

## THE GIANT BRANCH OF THE OPEN CLUSTER NGC 2539

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### ABSTRACT

Observations in the DDO and  $CMT_1T_2$  photometric systems have been obtained for 13 G and K stars in the field of NGC 2539. The likelihood of membership of each observed star has been evaluated by applying two independent photometric criteria. A reddening  $E(B-V) = 0.08 \pm 0.02$  mag, a distance modulus  $V_0 - M_v = 9.8 \pm 0.5$  mag, and an age of  $(6.4 \pm 0.8) \times 10^8$  yr have been derived. Within the limits of the DDO photometry, there is no firm evidence for any intrinsic differences in CN strengths among the cluster giants, the mean value of  $\delta\text{CN}$  being  $+0.075 \pm 0.012$  mag. Inspection of the abundance data indicates that the cluster giants have enhanced CNO abundances relative to "normal" stars. The Fe + CNO-sensitive  $[\text{Fe}/\text{H}]_{\text{CM}}$  abundance index yielded a result in excellent agreement with that obtained from the DDO data ( $[\text{Fe}/\text{H}] \approx +0.2$ ), while the abundance derived from the iron lines turned out to be  $[\text{Fe}/\text{H}]_{\text{MT}} = -0.2 \pm 0.1$ . The masses of the red cluster giants were found to be systematically lower than those predicted by the theoretical models. An analysis of the several variables that influence our mass determination strengthens the suggestion that the cluster giants could indeed have suffered mass loss during their red giant phase of evolution.

*Subject headings:* clusters: open — stars: abundances — stars: late-type — stars: mass loss

### I. INTRODUCTION

This is the third in a series of papers in which photometry with the DDO intermediate-band system (McClure and van den Bergh 1968; McClure 1976) and the  $CMT_1T_2$  broad-band system (Canterna 1976) is used to investigate the main astrophysical properties of red giants in open clusters. In the previous two papers we have determined the physical characteristics of red giants in the intermediate-age open clusters NGC 2482, NGC 3680, IC 4651 (Clariá and Lapasset 1983, hereafter Paper I) and NGC 5822 (Clariá and Lapasset 1985).

NGC 2539 (IAU designation C0808-126;  $l = 233^\circ.7$ ,  $b = +11.1$ ; Trumpler class II-1m) is a moderately concentrated open cluster whose color magnitude diagram suggests an age nearly similar to that of the Hyades and Praesepe clusters (Mermilliod 1981). Pesch (1961) obtained photoelectric  $UBV$  data for 59 stars in the cluster field. By using these data and the spectral types available for five main-sequence stars (Zug 1933), he derived a mean color excess  $E(B-V) = 0.10$  mag. He also determined a true distance modulus  $V_0 - M_v = 10.5$  mag, equivalent to 1260 pc, by means of the procedure outlined by Johnson (1960). The resulting distance modulus was estimated to be uncertain by about 0.5 mag. The results found by Pesch were later confirmed by Becker and Fenkart (1971), who derived a color excess  $E(B-V) = 0.11$  mag and a distance of 1130 pc by using method A applied at the Basel Observatory. No specific study of the composition of NGC 2539 has yet been made.

In the present study 13 red stars in the cluster field have been observed in the DDO and  $CMT_1T_2$  photometric systems. The measurements in the Washington system were mainly performed for separating the effects of blanketing by the molecular CN and CH bands, typical of G and K stars, from those of the

metallic lines in the ultraviolet. On the other hand, the new DDO observations were combined with existing  $UBV$  data with the main purpose of evaluating the interstellar reddening. We have also used the DDO data to examine the strength of the  $\lambda 4216$  band as well as to derive the effective temperatures, surface gravities, luminosities, and masses of the cluster giants.

### II. THE OBSERVATIONAL MATERIAL

The photometry reported here was obtained at Cerro Tololo Inter-American Observatory (CTIO) by using the 91 cm telescope during 1978 March and 1985 April. A single-channel photometer was used in conjunction with dry-ice-cooled S20 and RCA 31034A Ga-As photomultipliers, respectively. Only the four primary filters of the DDO system were used since these provide adequate information for the present purposes. The  $CMT_1T_2$  observations were also carried out during 1985 April by using the CTIO 91 cm telescope equipped with a Ga-As RCA 31034A photomultiplier. Pulse-counting electronics was utilized for all measurements. Typically  $\sim 15$  standard stars were observed each night from the lists of McClure (1976) and Canterna (1976) to place the observations on the standard DDO and  $CMT_1T_2$  systems. Mean DDO and  $CMT_1T_2$  extinction coefficients for CTIO were utilized in the reductions. Mean standard deviations of transformation of the standard stars to the DDO and  $CMT_1T_2$  systems for each color were:  $C(41-42) = 0.009$  mag;  $C(42-45) = 0.007$  mag;  $C(45-48) = 0.010$ ;  $C-M = 0.007$  mag;  $M-T_1 = 0.005$  mag;  $T_1 - T_2 = 0.007$  mag; these errors are essentially irrespective of the quality of the night.

The results of the DDO and  $CMT_1T_2$  photometry are listed in Tables 1 and 2, where  $n_1$  and  $n_2$  indicate the numbers of nights on which each star was observed in the DDO and  $CMT_1T_2$  systems, respectively. The star designations are from Pesch (1961). The standard deviations of the mean indices and the  $T_1$  magnitude were calculated for each star from the scatter of the individual observations. They are listed in Tables 1 and 2

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TABLE 1  
DDO PHOTOMETRY OF RED STARS IN NGC 2539

Star	C(45-48)	$\sigma$	C(42-45)	$\sigma$	C(41-42)	$\sigma$	$n_1$
6.....	1.176	6	0.807	9	0.220	11	3
7.....	1.161	11	0.977	4	0.209	16	3
15.....	1.427	3	1.284	3	0.264	19	2
16.....	1.372	5	1.243	3	0.263	6	3
21.....	1.317	5	1.078	9	0.362	10	4
22.....	1.243	6	1.039	9	0.271	5	3
26.....	1.190	2	0.849	12	0.259	15	3
28.....	1.155	11	0.793	6	0.179	12	3
29.....	1.367	3	1.270	21	0.316	10	2
32.....	1.182	12	0.796	9	0.241	4	3
42.....	1.127	12	0.770	13	0.181	5	4
47.....	1.358	17	1.252	18	0.129	1	3
51.....	1.146	4	0.780	15	0.185	14	3

in units of 0.001 mag. The mean standard deviations of a single observation are:  $\pm 0.011$  mag in  $C(41-42)$ ,  $\pm 0.010$  mag in  $C(42-45)$ ,  $\pm 0.007$  mag in  $C(45-48)$ ,  $\pm 0.008$  mag in  $C-M$ ,  $\pm 0.005$  mag in  $M-T_1$ ,  $\pm 0.005$  mag in  $T_1-T_2$ , and  $\pm 0.016$  mag in the  $T_1$  magnitude.

### III. ANALYSIS AND DISCUSSION OF THE DATA

#### a) Identification of Cluster Red Giants

The first problem we encounter is that of distinguishing physical members of NGC 2539 from yellow and red field stars. As has been pointed out in Paper I, the best procedure for doing this is probably on the basis of proper motions and/or radial velocities, but unfortunately these basic data are still lacking for NGC 2539.

According to the positions of the observed stars in the  $[V, B-V]$  and  $[U-B, B-V]$  diagrams (Figs. 1 and 2), all of them could be yellow or red giant members of NGC 2539. However, since this criterion alone is not sufficient to assess the likelihood of membership we have preferred to apply the two photometric criteria—denoted A and B—described in Paper I. Taking into account the different combinations that might result from the application of both criteria, we decided to consider a star to have a high probability of being a cluster member if one (or both) of the criteria implies membership, while the other indicates that the star is a probable member. If one criterion (or both) suggests nonmembership, the star is

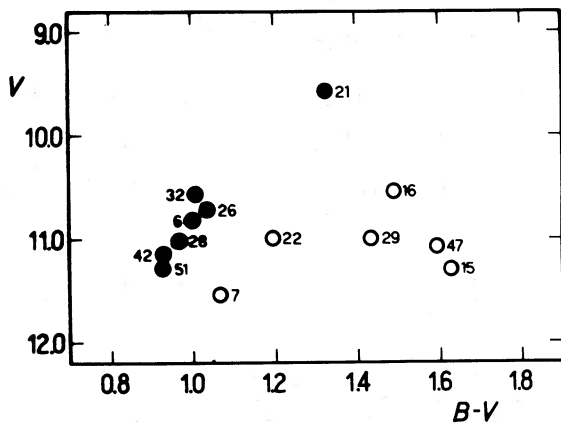


FIG. 1.—The color-magnitude diagram for giant stars in NGC 2539. Cluster members and red field stars are represented by filled and open circles, respectively. The numbers identify the stars from col. (1) of Tables 1–5.

TABLE 2  
 $CMT_1 T_2$  PHOTOMETRY OF RED STARS IN NGC 2539

Star	$C-M$	$\sigma$	$M-T_1$	$\sigma$	$T_1-T_2$	$\sigma$	$T_1$	$\sigma$	$n_2$
6.....	1.142	8	0.749	5	0.488	3	10.330	30	2
7.....	1.302	4	0.830	8	0.513	3	11.000	32	2
15.....	2.091	8	1.267	2	0.904	9	10.397	10	3
16.....	1.921	10	1.157	2	0.775	3	9.793	10	2
21.....	1.721	5	1.011	4	0.642	0	8.895	26	3
22.....	1.512	16	0.913	1	0.578	8	10.422	15	3
26.....	1.222	1	0.787	11	0.516	1	10.180	16	3
28.....	1.122	8	0.742	11	0.488	6	10.553	15	2
29.....	1.891	4	1.133	6	0.718	3	10.218	1	3
32.....	1.172	8	0.775	11	0.490	4	10.071	25	2
42.....	1.063	6	0.724	0	0.478	9	10.696	11	2
47.....	1.968	13	1.283	1	1.425	2	10.131	5	3
51.....	1.064	8	0.728	3	0.486	8	10.788	16	3

rejected as a cluster member. Finally, if both criteria simultaneously indicate probable membership, the star is considered to be a probable member of the cluster.

To apply criteria A and B, the color excess  $E(B-V)_{MS} = 0.10$  mag and true distance modulus  $V_0 - M_p = 10.5$  mag both derived by Pesch (1961) were adopted. We have also used  $\sigma_{B-V} = 0.015$  mag to compute the standard deviation  $\sigma_E$  from equation (2) of Paper I. The DDO colors were dereddened according to the reddening coefficients of McClure (1973) and the predicted luminosity class (LC) for each observed star was determined from the Schmidt-Kaler (1965) calibration assuming  $R = A_v/E(B-V) = 3.0$ .

Columns (6)–(8) of Table 3 contain the results from applying criteria A and B, separately, and the membership classes finally assigned to each star. Column (2) of Table 3 lists the

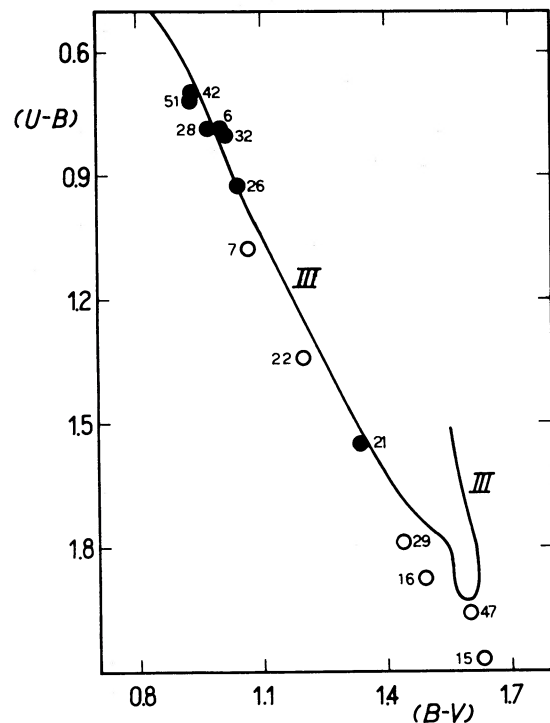


FIG. 2.— $[(U-B), (B-V)]$  diagram for the same stars as in Fig. 1, with the same notations. The continuous line is the standard relation of Schmidt-Kaler (1965) for luminosity class III stars.

TABLE 3  
RESULTS FROM APPLYING THE TWO INDEPENDENT MEMBERSHIP CRITERIA

STAR (1)	$E(B-V)_{\text{GK}}$ (2)	$\sigma_E$ (3)	LC (predicted) (4)	MK(DDO) (5)	CRITERIA		MEMBERSHIP (8)
					A (6)	B (7)	
6.....	0.08	0.04	II-III	G8 III	m	m	m
7.....	0.00	0.04	III	K2/3 IV	nm	pm	nm
15.....	0.17	0.03	III	K4/5 III	nm	m	nm
16.....	0.03	0.03	III	K4 III	nm	m	nm
21.....	0.09	0.04	II-III	K2/3 III	m	m	m
22.....	0.00	0.04	III	K2/3 III	nm	m	nm
26.....	0.05	0.04	II-III	G9 III	pm	m	m
28.....	0.08	0.04	III	G8 III	m	m	m
29.....	0.00	0.04	III	K4/5 III	nm	m	nm
32.....	0.10	0.04	II-III	G5/8 II-III	m	m	m
42.....	0.10	0.05	III	G8 IV	m	pm	m
47.....	0.25	0.05	II-III	K4 IV	nm	nm	nm
51.....	0.04	0.04	III	G5/8 III	pm	m	m

$E(B-V)_{\text{GK}}$  color excesses derived from Janes's (1977) iterative method, which is abundance independent and valid over a wide range of luminosities for Population I stars. The standard deviation  $\sigma_E$  of the  $E(B-V)_{\text{GK}}$  color excess is given in column (3), while columns (4) and (5) include the predicted luminosity class and the spectral type inferred from the unreddened DDO indices. As shown in the table, seven of the 13 red stars observed have a high probability of being cluster giants, while the six remaining stars are very likely red field stars.

#### b) Interstellar Reddening and CN Strengths

The interstellar reddening derived from the procedure of Janes's (1977) average to  $\langle E(B-V) \rangle = 0.08 \pm 0.02$  mag, in good agreement with Pesch's initial value of 0.10 mag. However, the individual  $E(B-V)_{\text{GK}}$  values listed in Table 3 were used to correct the DDO photometry for interstellar absorption.

Figures 3a and 3b illustrate the giant branch of NGC 2539 in the  $[C_0(45-48), C_0(42-45)]$  and  $[C_0(41-42), C_0(42-45)]$  diagrams. Cluster members and red field stars are represented by filled and open circles, respectively. The continuous lines are

the Population I luminosity class relations for solar neighborhood stars (Osborn 1979). Six of the seven red stars recognized as giant members are located at the blue end of the giant branch (see Fig. 1) in a region identified by Cannon (1970) as the Population I analog of the horizontal branch in globular clusters. These "clump" stars and the bright red giant (star 21) occupy a region intermediate between giants and supergiants in Figure 3b, whereas in Figure 3a they all lie along the mean sequence for luminosity class III stars. This apparent inconsistency is clearly due to the CN excesses of these stars with respect to those of solar composition.

We have computed the DDO cyanogen strength index,  $\delta\text{CN}$ , for each star by applying the method described by Janes (1975). Star 7 falls outside the range of Janes's calibration. According to the positive  $\delta\text{CN}$  values listed in Table 4, NGC 2539 should be moderately metal-rich. The average value of the cyanogen strength index is  $\langle \delta\text{CN} \rangle = 0.075 \pm 0.012$  ( $\sigma_m$ ), where  $\sigma_m$  is the standard deviation of the mean. Therefore, the red giants in NGC 2539 have CN strengths comparable to those of the Hyades giants [ $\delta\text{CN} = 0.074$  (McClure 1979)]. The cluster iron abundance derived from equation (4) of Paper

TABLE 4  
ABUNDANCE PARAMETERS AND DISTANCE MODULI OF NGC 2539 GIANTS

STAR (1)	$\delta\text{CN}$ (2)	$[\text{Fe}/\text{H}]_{\text{DDO}}$ (3)	$[\text{Fe}/\text{H}]_{\text{CM}}$ (4)	$[\text{Fe}/\text{H}]_{\text{MT}}$ (5)	$M_v(\text{DDO})$ (6)	$V_0 - M_v$ (7)
Cluster Giants						
6.....	0.059	0.17	0.3	-0.1	0.8	9.8
21.....	0.057	0.16	0.5	-0.2	0.2	9.1
26.....	0.071	0.22	-0.1	-0.3	0.4	10.2
28.....	0.054	0.14	0.2	-0.2	1.3	9.5
32.....	0.134	0.50	0.4	0.1	0.0	10.3
42.....	0.101	0.36	0.3	-0.1	...	...
51.....	0.047	0.11	-0.3	-0.3	1.0	10.0
Nonmembers						
7 <sup>a</sup> .....	...	...	0.0	0.0	3.8	7.8
15.....	-0.048	-0.32	-0.2	-0.1	0.0	11.0
16.....	-0.090	-0.51	0.0	-0.2	0.7	9.8
22.....	0.021	-0.01	0.1	-0.2	1.3	9.7
29.....	0.028	0.03	0.3	-0.1	0.4	10.9
47.....	-0.133	-0.70	...	...	...	...

<sup>a</sup> The cyanogen anomaly cannot be computed because the intrinsic DDO colors fall outside the range of Janes's 1975 calibration.

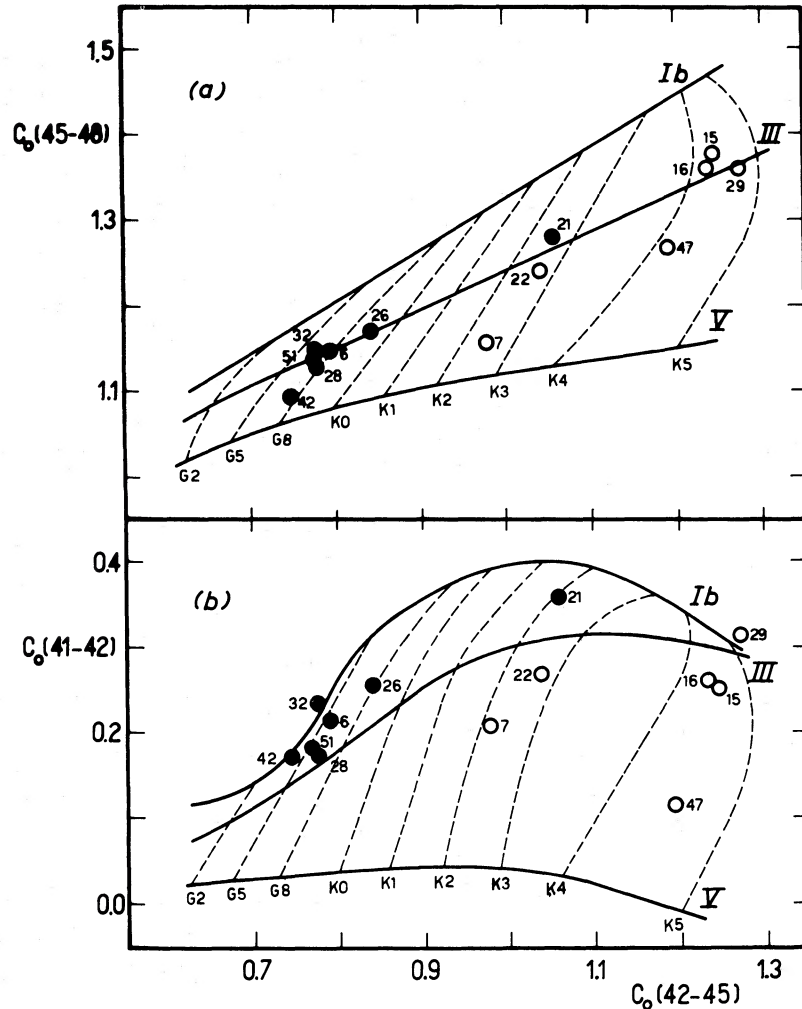


FIG. 3.—The observed red stars in the field of NGC 2539 plotted on the unreddened  $[C_0(45-48), C_0(42-45)]$  and  $[C_0(41-42), C_0(42-45)]$  planes. The continuous lines labeled “Ib”, “III”, and “V” are the Population I luminosity class relations for solar neighborhood stars (Osborn 1979). Symbols are as in Fig. 1.

I is  $[\text{Fe}/\text{H}]_{\text{DDO}} = 0.24 \pm 0.06$ . It is seen from Table 4 that three of the stars considered to be red field stars exhibit large deviations from the mean value of  $\delta\text{CN}$ , whereas the most discordant value of  $\delta\text{CN}$  among the cluster giants is off from the mean by less than twice the standard deviation. We thus conclude that no evidence for anomalous stars among the giants of NGC 2539 is observed.

### c) $\text{CMT}_1\text{T}_2$ Abundance Parameters

The  $\text{CMT}_1\text{T}_2$  photometric system provides two independent metallicity parameters, denoted  $\Delta(M-T_1)$  and  $\Delta(C-M)$ , defined as the color excess in the  $M-T_1$  or  $C-M$  index over the normal value for a given  $T_1-T_2$  color.  $\Delta(M-T_1)$  is a reddening-free, surface gravity-free parameter which measures the metallic line blanketing (primarily due to iron). On the other hand,  $\Delta(C-M)$  measures CN and CH, as well as metallic absorption.  $\Delta(M-T_1)$  is quite sensitive to metallicity for metal-rich stars, i.e.,  $[\text{Fe}/\text{H}] > -1.0$ , while  $\Delta(C-M)$  is strongly sensitive to metal abundance for all values of  $[\text{Fe}/\text{H}]$ . Canterna and Harris (1979) have established empirical and theoretical calibrations of unreddened  $\text{CMT}_1\text{T}_2$  data in terms of iron abundances  $[\text{Fe}/\text{H}]$ .

To determine the quantities  $\Delta(M-T_1)$  and  $\Delta(C-M)$  for the

red giants of NGC 2539, the observed color indices were first dereddened by using the  $E(B-V)_{\text{GK}}$  values of Table 3 and the reddening ratios given by Canterna (1976). Then, we made use of the empirical calibrations of Canterna and Harris (1979) to determine the iron abundances  $[\text{Fe}/\text{H}]_{\text{MT}}$  and  $[\text{Fe}/\text{H}]_{\text{CM}}$  derived from the indices  $M-T_1$  and  $C-M$ , respectively.

As shown in Table 4, the abundances derived from the CN-contaminated  $C-M$  index are all systematically higher than those derived from the iron lines, the mean values being  $\langle[\text{Fe}/\text{H}]_{\text{CM}}\rangle = +0.2 \pm 0.1$  and  $\langle[\text{Fe}/\text{H}]_{\text{MT}}\rangle = -0.2 \pm 0.1$ . We interpret this result as indicating that the red giants of NGC 2539 are probably enriched in elements of the CNO group. If this is indeed the case, we offer two alternative possibilities to explain this observational result: either some physical process, such as mixing of processed material from the stellar envelope to the surface, could be causing the surface abundances to be enriched in CNO elements, or we would accept that the cluster stars may have formed from gas already contaminated by elements of the CNO group. The uniformity of cyanogen strengths detected among the cluster giants seems to favor the second possibility. Some observational evidence for CNO enrichment has also been found in the red giants of other open clusters, such as NGC 2243 (Hardy 1981), NGC

2204 (Dawson 1981), NGC 2482 and NGC 3680 (Paper I), Melotte 66 (Geisler and Smith 1984), and NGC 5822 (Clariá and Lapasset 1985).

The metallicity inferred from the Fe + CNO-sensitive  $\Delta(C - M)$  abundance index of the  $CMT_1 T_2$  photometry is in excellent agreement with that obtained from the  $\delta CN$  abundance index of the DDO photometry. This is an expected result since both abundance parameters are based on spectral regions which are affected, for G and K stars, by the presence of strong CN and CH molecular bands.

We would like to point out, however, that the conclusion of the NGC 2539 giants being enhanced in CNO abundances is rather strongly dependent on the DDO and  $CMT_1 T_2$  calibrations, both of which are subject to considerable zero-point uncertainties. Since relatively small changes in these calibrations could alter the results significantly, the above conclusion could be revised if a recalibration of the  $CMT_1 T_2$  (or DDO) system leads to a new zero point. Anyway, it would be evidently of considerable interest to test by spectroscopic methods if the CN and CH bands of the cluster giants are indeed enhanced relative to "normal" stars.

#### d) Distance Modulus, Age, and Physical Properties

The absolute magnitude and distance modulus of each star were computed according to the procedure described in Paper I. These quantities are listed in columns (6) and (7) of Table 4. Stars 42 and 47 fall outside the range of Janes's calibrations. The mean distance modulus is  $V_0 - M_v = 9.8 \pm 0.5$  mag. The derived distance modulus yields a distance  $z = 175$  pc above the Galactic plane, as compared with  $z = 243$  pc for Pesch.

A correlation between the mean absolute magnitude of the red giant concentration and the ages of open clusters in the range  $7.3 < \log t < 8.9$  has been established by Mermilliod (1981). This relation is given by  $\log t = 8.610 + 0.280 \langle M_v \rangle$ , where  $\langle M_v \rangle$  represents the mean absolute magnitude of the red giant concentration. The above relation and the cluster distance here estimated lead to an age of  $6.4 \times 10^8$  yr for a mean absolute magnitude  $\langle M_v \rangle = 0.7$  mag. Therefore, as suggested by the color-magnitude diagram, NGC 2539 has an age nearly similar to that of the Hyades and Praesepe clusters.

Effective temperatures ( $T_{\text{eff}}$ ) and surface gravities ( $g$ ) of the cluster giants were determined from the calibration of the unreddened DDO indices with  $T_{\text{eff}}$  and  $\log g$  (Osborn 1973; Osborn and Clariá 1976) following the procedure described in Paper I. In order to obtain the normal—blanketing corrected—colors for the cluster giants, the iron abundances  $[\text{Fe}/\text{H}]_{\text{MT}}$  of Table 4 have been used. The DDO temperature calibration is based on the  $T_{\text{eff}}$  scale of Schlesinger (1969), which has been shown to be too low by about 200–300 K (Cohen, Frogel, and Persson 1978; McClure 1979). For this reason, we have added 250 K to each temperature obtained from Osborn's calibration. Anyway, the error involved in the  $T_{\text{eff}}$  determination is about 200 K, while the  $\log g$  values have random errors of about  $\pm 0.2$ .

In addition, rough estimates of the masses were also made by using equation (13) of Paper I. The resulting effective temperatures, surface gravities and masses for the cluster giants are shown in Table 5. Column (4) of the table lists the bolometric absolute magnitude calculated from equation (12) of Paper I using the bolometric correction (BC) given by Schlesinger (1969).

The average value of the masses of the cluster giants is  $M/M_\odot = 1.3 \pm 0.2(\sigma_m)$ , and no evidence of deviation of any

TABLE 5  
PHYSICAL PROPERTIES OF NGC 2539 GIANTS

Star (1)	$T_{\text{eff}}$ (K) (2)	$\log g$ (cgs) (3)	$M_b$ (4)	$\log M/M_\odot$ (5)	$M/M_\odot$ (6)
6.....	5230	2.7	0.60	0.08	1.2
21.....	4420	2.0	-0.31	0.03	1.1
26.....	5000	2.4	0.12	0.05	1.1
28.....	5250	3.0	1.10	0.37	1.5
32.....	5360	2.6	-0.16	0.24	1.7
42.....	5470	(3.8)	...	...	...
51.....	5220	2.8	0.80	0.10	1.3

star from this mean value is apparent. In particular, the non-clump star 21 has a mass which is undistinguishable from those of the clump stars.

According to Iben's (1967) evolutionary tracks, the masses of stars at the cluster turnoff point should be  $M \approx 2.4 M_\odot$  to be consistent with the age of NGC 2539. Since the red giants here considered are stars that have evolved from positions on the main sequence above the turnoff point, their masses should be equal or somewhat larger than the turnoff point mass. Contrary to what would be expected, however, the derived masses appear all to be systematically lower than the turnoff point mass. Thus, two alternatives appear to be possible: either we have underestimated the average mass of the cluster giants or we should accept that these stars could have undergone mass loss before reaching their helium core burning phase of evolution.

Concerning the first possibility, we would like to note that the uncertainty of  $\log M/M_\odot$  depends not only on the uncertainty of the  $C(45-48)$  index but also on the adopted cluster reddening, metal abundance, distance modulus, as well as on possible errors in the zero points of the DDO calibrations.

It appears unlikely that the photometric errors quoted for the  $C(45-48)$  index are responsible for the small masses derived. On the other hand, although decreasing the  $[\text{Fe}/\text{H}]$  ratio and/or increasing the interstellar reddening would have the effect of increasing individual masses, these are also two unlikely possibilities because (i) we have used the  $[\text{Fe}/\text{H}]_{\text{MT}}$  individual abundances, and (ii) the mean reddening here derived is very close to that obtained by other authors.

To assume that the adopted distance modulus is the cause of the small masses derived does not seem probable either, since it would be necessary to increase the distance modulus by about 1.0 mag to obtain masses as predicted by the theoretical models. Finally, it is true that the mass results are quite sensitive to the zero points of the DDO calibrations, i.e., to the positions of the lines in Osborn and Clariá's (1976) Figure 3, which are uncertain by about 200 K in  $T_{\text{eff}}$  and 0.2–0.3 in  $\log g$  in the worst cases. However, there seems to be little chance that this source of error could account for an underestimation of the mass since the same procedure and calibrations were utilized by Osborn (1974) to determine masses in M67, which agree with independent determinations. Thus, although the individual mass determinations are rather uncertain, we interpret the present results as indicating that the red cluster giants could have suffered mass loss before entering the helium core burning phase of evolution. Masses lower than expected have also been found among the red giants of other intermediate-age and old open clusters (see, e.g., Osborn 1974; Dawson 1978; Clariá 1979; Paper I).

## IV. SUMMARY AND CONCLUSIONS

New photoelectric DDO and  $CMT_1T_2$  photometry combined with existing  $UBV$  data of G and K stars in the field of NGC 2539 have been used to determine the main astrophysical properties of the cluster giants. Although it is not possible to make definitive statements with regard to the evaluation of cluster membership, this study has enabled us to distinguish several red field stars from the physical members of NGC 2539. It was found that seven red stars have a high probability of being cluster giants, while the six remaining stars are almost certainly red field objects. NGC 2539 appears to be an open cluster aged  $(6.4 \pm 0.8) \times 10^8$  yr. The foreground reddening and distance modulus were found to be  $E(B-V) = 0.08 \pm 0.02$  mag and  $V_0 - M_v = 9.8 \pm 0.5$  mag ( $r = 910$  pc). The cluster giants have CN strengths nearly identical to those of the Hyades giants ( $\delta\text{CN} = 0.075$ ), and no evidence for anomalous stars is observed. A comparison among the different abundance indicators suggests the cluster giants to be slightly enriched in elements of the CNO group. In fact,  $\langle[\text{Fe}/\text{H}]_{\text{MT}}\rangle = -0.2 \pm 0.1$  is inferred from the iron lines, while abundances derived from the blue spectral features contaminated by CN and CH are somewhat higher ( $\langle[\text{Fe}/\text{H}]_{\text{CM}}\rangle = +0.2 \pm 0.1$  and  $\langle[\text{Fe}/\text{H}]_{\text{DDO}}\rangle = 0.24 \pm 0.06$ ). However, this apparent difference between the iron peak and CNO abundances could be revised if a recalibration of the Washington (or DDO) system leads to a new zero point. Adopting the iron-peak abundance and assuming  $X_{\text{star}} \approx X_{\odot}$ , equation (8) of Paper I implies a heavy-element abundance of  $Z = 0.016$ .

Effective temperatures, surface gravities, and masses have also been determined for the cluster giants. The derived masses are all found to be systematically lower than the expected theo-

TABLE 6

SUMMARY OF RESULTS OBTAINED FOR THE CLUSTER GIANTS

Parameter	Value
Age (yr) .....	$(6.4 \pm 0.8) \times 10^8$
$\langle E(B-V)_{\text{GK}} \rangle$ (mag) .....	$0.08 \pm 0.02$
$\langle V_0 - M_v(\text{DDO}) \rangle$ .....	$9.8 \pm 0.5$ ( $r = 910 \pm 210$ pc)
$\langle \delta\text{CN} \rangle$ (mag) .....	$0.075 \pm 0.012$
$\langle [\text{Fe}/\text{H}]_{\text{MT}} \rangle$ .....	$-0.2 \pm 0.1$
$\langle [\text{Fe}/\text{H}]_{\text{CM}} \rangle$ .....	$+0.2 \pm 0.1$
$\langle [\text{Fe}/\text{H}]_{\text{DDO}} \rangle$ .....	$+0.24 \pm 0.06$
Average mass (red giants) ( $M_{\odot}$ ) .....	$1.3 \pm 0.2$
Heavy-element abundance ( $Z$ ) .....	0.016

retical value. Although the mass results are rather strongly dependent on the zero points of the DDO calibrations, an analysis of the different sources entering our mass determination indicates that the red giants could have undergone mass loss before reaching the helium core ignition stage of evolution. It would be very useful to verify this result by using some other method. Table 6 summarizes the relevant properties of NGC 2539 derived in this study.

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