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SPECTROSCOPIC EVIDENCE FOR A WIDE RANGE IN ABUNDANCES AMONG FAINT SUBGIANT STARS IN THE GLOBULAR CLUSTER OMEGA CENTAURI

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ABSTRACT

Intermediate dispersion spectra have been obtained for 11 stars with $16.7<B<18.4(+2<M_V<3.5)$ on the lower subgiant branch of ω Cen using a SIT vidicon camera on the spectrograph at the Ritchey-Chrétien focus of the CTIO 4 m telescope. Five of the stars, generally the redder ones, have radical velocities incompatible with cluster membership, while the remaining six stars are probably all cluster members. Five of the probable members have abundances $-1.0\leq[\mathrm{M/H}]\leq-1.5$, with some evidence for carbon depletion. The sixth has $[\mathrm{M/H}]\approx-0.5$, as high an abundance as is known for any of the more highly evolved stars in ω Cen. This object also has an enhanced nitrogen abundance, the enhancement being possibly as much as a factor of 3. Possible reasons for the variation in the nitrogen abundance are: mixing of the stars during their evolution, differences in abundances at the time of star formation (the primordial hypothesis), accretion of material lost by the cluster red giants, and accretion of material lost by a binary comparison. These possibilities are discussed.

Subject headings: clusters: globular — stars: abundances — stars: late-type

I. INTRODUCTION

It is now well established that the highly evolved stars on the giant and horizontal branches of ω Centauri (NGC 5139=C1323−472) exhibit a range of metallicities, with both the CNO group elements and some heavier elements showing large star-to-star differences. The evidence comes from various sources—e.g., relatively high dispersion spectroscopy (Mallia and Pagel 1981), Ca II and hydrogen line strengths in RR Lyrae stars (Freeman and Rodgers 1975; Manduca and Bell 1978), low dispersion spectroscopy (Dickens and Bell 1976), and from photometry (Cannon and Stobie 1973; Hesser, Hartwick, and McClure 1977). From the data of Mallia and Pagel, and those of Manduca and Bell, it seems that the overall abundances [M/H] $[=\log(\mathrm{M/H})^*-\log(\mathrm{M/H})^{\odot}]$ lie in the range $-2.0\leq[\mathrm{M/H}]\leq-0.5$, with very few stars being more metal rich than $[\mathrm{M/H}]=-1.0$.

There has been much debate as to whether these abundance variations are primordial or whether they are due to mixing of processed material during stellar evolution; Kraft (1979) and McClure (1979) have given comprehensive reviews of the problem. It is very likely that the variations in calcium and other heavy elements are primordial, but there are arguments (Dickens and Bell 1976; Bessell and Norris 1976) that at least some of the CNO group variations are due to mixing. Schatzman (1977, 1978) has suggested that mixing may occur in stars near the main sequence but there is evidence that the mixing of cluster stars is most likely to occur during the red giant phase of evolution (Bell, Dickens, and Gustafsson 1979) and will cause surface abundance variations only above some limiting luminosity. One possible mechanism is meridional circulation, proposed by Sweigart and Mengel (1979). If this is the only mixing mechanism, it should be possible to distinguish between primordial and evolutionary CNO abundance variations by observing sufficiently faint subgiants or main sequence stars. Cannon and Stewart (1981) attempted to do this photometrically by studying the spread in the

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(V, $B-V$) color-magnitude (C-M) diagram near the main sequence turnoff point. They found a small color spread, consistent with primordial abundance variations equal to those seen in the highly evolved stars, but not much larger than the spread expected from observational errors alone. Furthermore, they had to make a rather uncertain statistical correction for the contamination of their sample by field stars.

A much better approach is to obtain intermediate dispersion spectra of a sample of faint stars and to look for abundance variations directly, by comparison with theoretical synthetic spectra. A great advantage of using spectra is that they also give a good criterion for cluster membership, since the radial velocity of the cluster is $\sim$228 km s^{-1} (Webbink 1981). The present paper gives spectral data for 11 faint stars near ω Cen, and a discussion of their cluster membership and metallicities.

II. OBSERVATIONS

The stars observed were selected from the lists of Cannon and Stewart (1981) and Cannon (1981) and are listed in Table 1, along with some relevant photometric data. Mean photographic values are quoted since they have higher internal precision, although all the stars except CS 23-01 have been measured photoelectrically by Cannon (1981) or by Cannon and Stobie (1973). The locations of the stars in the C-M diagram are shown in Figure 1, from which each star has been qualitatively assigned to either a red or blue color group, depending on its luminosity and color.

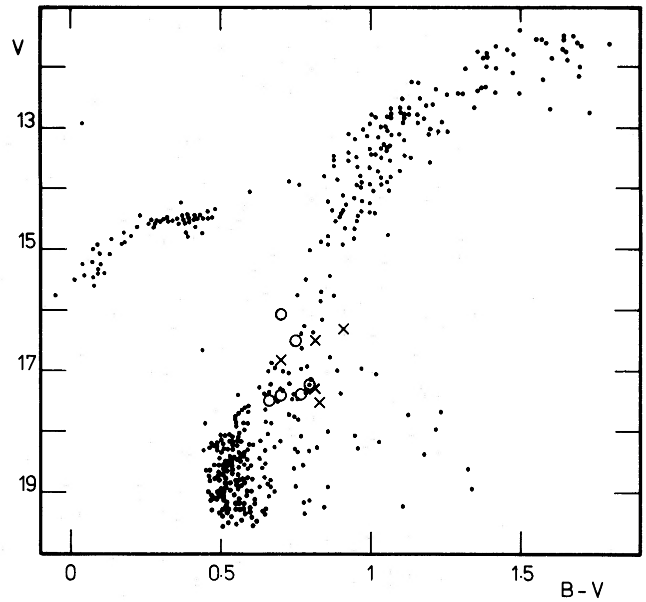


FIG. 1.—A C-M diagram of ω Cen, taken from Cannon and Stewart (1981). The data for the brighter stars ($V<16$) are mostly photoelectric, taken from several sources, while photographic photometry was used for the fainter stars. The 11 subgiants observed spectroscopically are indicated; the six believed to be cluster members are circled, while crosses represent the five field stars.

TABLE 1

SUMMARY OF OBSERVATIONAL DATA

Star[a]	Group	V (mag)	$B-V$ (mag)	Date (1980)	Exposure[b] (min)	v (km s^{-1})[c]	σ (km s^{-1})	Remarks
CS 22-52 ...	Blue	16.08	0.70	18/06	20	185	24	[d]
CS 12-61 ...	Red	16.31	0.91	17/06	30	7	22	Field star[e]
CS 22-15 ...	Red	16.50	0.82	18/06	60	56	22	Field star
CS 11-57 ...	Blue	16.51	0.75	18/06	30	226	27	[f]
CS 23-01 ...	Blue	16.81	0.70	18/06	30	−9	17	Field star
CS 32-55 ...	Red	17.29	0.81	19/06	60	−18	21	Field star
CS 13-35 ...	Red	17.22	0.80	17/06	60	201	22	
CS 13-53 ...	Blue	17.43	0.69	16/06	60	193	29	
				17/06	30	221	23	
CS 32-48 ...	Red	17.40	0.77	19/06	60	229	23	[g]
C 1	Red	17.52	0.83	17/06	60	−127	24	Field star
CS 23-42 ...	Blue	17.50	0.66	19/06	60	309	29	[h]

[a] The stars are identified by Cannon and Stewart 1981, except for C 1 which is from Cannon 1981.

[b] Exposures of 60 min are the sum of two 30-min exposures that were co-added before measuring the velocities. The two exposures of CS23-42 were also reduced independently.

[c] The radial velocities (col. [6]) have been corrected for the zero point error described by Hesser and Harris 1981.

[d] ROA 4655.

[e] ROA 4659.

[f] ROA 5315.

[g] Photometry uncertain due to faint companion.

[h] Membership questionable-see text.

Spectra with ~4 Å resolution were obtained with the Ritchey-Chrétien spectrograph on the CTIO 4 m telescope during parts of the nights of 1980 June 15–18. The instrumental configuration consisted of: 300 μm (2″.0) slit, KPNO Grating Lab grating number 1 (632 lines mm^{-1}) in the first-order blue (angle 59°.20), and an RCA 4804 UV transmitting SIT vidicon (Atwood *et al.* 1979) with a new 250 mm focal length, f/1.4 camera and no beam reducing optics. The seeing was better than 2″.5, and the skies were clear for most of the observations.

III. MEMBERSHIP AND SPECTRAL CHARACTERISTICS

a) *Membership from Radial Velocities*

The elimination of field stars from a sample destined to be used for abundance analysis is, of course, crucial for a low galactic latitude ($b=15°$) cluster such as ω Cen. Fortunately we find (cf. also Hesser and Harris 1981) the recently improved SIT vidicon system on the CTIO 4 m telescope spectrograph capable of yielding radial velocities of sufficient precision (~25 km s^{-1}) to establish membership for stars to about B~18.5 mag in this high velocity cluster.

We measured the bright giants ROA 65 and 67 each night as local reference stars and find heliocentric radial velocities $V_{r,0}=202\pm12$ and 209 ± 10 km s^{-1}, respectively, compared with the previous measures of 245 and 226 km s^{-1} summarized by Webbink (1981). The agreement is satisfactory for our purposes.

The data given in Table 1 show that five of the 11 stars observed have velocities inconsistent with cluster membership. Of the remainder, the star CS 23-42 has a measured velocity ~3σ above the cluster value. This is the *only* star for which the velocities derived from the individual 30 minute exposures differ by more than 40 km s^{-1} (the individual spectra yielded 272 and 349 km s^{-1}). We consider it likely, but by no means certain, that CS 23-42 is a member of ω Cen. We assume that the remaining five stars are cluster members.

The high percentage of field stars in our sample is not particularly surprising in that the spectroscopic measurements were made on a subset of the photoelectric standard stars. In order to minimize crowding difficulties, these standard stars were selected to lie between 20′ and 30′ from the cluster center (ω Cen has core and tidal radii of 2′.4 and 55′, respectively [Peterson and King 1975]). While it is impossible to draw definite conclusions from our small sample, there is already a suggestion that the redder stars in the analysis

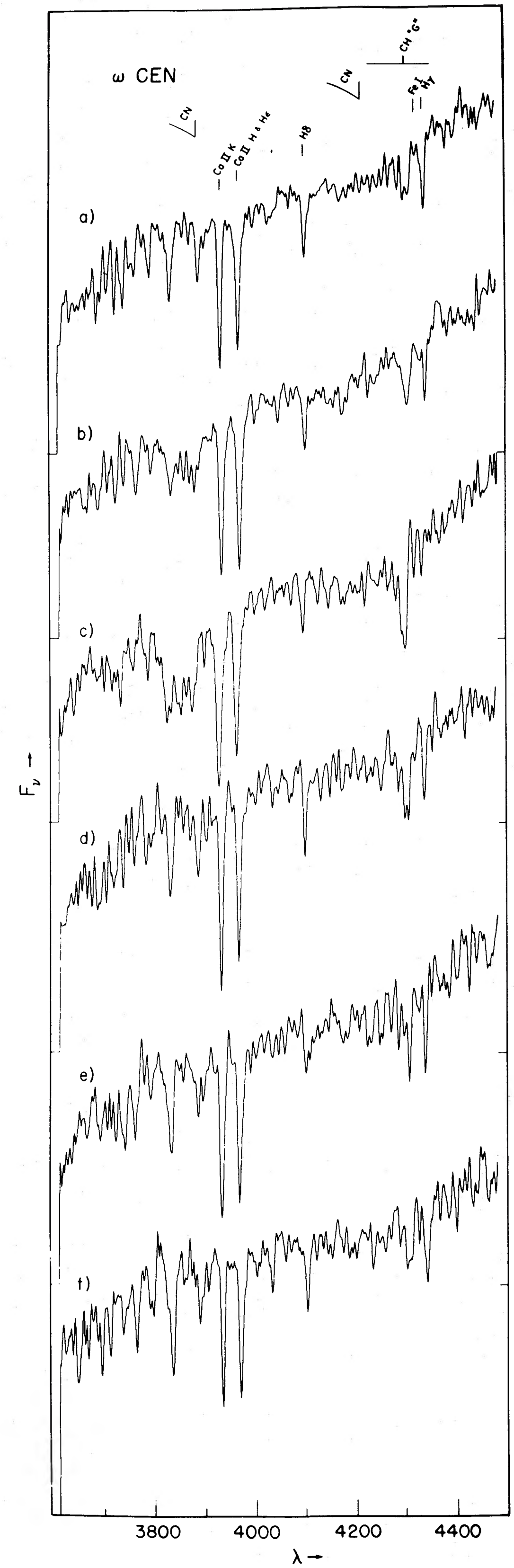


FIG. 2.—Spectra for the stars found to be radial velocity members of the cluster. (*a*) CS 22-52. (*b*) CS 11-57. (*c*) CS 13-35. (*d*) CS 13-53. (*e*) CS 32-48. (*f*) CS 23-42. The wavelength scale is approximate. When available, the summed spectra are plotted. The positions of a few strong spectral features are indicated.

of Cannon and Stewart (1981) may include a high percentage of field stars.

b) *Appearance of the Spectra*

Spectra for the probable cluster member stars, shown in Figure 2, suggest several important results. Comparison of the spectra of CS 13-53 and CS 13-35, for instance, suggest the presence of a range of temperature and/or abundances among the stars. The spectral differences in these two stars correlate with the measured colors (cf. Table 1), indicating that the broad-band photometric results are detecting real color differences between stars at the same apparent magnitude on the lower subgiant branch, and not merely scatter due to observational errors. The suggestion that a range of metallicities may also be present leads us to evaluate the relative roles of temperature, gravity, and abundances by comparison of the observed spectra with synthetic spectra.

IV. ANALYSIS OF STELLAR SPECTRA

a) *Synthetic Spectra Calculations*

The general methods used to analyse the spectra closely followed those used elsewhere (Bell, Dickens, and Gustafsson 1979; Hesser and Bell 1980). The procedure begins with the derivation of effective temperatures and gravities for the stars.

A number of model stellar atmospheres for dwarf stars have been computed by Gustafsson, Eriksson, and Bell (1981), using the methods and programs of Gustafsson *et al.* (1975), with colors and synthetic spectra computed using the methods of Bell and Gustafsson (1978). We computed the absolute bolometric magnitudes of a number of models from the equation

$$M_{\rm bol}=4.72+2.5[g]-10[T_{\rm eff}]-2.5[m],$$

with g, $T_{\rm eff}$, and m being surface gravity, effective temperature, and mass, respectively, and with a mass of $0.8m_{\odot}$ being used. Model bolometric corrections were applied to $M_{\rm bol}$ and theoretical $(M_V, B-V)$ diagrams plotted for [A/H]$=-0.5$, -1.0, and -2.0, A denoting overall metal abundance.

The stellar photometry was corrected for interstellar reddening using $E(B-V)=0.14$ mag and the reddening-corrected apparent magnitudes converted to absolute magnitudes using the distance modulus $V_0-M_V=13.5$ mag (Cannon 1974). The resultant $[M_V,(B-V)_0]$-values were then compared with the theoretical diagrams to deduce $(T_{\rm eff}, \log g)$ values for the stars for [A/H]$=-0.5$, -1.0, and -2.0. The values obtained are given in Table 2.

Models with slightly different $(T_{\rm eff}, \log g)$ values were actually used to analyze each star, these changes being made to minimize the number of new models needed.

TABLE 2

TEMPERATURES AND GRAVITIES OF OMEGA CENTAURI STARS AND MODELS FOR DIFFERENT ASSUMED ABUNDANCES

	Stellar Values		Adopted Model	
Star $T_{\rm eff}$	log g	$T_{\rm eff}$	log g	$T_{\rm eff}$
Abundance [A/H]$=-0.5$				
CS 22-52	5750	3.2	5750	3.0
CS 11-57	5500	3.4	5500	3.75
CS 13-35	5500	3.6	5500	3.75
CS 13-53	5800	3.9	5750	3.75
CS 32-48	5500	3.7	5500	3.75
CS 23-42	6000	3.9	6000	3.75
Abundance [A/H]$=-1.0$				
CS 22-52	5650	3.3	5650	3.0
CS 11-57	5400	3.3	5500	3.0
CS 13-35	5300	3.6	5250	3.75
CS 13-53	5650	3.7	5650	3.75
CS 32-48	5400	3.7	5500	3.75
CS 23-42	5750	3.9	5750	3.75
Abundance [A/H]$=-2.0$				
CS 22-52	5500	3.1	5500	3.0
CS 11-57	5250	3.3	5250	3.0
CS 13-35	5200	3.6	5250	3.75
CS 13-53	5500	3.7	5500	3.75
CS 32-48	5250	3.6	5250	3.75
CS 23-42	5500	3.8	5500	3.75

The new models were computed using the methods and programs of Gustafsson *et al.* (1975), and colors and synthetic spectra were computed for these models. The spectra covered the wavelength interval 3700–4600 Å with a resolution of 0.1 Å. In the initial calculations, the abundances of all elements were varied in unison and a Doppler broadening velocity of 2 km s^{-1} was used.

Prior to comparison with the observations, the synthetic spectra were convolved with an instrumental profile of the form $\exp(-|\Delta\lambda|/3.0)$, which has a FWHM of 4 Å. The observed spectra were placed on an approximate relative flux scale through the use of flux standard stars. However, the narrow spectrograph slit plus seeing effects, guiding errors and differential refraction can result in errors in this procedure. Moreover, the fluxes of the flux standard stars are known only at relatively widely separated wavelengths. For these reasons, we did not attempt to place the calculated spectra on a similar flux scale but simply scaled the computed continuum height before plotting. Before discussing the comparison of the observed and synthetic spectra, we will describe some of the properties of the latter.

In the synthetic spectra computed for [A/H]$=-2.0$, the most prominent features at our 4 Å resolution are the hydrogen lines, the G band, Ca II H and K, a feature at ~3830 Å due to Fe I and Mg I and some metal lines such as λ4325 of Fe I. With decreasing $T_{\rm eff}$, and with increasing log g, the G band strengthens but the other features change by negligible amounts. A similar change occurs for the [A/H] = −1.0 models, but with the [A/H] = −0.5 models the change of the G band with gravity is small and a general increase in metal line absorption occurs with decreasing $T_{\rm eff}$. More metal lines, e.g., λ 4226 of Ca I, can be seen in these more metal rich models.

b) *Comparison of Observed and Synthetic Spectra*

A comparison of some observed and computed spectra is given in Figures 3*a* and 3*b* so the reader may judge the quality of the fits, while comments on the individual comparisons are given below.

CS 11-57. The 3830 Å feature, the H and K lines, and the Ca I λ 4226 and FE I λ4325 lines are stronger in the spectrum of the model 5500/3.0/−0.5 ($T_{\rm eff}$/log g/[A/H]) than they are in the stellar spectrum. The [A/H] = −1.0 model gives a good fit at 3830 and to H and K. The computed G band is, however, too strong. The H and K lines in the [A/H] = −2.0 model are, of course, too weak, while the G band gives a good fit. The general line absorption appears weaker in this model than it does in the star, but some of this effect may be due to noise in the observations. On the basis of these comparisons, we have tentatively adopted [M/H] ≈ −1.5 for all metals, but the possibility that the carbon abundance is lower and the overall metal abundance higher cannot be ruled out. We shall return to the question of the carbon abundance and G band strength at the end of this section.

CS 13-53. The star is about 200 K hotter than CS 11-57. The [A/H] = −1.0 model gives a good fit to most spectral features, but the computed G band is too strong. The G band and H and K lines of the [A/H] = −2.0 model are too weak. An overall abundance of [M/H] ≈ −1.3 seems the best estimate, but carbon depletion cannot be excluded. The observed spectrum is compared with spectra of the models 5500/3.75/−1.0 and 5500/3.75/−2.0 in Figure 3*a*.

CS 22-52 is another very metal poor star. Comparison of spectral features, except for the G bands, with the models again suggests [M/H] ≈ −1.5. The G band is as weak in the star as it is in the [A/H] = −2.0 model, suggesting likely carbon depletion.

CS 32-48 has a temperature that is uncertain since the $B-V$ color may be affected by the presence of a close companion. The hydrogen lines are certainly weaker in the model spectra than they are in the stellar spectrum. The suggested abundance is [M/H] ≈ −1.5 with greater uncertainty than for the other stars.

CS 13-35 is the reddest star and seems significantly more metal rich than all the others in the sample, judging from the overall fit of the spectra. The 3830 Å feature, H and K lines, and the G band are fitted quite well by the 5500/3.75/−0.5 model. The fit of λ4325 of Fe I, and λ4226 of Ca I is also good, and the observed and computed Balmer lines agree. However, it appears from the CN features than N is overabundant; this is discussed below. The stellar spectrum is compared with model spectra in Figure 3*b*.

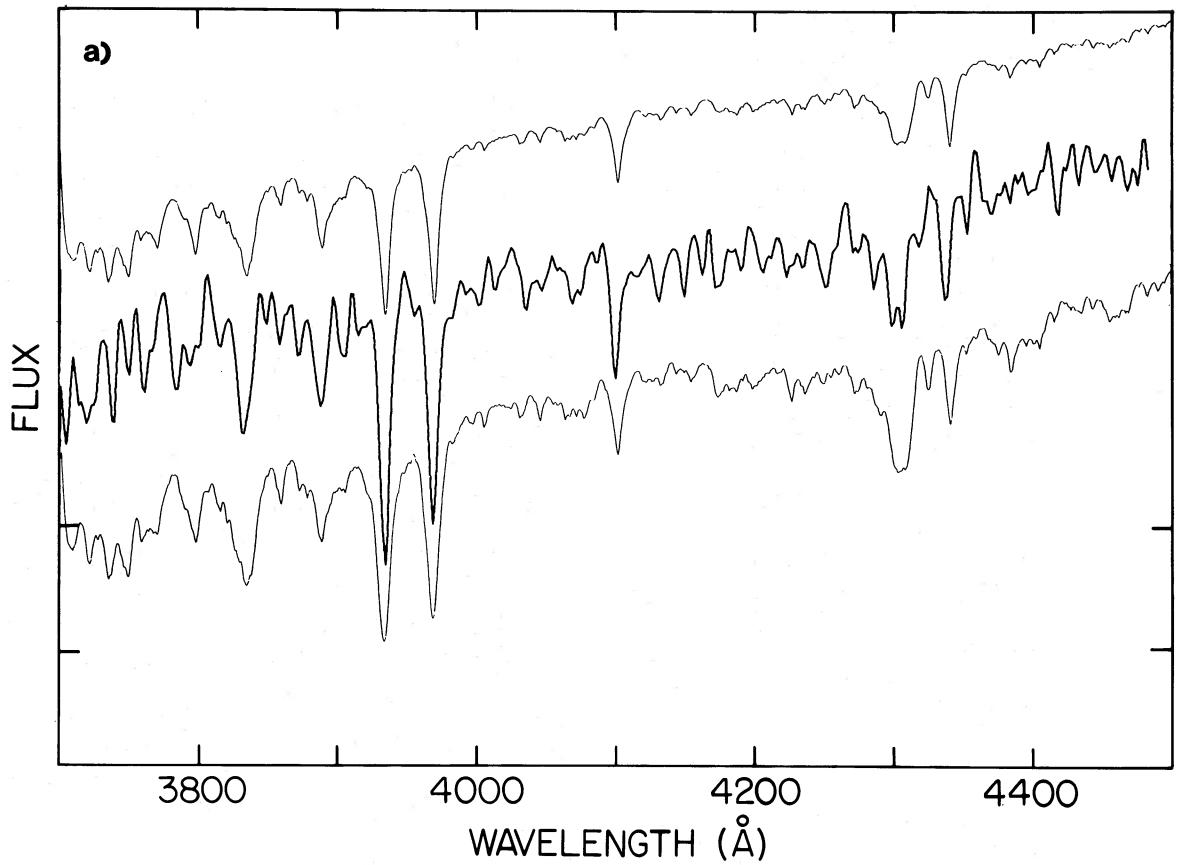
CS 23-42 has H and K lines and Balmer lines definitely stronger than those of the model 5500/3.75/−2.0. However, the G band of this model fits the observed G band quite well. The spectrum of the model 5750/3.75/−1.0 seems a better fit to the observations than does 6000/3.75/−0.5.

In addition to estimating the overall metal abundance by comparing the fit of the observed and computed spectra over the wavelength interval 3700–4600 Å, we also measured the combined pseudo-equivalent widths of the H and K lines in both sets of spectra. We refer to these measurements as pseudo-equivalent widths since the continuum level is, of course, unknown and we simply measure the area of the profiles between 3914 and 3992 Å. These results are: CS 23-42 and CS 22-52, [M/H] ≈ −1.5; CS 11-57 and CS 32-48, [M/H] ≈ −1.0; CS 13-35, [M/H] ≈ −0.5. The results for these five stars are generally consistent with the previous discussion, but some difference is found for CS 13-53. In this case we find [M/H] ≈ −0.7, somewhat higher than the value found by inspection of the spectra. We have adopted the average value, [M/H] ≈ −1.0, as the abundance for this object. Note that we have neglected the effect of the interstellar Ca II contribution to the observed pseudo-equivalent widths but we assume, following Manduca and Bell (1978), that this is unlikely to cause us to overestimate [M/H] by more than 0.1.

In view of the possibility that the star CS 13-35 might exhibit an overabundance of nitrogen and that it and other stars might be depleted in carbon, a number of additional spectra were computed.

Spectra of the model 5500/3.75/−0.5, computed for nitrogen abundances of [N/A] = 0.0, 0.3, 0.5, and 1.0, are shown in Figure 4 for the spectral region 3750–3900 Å. Comparison of spectra of CS 13-35 with these calculations show that the best fit is obtained for [N/A] = +0.5. While experience with the accuracy of such comparisons is limited, the reproducibility of strong features in the observational data is quite satisfactory as shown in the individual spectra plotted by Hesser and Harris (1981).

Similar calculations for the G band region, for [C/A] = 0.0, −0.5, and −1.0, are shown for the model 5650/3.75/−1.0 in Figure 5. If overall metal abundance is known, it should be possible to identify carbon-depleted stars. In view of this, comments on the strength of the G band in the individual spectra have been made earlier. Comparison of the data of Figure 5 with spectra of CS 11-57 does bear out earlier comments, that if CS 11-57 does have [M/H] ≈ −1.0, the observed G band is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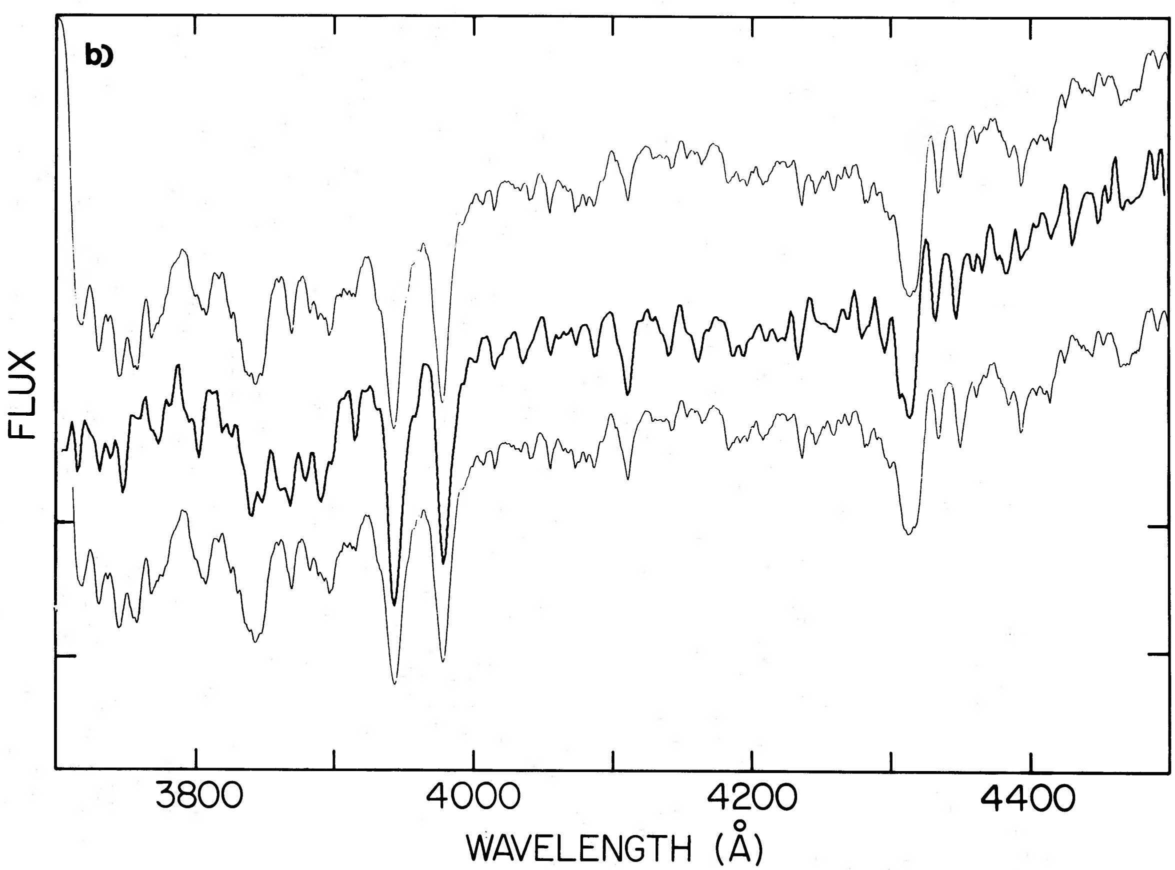
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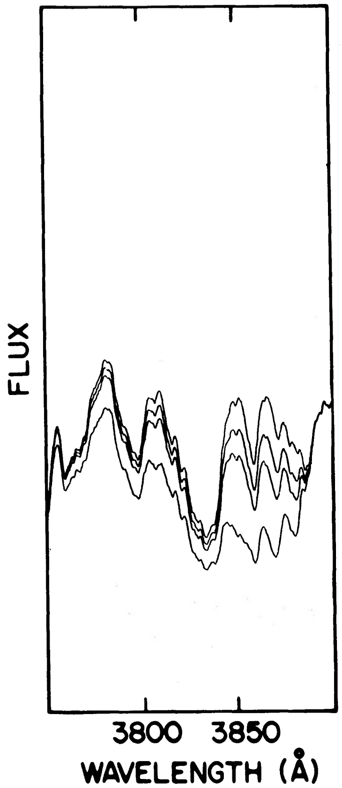

FIG. 4

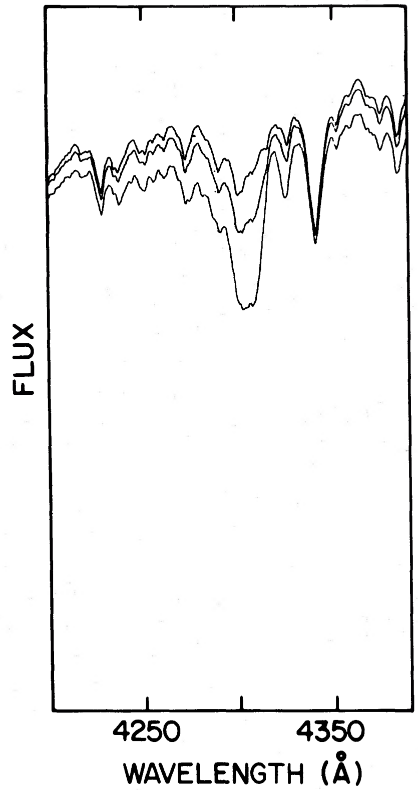

FIG. 5

FIG. 4.—Spectra of the model 5500/3.75/−0.5 are shown for the region of the violet CN $\Delta v=0$ sequence. The spectra have been computed with four different values of the nitrogen abundance, viz., [N/A]=0.0, 0.3, 0.5 and 1.0. The zero level of the flux is the horizontal axis.

FIG. 5.—Spectra of the model 5650/3.75/−1.0 are shown for the region of the G band. These spectra have been computed for [C/A]=0.0, −0.5, and −1.0. The zero level of the flux is the horizontal axis.

weaker than that of the model. Even if the metal abundance is [M/H]≈−1.5, the carbon may be depleted. Similar calculations for CS 13-35 show that carbon cannot be depleted by as much as [C/A]=−0.5, but a more modest depletion cannot be ruled out.

V. RESULTS AND DISCUSSION

The basic results for the six faint subgiant cluster members are as follows:

1. The range of $B-V$ color in the C-M diagram is real. However, the majority of the stars in our original sample on the redward side of the lower subgiant branch are field stars.

2. Five of the six members have [M/H]≈−1.2, with the possibility or even likelihood that carbon is depleted. Their overall metal abundance lies in the range found from the analysis of RR Lyrae stars and giant stars. No results are currently available for the carbon abundance in the evolved stars.

3. The reddest star which is believed to be a member, CS 13-35, has the relatively high overall metal abundance of [M/H]≈−0.5. Such a high abundance is not unknown in ω Cen (one RR Lyrae star has this abundance), but it is rare. The nitrogen overabundance of about a factor of 3 is, if real, smaller than that found for the ω Cen giants by Dickens and Bell (1976).

There are at least four possible ways in which these results can have arisen. These are: differences in stellar abundances at the time of star formation (the primordial hypothesis), mixing of the stars during their evolution, accretion of material lost by the single evolving stars, and accretion of material lost by a binary companion. These possibilities are discussed below.

FIG. 3.—(*a*) The spectrum of the star CS 13-53 (*center thick line*) is compared with that of the models 5500/3.75/−1.0 and 5500/3.75/−2.0 (*lower and upper thin lines*, respectively). The zero levels for the upper two spectra are marked. (*b*) As in Fig. 3*a*, the star being CS 13-35 and the models being 5250/3.75/−1.0 and 5500/3.75/−0.5 (*upper and lower*, respectively).

a) *The Primordial Hypothesis*

It is generally believed that the range in calcium and iron abundances seen in the evolved stars in ω Cen is primordial in origin—the stars were formed with different abundances, the elements being formed in supernova explosions of massive stars. It is to be expected that the calcium and iron abundances in less evolved stars should show a similar range, and our observations of faint subgiants within 0.7 mag of the main sequence suggest that they do. Our present results, with five stars having $[M/H] \leq -1.0$ and only one having a higher value, are in fact consistent with results inferred from V, $B-V$ for dwarfs (Cannon and Stewart 1981), and from spectra of RR Lyrae variables (Manduca and Bell 1978) and giants (Mallia and Pagel 1981). We have not observed enough stars to study the problem of a possible radial gradient in stellar metallicity or to investigate whether the relative numbers of giants and dwarfs with the same Ca and Fe abundances are the same.

In contrast to the heavier elements, nitrogen is believed to be produced by CNO processing and not in supernova explosions. Since the main contributors are believed to be stars of 1–2.5 $m_{\odot}$ (Edmunds and Pagel 1978), it seems unlikely that the strong CN bands seen in the star CS 13-35 and in main sequence stars in 47 Tuc (Hesser and Bell 1980) can be due to a primordial enhancement of nitrogen. However, if star formation has occurred after the initial cluster collapse, it is possible that such stars have been formed from gas which has been enriched in nitrogen through material being lost by evolving stars, particularly red giants and novae. It is observationally difficult, if not impossible, to distinguish such low mass stars from those of the original collapse using currently available color-magnitude diagrams, since the resulting stellar structure changes are small (Rood 1981).

b) *The Mixing Hypothesis*

Transport of material processed in the CNO cycle to the surface of a star will result in the enhancement of the surface nitrogen abundance and the depletion of the surface carbon and, possibly, oxygen abundances. The suggestion of Sweigart and Mengel (1979) that meridional circulation currents could act as the means of transport offers a mechanism by which the mixing may occur. The mechanism seems plausible since it predicts carbon depletion will occur at an M_V equal to that at which carbon depletion is seen in M92 and NGC 6397 (Bell, Dickens, and Gustafsson 1979).

It is much more difficult to explain the strong CN seen in CS 13-35 and the 47 Tuc main sequence stars by the mixing hypothesis. These stars have not yet produced enough nitrogen to cause the enhanced surface abundance and are, furthermore, too faint for the meridional circulation method to work.

Schatzman (1977, 1978) and Genova and Schatzman (1979) have suggested that mixing in stars near the main sequence can be caused by a process of turbulent diffusion, occurring in regions in radiative equilibrium. This concept does offer, for example, an explanation for the very low $^{12}C/^{13}C$ ratio seen in the Population I subgiant γ Cep (Lambert and Ries 1981). We cannot exclude the operation of this mechanism in CS 13-35. However, no physical theory of this turbulence exists. Moreover, there still remains the difficulty that enhancement of the surface cyanogen and hence nitrogen by a factor of 3 requires the mixing of more nitrogen than has been produced by the CNO nuclear reactions (Sweigart, private communication) since ON processing will have reached equilibrium in only the central 15% of the star. A major part of the surface N must come from this reaction rather than from carbon since the G band is not appreciably weakened. Any decrease in carbon abundance would also require an even greater enhancement of nitrogen to maintain the observed cyanogen strength.

c) *The Accretion Hypothesis*

A ready source of the excess nitrogen in subgiant and main sequence stars may be the red giant stars, many of which are known to have enhanced nitrogen, accompanied by a depletion of carbon. Any material lost by these stars which is deposited on the cluster dwarf stars will increase their surface nitrogen abundance and decrease their surface carbon abundance. The abundances of other elements will not be affected. Is it feasible that the subgiants have changed their surface composition by accretion?

Presumably the mass that it is necessary for a subgiant ($M_V \sim 3.0$) to accrete in order for its surface composition to be changed is of the order of the mass of the convective envelope. This mass varies with the overall mass and evolutionary phase of the star. For a model with $m=0.9$ $m_{\odot}$, helium content $Y=0.30$, and metal content $Z=0.001$, the calculations of Mengel *et al.* (1979) show that the convective envelope mass is 3×10^{-5} $m_{\odot}$ when the model is on the main sequence, decreases to 4×10^{-6} $m_{\odot}$ at $M_V \sim 3.5$, and then increases, becoming 10^{-5} $m_{\odot}$ at $M_V \sim 3.0$ and $0.5 m_{\odot}$ at $M_V \sim 2.7$. A 0.7 $m_{\odot}$ model has a more massive envelope, the minimum mass being 1.5×10^{-3} $m_{\odot}$. Tayler and Wood (1975) have shown that if 0.2 $m_{\odot}$ is lost by each star on the first ascent of the giant branch, then in each 10^8 years between passages through the galactic disk, 400 $m_{\odot}$ are shed by ω Cen giant stars. Presumably this material will be rich in nitrogen since many red giants have high nitrogen abundances in their atmospheres (Dickens and Bell 1976). Thus, were none of the stellar wind ejecta lost from the cluster, each cluster star could, in principle, accrete $\sim 4\times10^{-4}$ $m_{\odot}$ each 10^8 years, since the 47

Tuc cluster mass of 10^6 $m_\odot$ (Illingworth 1976) implies that there are roughly 10^6 stars in the cluster. The rate of accretion of mass by a star is given by $dm/dt = 4\pi G^2 m^2 \rho / v^3$ (McCrea 1975), where ρ is the density of interstellar material and v the velocity of the star relative to the gas. If we adopt a value of 1 $m_\odot$ for the current gas content of a globular cluster (Hesser and Shawl 1977; Schneps *et al.* 1978; Bowers *et al.* 1979) and assume the star is moving at 5 km s^{-1} relative to the gas, the mass accreted in a cluster lifetime of 10^{10} years is about 10^{-7} $m_\odot$, smaller than the mass of the convective envelope.

However, it seems unlikely that the cluster gas is distributed uniformly. If a star should be moving slowly in a region where the gas density is high, such as in the shell of material recently lost from a red giant, it seems conceivable that a mass of, say, 10^{-3} $m_\odot$ could be accreted.

In view of the uncertainty in the accretion rate, it is not possible to argue that the excess nitrogen in some subgiants, in both ω Cen and 47 Tuc, has resulted from accretion. Nevertheless, since the red giants are such a ready source of nitrogen and the material is desposited on the stellar surface thereby avoiding the mixing problem, the possibility seems worthy of further study. This is particularly true in view of the related problem that the interstellar mass observed in globular clusters is very low compared to that believed lost by the red giants. However, the increase in mass of the convective envelope with increasing luminosity does suggest that it is difficult for accretion to affect the composition of cluster stars with M_V of $+1$ or $+2$. Such stars have been observed to have variations in CN strength in 47 Tuc by Hesser (1978) and by us in NGC 288 and NGC 6752.

d) *Binary Star Accretion*

If CS 13-35 is a member of a binary system, with its companion being a white dwarf or a neutron star, it could easily have accreted material by Roche lobe overflow from the companion during its previous existence as a red giant. Unfortunately it seems impossible to check if CS 13-35 is a member of a binary system—eclipses will not be observable if the companion is a degenerate star, and our radial velocity observations are not precise enough to detect binary motion. McClure, Fletcher, and Nemec (1980) have found that Population I Ba II stars are binaries and suggest that CH stars may also be. In addition to six CH stars, stars with strong Ba II lines (e.g., RGO 371, Dickens and Bell 1976) are known in ω Cen and thereby indicate binary stars may be present. Observational evidence for the existence of binary stars in ω Cen is contradictory. Liller (1979) found no definite evidence for the existence of binaries whereas Niss, Jørgensen, and Lautsen (1978) conclude that between 0.6% and 6.0% of the giant stars have giant star companions. The likelihood of a subgiant having a degenerate companion seems greater than this latter estimate, owing to the larger number of possible progenitors, so it is not impossible that CS 13-35 is either a binary star now or has been a member of a binary system in the past.

Clarification of the origin of the spectral differences detected during this initial spectroscopic survey of faint ω Cen stars justifies observations of the highest possible signal-to-noise ratio for a larger sample of subgiant and upper-main-sequence stars, and we are planning to secure such data.

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