sect., Astron. and Astrophys. Div., European Geophys. Soc., Toulouse, France, March 8-10, 1978.

Newkirk, G. A., Coronal magnetic fields and the solar wind, in Solar Wind, edited by C. P. Sonett, P. J. Coleman, Jr., and J. M. Wilcox, p. 11, NASA SP-308, Washington, D. C., 1972.

Pneuman, G. W., Structure of coronal neutral sheets, in Solar Wind, edited by C. P. Sonnett, P. J. Coleman, Jr., and J. M. Wilcox, p. 11, NASA SP-308, Washington, D. C., 1972.

Rosenberg, R. L., and P. J. Coleman, Jr., Heliographic latitude dependence of the dominant polarity of the interplanetary magnetic field, J. Geophys. Res., 74, 5611, 1969.

Schatten, K. H., Large-scale properties of the interplanetary magnnetic field, in Solar Wind, NASA SP-308, edited by C. P. Sonett, P. J. Coleman, Jr., and J. M. Wilcox, p. 65, Washington, D. C., 1972.

Schulz, M., Interplanetary sector structure and the heliomagnetic equator, Astrophys. Space Sci., 24, 371, 1973.

Smith, E. J., B. T. Tsurutani, and R. L. Rosenberg, Observations of the interplanetary sector structure up to heliographic latitudes of 16°: Pioneer 11, J. Geophys. Res., 83, 717, 1978.

Sonnerup, B. U. O., and L. J. Cahill, Magnetopause structure and attitude from Explorer 12 observations, J. Geophys. Res., 72, 171, 1967.

Svalgaard, L., and J. M. Wilcox, A view of solar magnetic fields, the solar corona, and the solar wind in three dimensions, Ann. Rev. Astron. Astrophys., 16, 429, 1978.

Svalgaard, L., J. M. Wilcox, and T. L. Duvall, A model combining the polar and the sector structured polar magnetic fields, Solar Phys., 37, 157, 1974.

Svalgaard, L., J. M. Wilcox, and P. H. Scherrer, The sun's magnetic sector structure, Solar Phys., 45, 83, 1975.

Thomas, B. T., and E. J. Smith, The structure and dynamics of the heliospheric current sheet, J. Geophys. Res., 86, 11105, 1981.

ORIGINAL PAGE IS
OF POOR QUALITY



Villante, U., and R. Bruno, Structure of current sheets in the sector boundaries: Helios 2 observations during early 1976, J. Geophys. Res., 87, 607, 1982.

Villante, U., R. Bruno, F. Mariani, L. F. Burlaga, and N. F. Ness, The shape and location of the sector boundary surface in the inner solar system, J. Geophys. Res., 84, 6641, 1979.

Wilcox, J. M., and L. Svalgaard, Coronal magnetic structure at a solar sector boundary, Solar Phys., 34, 461, 1974.

Zirker, J. B., editor, Coronal Holes and High Speed Wind Streams, Colorado Associated University Press, Boulder, Colorado, 1977.

## Figure Captions

Figure 1 — Brightness contours (solid curves) measured by the Mauna Loa K coronameters at 1.75 $R_\odot$ as a function of solar latitude and longitude for a portion of Carrington rotation (CR) 1566. The contour levels are in units of $10^{-8}$ times the brightness of the photophere. Also shown is a curve (dashed) giving the estimated latitude of maximum brightness as a function of longitude. Superimposed are the projected trajectories of Voyagers 1 (V1) and 2 (V2) delineated by IMF sector polarity (+ away from sun, - toward sun) observed at 2.8 AU. The spacecraft crossed the interplanetary current sheet twice during this interval; time runs from right to left.

Figure 2 — Voyager 2 48s magnetic field averages (left-hand panels) during the second (+/-) crossing of a steeply inclined current sheet (at left in Figure 1). Shown for a period of 16 hours are the field magnitude (top) and direction in heliographic (HG) coordinates in terms of the longitude $\lambda$ and latitude $\delta$, where $\lambda = 0^\circ$ is directed away from the sun. At the right are the corresponding hodograms in a minimum variance coordinate system (see text). $\lambda_Z$ and $\delta_Z$ are the angular coordinates of the tip of a unit vector along the minimum variance direction.

Figure 3 — K corona brightness contours and Voyager IMF polarities in same format as Figure 1 for the case of a nearly horizontal current sheet. Note the alternation of polarity at both V1 and V2 (at 1.4 AU) over the range of longitude for which the maximum brightness line was observed to be approximately parallel to the equator.

Figure 4 — Distributions of minimum variance normals for the multiple current sheet crossings of the nearly horizonal sheet. V2 was north of V1 and had a larger number of sheet traversals. In each case, the average direction was near 30°.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 1

Minimum Variance Analysis Results from "Vertical" Current Sheets

| S/C | YR/DY/TIME | $\omega$ | $B_z/\langle B \rangle$ | $\lambda_N$ | $\lvert\delta_N\rvert$ | N | Type of Average |
|---|---|---|---|---|---|---|---|
| V1 | 78 092/22-094/05 | 138° | 0.055 | 196° | 6° | 27 | Hrly |
| V2 | 78 092/04-093/20 | 142° | 0.142 | 201° | 6° | 30 | Hrly |
| V2 | 78 093/07-20 | 139° | 0.126 | 204° | 5° | 383 | 48s |
| V1 | 78 103/0732-0912 | 165° | 0.132 | 171° | 32° | 125 | 48s |
| V2 | 78 102/2030-103/1245 | 165° | 0.500 | 176° | 5° | 1217 | 48s |
| V2 | 78 102/20-103/15 | 160° | 0.347 | 178° | 11° | 20 | Hrly |

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 2

Minimum Variance Analysis Results* from "Horizontal" Current Sheet

| S/C | YR/DY/TIME | $\omega$ | $B_z/\langle B \rangle$ | $\lambda_N$ | $\lvert\delta_N\rvert$ | N |
|---|---|---|---|---|---|---|
| V1 | 77 306/1705-1747:30 | 153° | 0.157 | 241° | 49° | 1196 |
| V1 | 77 307/0437-0523 | 153° | 0.157 | 202° | 38° | 1540 |
| V1 | 77 310/1639:30-1640:15 | 159° | 0.701 | 207° | 26° | 25 |
| V1 | 77 310/1711-1714 | 138° | 0.601 | 190° | 40° | 131 |
| V1 | 77 310/1740-1751 | 144° | 0.497 | 208° | 11° | 391 |
| V2 | 77 307/1918-1950 | 165° | 0.150 | 205° | 9° | 1041 |
| V2 | 77 308/0515-0523 | 140° | 0.235 | 116° | 11° | 261 |
| V2 | 77 308/0803-0820 | 146° | 0.309 | 214° | 46° | 553 |
| V2 | 77 309/1720-1730 | 158° | 0.578 | 197° | 44° | 326 |
| V2 | 77 310/0426-0450 | 170° | 0.151 | 184° | 23° | 781 |
| V2 | 77 311/0128-0134 | 177° | 0.139 | 230° | 44° | 196 |
| V2 | 77 311/0200-0209 | 176° | 0.159 | 216° | 17° | 293 |
| V2 | 77 311/0451-0457 | 137° | 0.050 | 211° | 30° | 196 |

*All results listed are from analysis of 1.92s averages.

ORIGINAL PAGE IS
OF POOR QUALITY

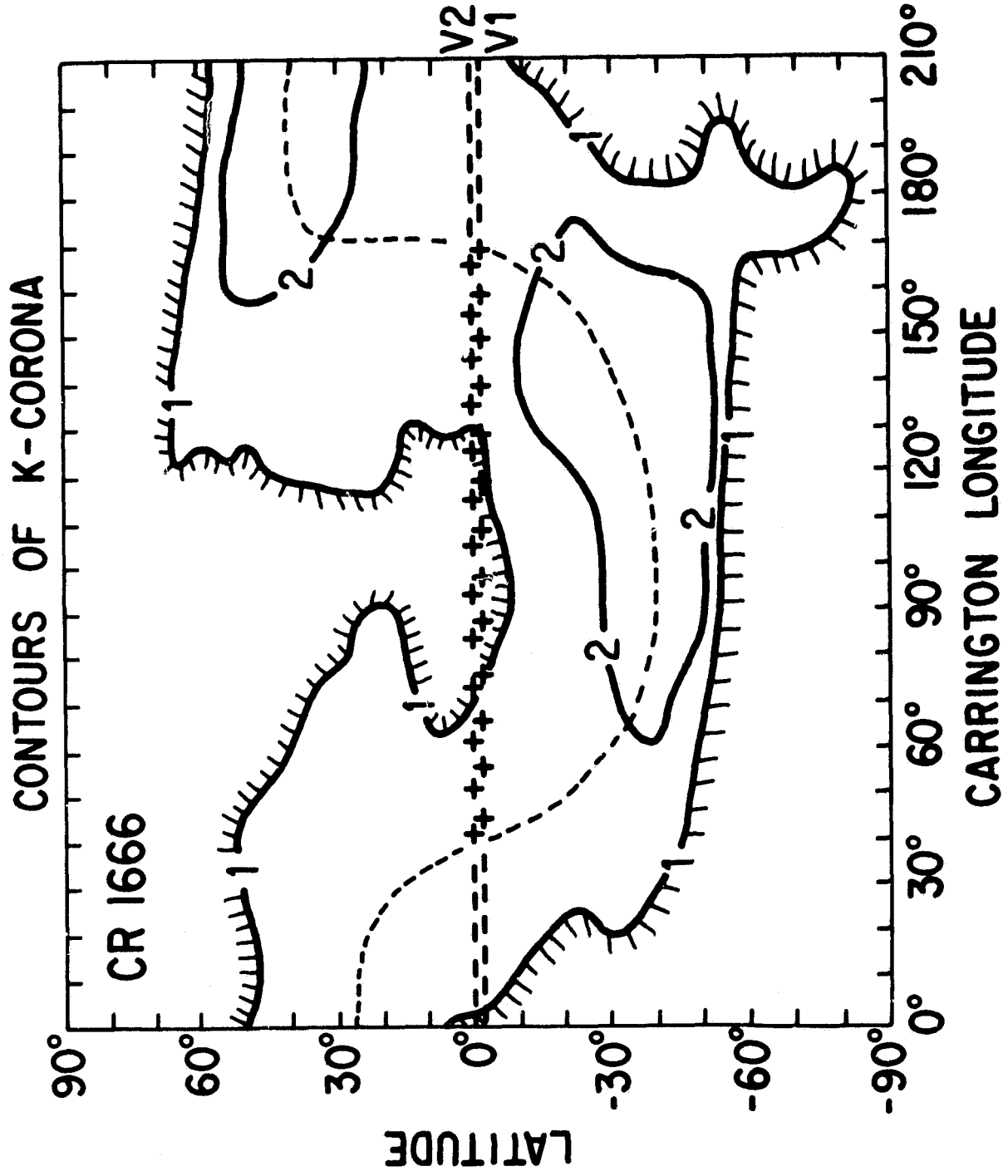



Figure 1

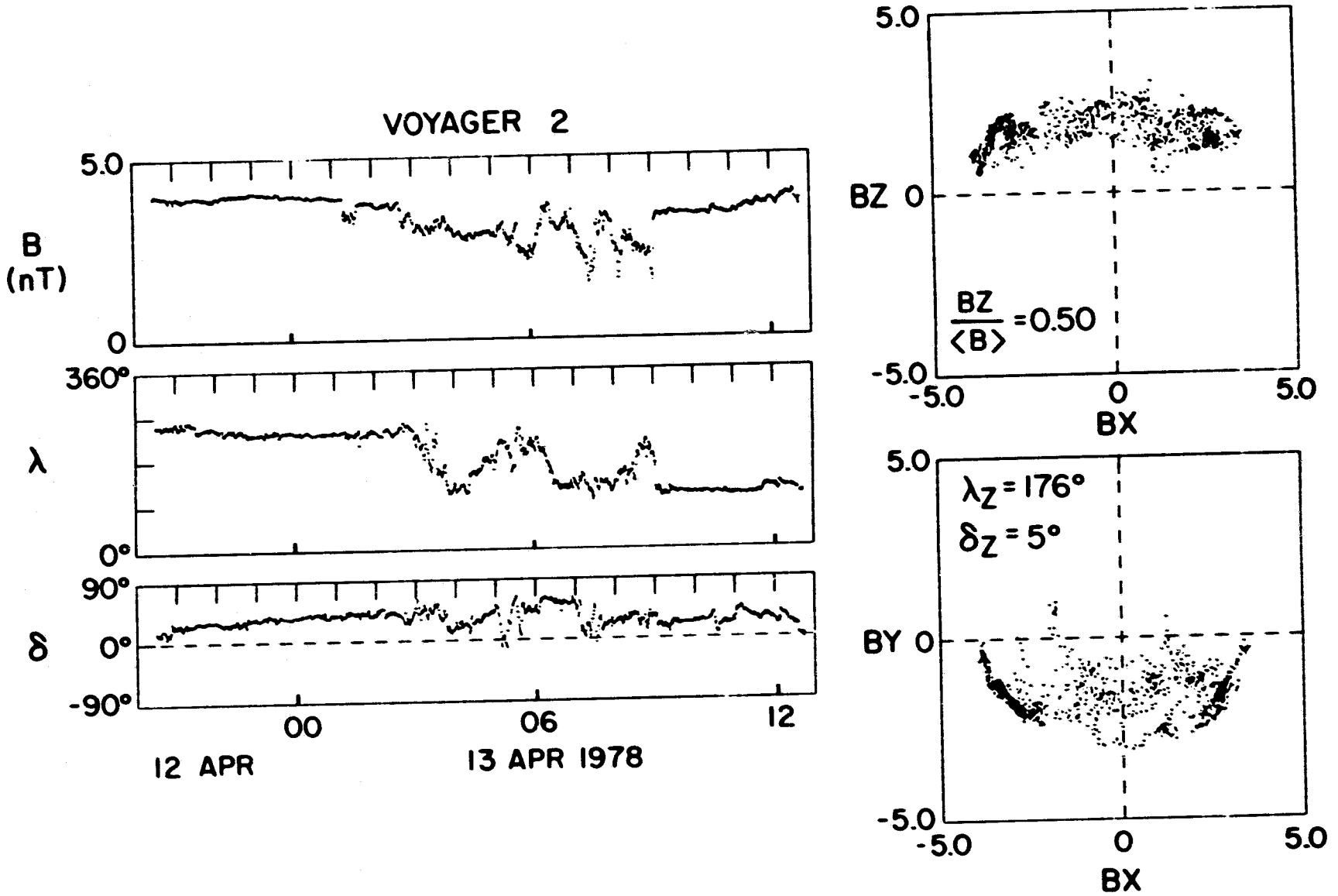
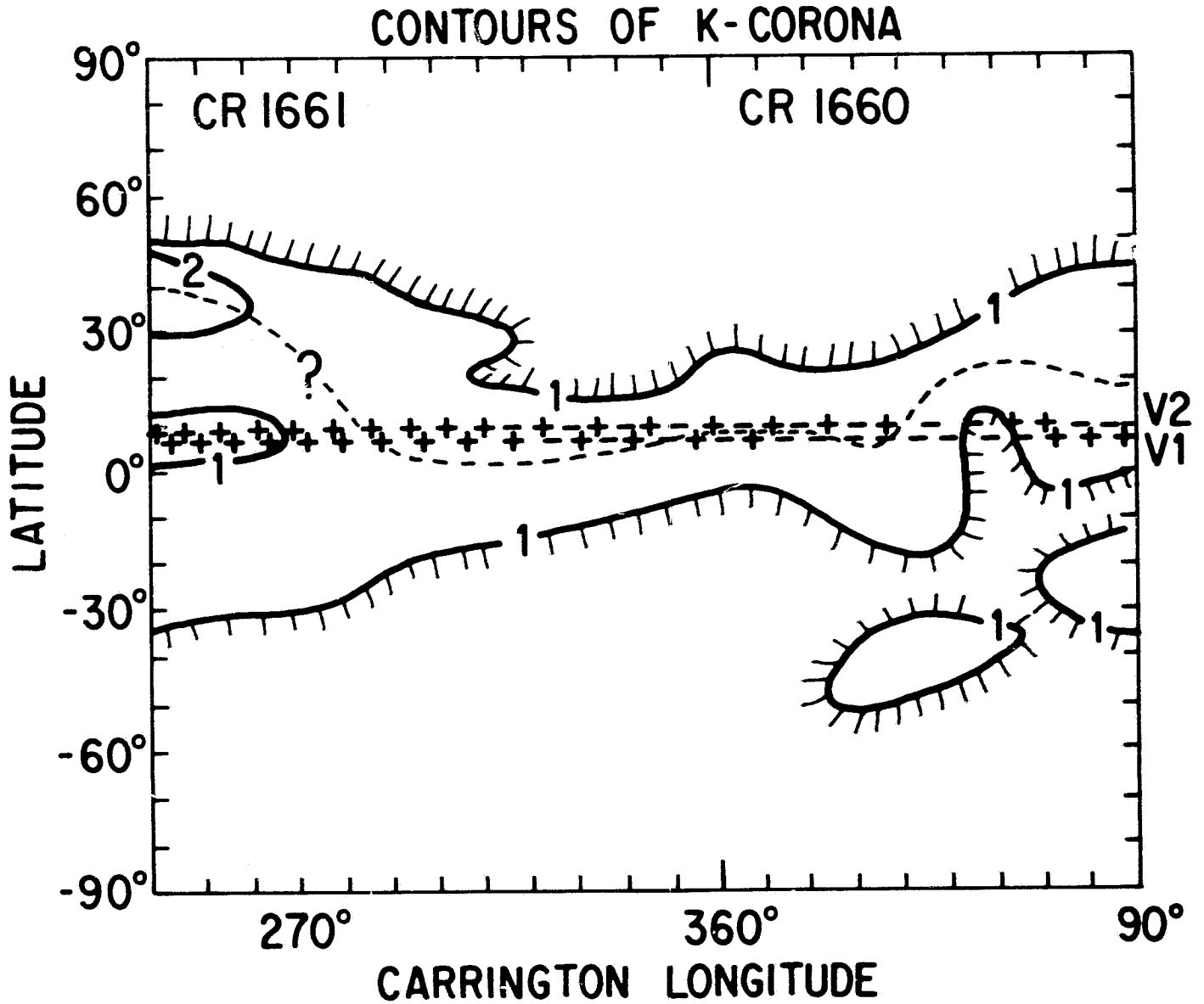


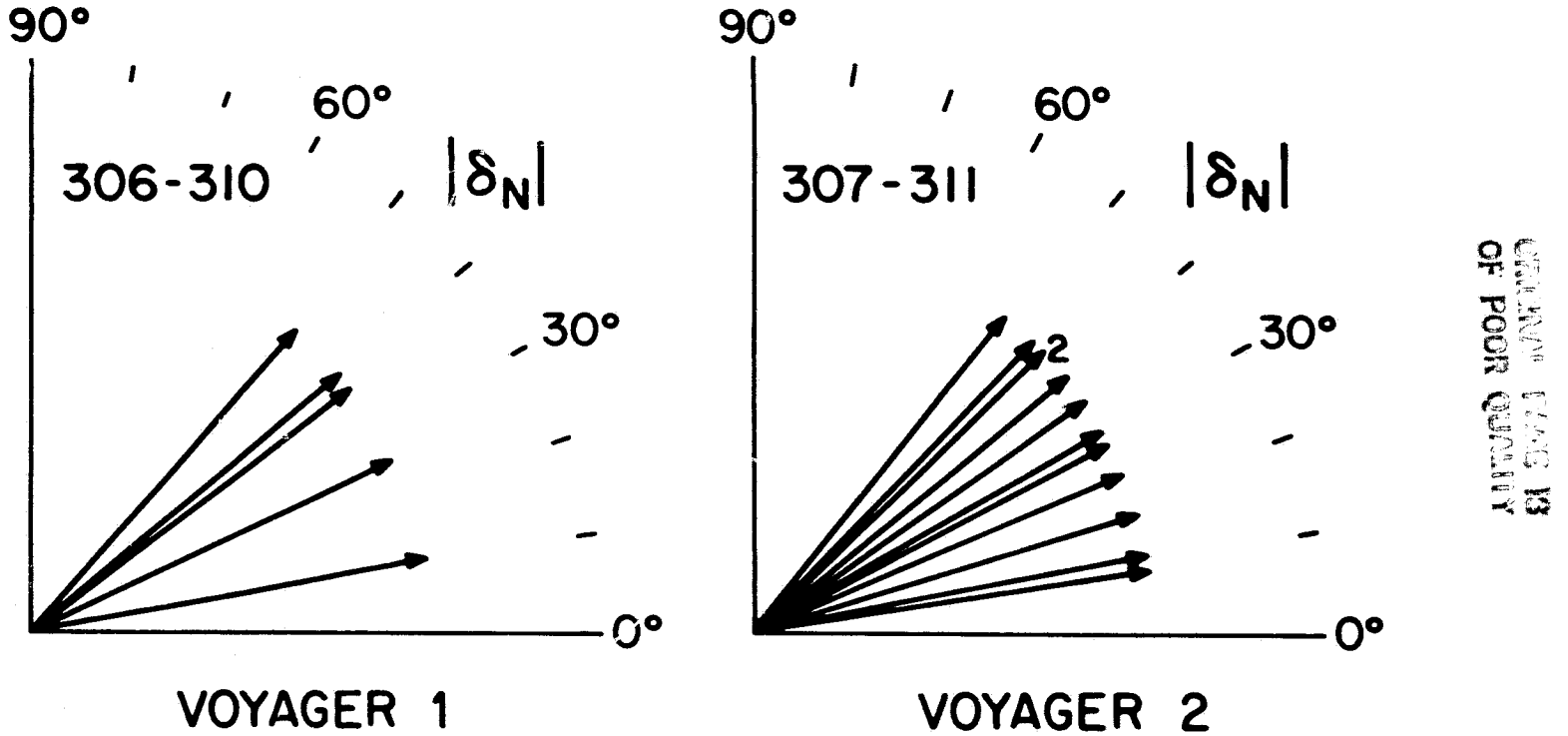

Figure 2

ORIGINAL PAGE IS
OF POOR QUALITY




ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3




ORIGINAL PAGE IS
OF POOR QUALITY

Figure 4