Chemical abundance analysis of the open clusters Berkeley 32, NGC 752, Hyades, and Praesepe

R. Carrera1,2,3,4 and E. Pancino3

1 Instituto de Astrofísica de Canarias, La Laguna, Tenerife, Spain
e-mail: rcarrera@iac.es
2 Departamento de Astrofísica, Universidad de La Laguna, Tenerife, Spain
3 INAF-Osservatorio Astronomico di Bologna, Bologna, Italy
4 Centro de Investigaciones de Astronomía, Mérida, Venezuela

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ABSTRACT

Context. Open clusters are ideal test particles for studying the chemical evolution of the Galactic disc. However, the number and accuracy of existing high-resolution abundance determinations, not only of [Fe/H], but also of other key elements, remains largely insufficient.

Aims. We attempt to increase the number of Galactic open clusters that have high quality abundance determinations, and to gather all the literature determinations published so far.

Methods. Using high-resolution (R ≈ 30000), high-quality (S/N ≥ 60 per pixel), we obtained spectra for twelve stars in four open clusters with the fibre spectrograph FOCES, at the 2.2 Calar Alto Telescope in Spain. We employ a classical equivalent-width analysis to obtain accurate abundances of sixteen elements: Al, Ba, Ca, Co, Cr, Fe, La, Mg, Na, Nd, Ni, Sc, Si, Ti, V, and Y. We derived oxygen abundances derived by means of spectral synthesis of the 6300 Å forbidden line.

Results. We provide the first determination of abundance ratios other than Fe for NGC 752 giants, and ratios in agreement with the literature for the Hyades, Praesepe, and Be 32. We use a compilation of literature data to study Galactic trends of [Fe/H] and [α/Fe] with Galactocentric radius, age, and height above the Galactic plane. We find no significant trends, but some indication for a flattening of [Fe/H] at large $R_{gc}$, and for younger ages in the inner disc. We also detect a possible decrease in [Fe/H] with $|z|$ in the outer disc, and a weak increase in [α/Fe] with $R_{gc}$.

Key words. Stars: abundances – Galaxy: disc – Galaxy: open clusters and associations: individual: NGC 752; Hyades; Berkeley 32; Praesepe (M 44)

1. Introduction

Open clusters (hereafter OC) are ideal test particles for studying the evolution of metallicity with time, inferring the so-called age-metallicity relation, and with Galactocentric radius, the metallicity gradient, measuring in the Galactic disc. Their properties can be determined with smaller uncertainties than for field stars, since they are coeval group of stars at the same distance that have a homogeneous chemical composition. Unfortunately, of the ≈ 1700 known OC (e.g. Dias et al., 2002), only ≈ 140 possess some metallicity determination, mostly obtained from photometric indicators, such as Washington or Strömgren photometry (e.g. Twarog et al., 1997; Chen et al., 2003, and references therein) and low-resolution spectroscopy (e.g. Friel & Janes, 1993; Friel et al., 2002).

The most accurate way to determine the chemical abundances is to analyse high-resolution spectroscopy. It allows us to investigate not only metallicity, but also abundance ratios – with respect to iron or hydrogen – of other chemical species such as $\alpha$-elements, s-process elements, and r-process elements, which are synthesised in different environments and on different timescales (e.g. SNe Ia, SNe II, giants, supergiants, etc). In the past few years, a number of research groups have addressed the challenge of increasing the number of OC with chemical abundances determined from high-resolution spectroscopy (e.g. Sestito et al., 2004, D’Orazi et al., 2006, Sestito et al., 2006, Bragaglia et al., 2008, Pace et al., 2008, D’Orazi et al., 2009, Friel et al., 2010, Pace et al., 2010, Pancino et al., 2010a, Jacobson et al., 2011). However, the number of OC with chemical abundances determined with this technique is still small (see Section 5), and significant uncertainties remain in the determinations of both the metallicity gradient and the age-metallicity relation, which are the fundamental ingredients of chemical evolution models.

In this paper, the second of a series initiated by Pancino et al. (2010a, hereafter Paper I), we present high quality and homogeneous measurements of chemical abundances for red clump stars in four OC: Be 32, NGC 752, Hyades, and Praesepe. The Hyades is the nearest OC and its four known red giants have been widely studied (Schuler et al., 2009, Mishenina et al., 2007, Fulbright et al., 2007, Schuler et al., 2006, Mishenina et al., 2006, Bovarchuk et al., 2003, Luck & Challenger, 1995), hence it provides a very good reference frame to compare our abundances with the literature. Both NGC 752 and Praesepe have been well-studied, but all information about their chemical
Table 1. Observing logs and programme star properties.

| Cluster | Star | $\alpha_{2000}$ (hrs) | $\delta_{2000}$ (deg) | B (mag) | V (mag) | R (mag) | $K_s$ (mag) | $n_{exp}$ | $t_{exp}$ (sec) | S/N$^a$ |
|---------|------|----------------------|----------------------|---------|---------|---------|------------|----------|-------------|---------|
| Be 32$^c$ | 0456  | 06:58:08.2           | +06:24:19.6          | 14.76   | 13.67   | —       | 12.53      | 11.03    | 7           | 18900   | 60        |
|         | 1948  | 06:58:04.2           | +06:27:17.1          | 14.50   | 13.37   | —       | 12.20      | 10.68    | 6           | 16200   | 70        |
| NGC 752$^c$ | 001  | 01:55:12.6           | +37:50:14.6          | 10.47   | 9.51    | —       | 7.23       | 4        | 2400      | 160     |
|         | 028   | 01:57:37.6           | +37:39:38.1          | 10.04   | 8.97    | —       | 6.41       | 4        | 2400      | 180     |
|         | 213   | 01:57:38.9           | +37:46:12.5          | 10.08   | 9.07    | —       | 6.68       | 3        | 1800      | 80      |
|         | 311   | 01:58:59.2           | +37:48:57.3          | 10.11   | 9.07    | —       | 6.64       | 4        | 2400      | 100     |
| Hyades$^d$ | 028 (y tau) | 04:19:47.6       | +15:37:39.5          | 4.64    | 3.65    | 2.92    | 2.45       | 1.52     | 2        | 120     | 560      |
|         | (Mel 25) | 041 (d tau) | +17:32:33.0          | 4.75    | 3.76    | 3.03    | 2.56       | 1.64     | 3        | 180     | 450      |
|         | 070 (e tau) | 04:28:37.0    | +19:10:49.5          | 4.55    | 3.54    | 2.81    | 2.31       | 1.42     | 3        | 180     | 270      |
| Praesepe$^e$ | 212   | 08:39:50.7           | +19:32:27.0          | 7.53    | 6.58    | 5.87    | 5.38       | 4.39     | 4        | 240     | 165      |
|         | (NGC 2632) | 253      | 08:40:06.4           | 7.35    | 6.38    | 5.67    | 5.20       | 4.20     | 4        | 240     | 215      |
|         | (M 44) | 283      | 08:40:22.1           | 7.42    | 6.41    | 5.68    | 5.21       | 4.18     | 2        | 120     | 150      |

$^a$ All I magnitudes are in the Johnson system (I$_c$) with the exception of those of the Be 32 stars which are in the Cousins system (I$_{c'}$).
$^b$ Star names from Richtler & Sagar (2001); Coordinates, B, V & I$_c$ magnitudes from D'Orazi et al. (2006); $K_s$ magnitudes from 2MASS.
$^c$ Star names from Heinemann (1926); Coordinates from Høg et al. (2000); B & V magnitudes from Jennens & Helfer (1975); $K_s$ magnitudes from 2MASS.
$^d$ Star names from van Bueren (1952); Coordinates from Perryman et al. (1997); B, V, R & I$_c$ magnitudes from Johnson et al. (1966); $K_s$ magnitudes from 2MASS.
$^e$ Star names from Klein Wassink (1927); Coordinates from Perryman et al. (1997); B, V & R magnitudes from Coleman (1982); I$_c$ magnitudes from Mendoza (1967); Johnson et al. (1966). $K_s$ magnitudes from 2MASS.

The properties and previous studies of each cluster are described in more depth in Section 4.

To our knowledge, there have been no recent measurements of the chemical abundance of their giants from high-resolution spectroscopy. Finally, Be 32 has been the subject of some studies (e.g. Pace et al., 2008; An et al., 2007; Sestito et al., 2004; Briquet et al., 1998) attached at the 2.2 m Calar Alto Telescope (Almería, Spain) between the 1 and 3 of January 2005. The chosen set-up provides a spectral resolution ($R$ = $\lambda$/840 Å) of about 30000. In summary, all stars were observed in 2–7 exposures lasting 10–30 min each, depending on their magnitudes, until a global signal-to-noise ratio (S/N) of at least 60 per pixel was reached around 6000 Å. Exposures with S/N < 20 were neglected because they were too noisy. Finally, sky exposures as long as our longest exposures (30 min) were taken, but the levels were sufficiently low for us to avoid sky subtraction (as in Paper I). The number of useful exposures, the total integration time, and the global S/N for each star are listed in the last three columns of Table 1.

2. Observational material

A total of twelve stars spread in the four OC were observed. They were selected from the WEBDA database (Mermilliod, 1995), and the 2MASS $^1$ database (Cutri et al., 2003). The same two hot, rapidly rotating stars, HR 3982 and HR 8762, of Paper I were used. The strong telluric bands around 7600 Å had been saturated and therefore could not be properly removed. This spectral region was not used for the abundance analysis, in addition to the small gaps between echelle orders that appeared after $\lambda$ ≃ 8400 Å.

Before combining all exposures of each star, we removed sky absorption features (telluric bands of O$_2$ and H$_2$O) with the help of the IRAF $^3$ tasks ccdproc and apflatten. The spectra were then extracted, wavelength-calibrated, normalized, and the echelle orders were merged using tasks in the IRAF echelle package. Finally, the noisy ends of each combined spectrum were cut, allowing for an effective wavelength coverage from 5000 to 9000 Å.

2.2. Radial velocities

We used DAOESPEC (Stetson & Pancino, 2008) to measure the observed radial velocities for each individual exposure with 1 Image Reduction and Analysis Facility, IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

1 http://www.univie.ac.at/webda
2 http://www.ipac.caltech.edu/2mass
3 All Sky Survey is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.
S/N\geq 20, using \approx 300 absorption lines of different elements, with typical uncertainties of about 0.1 km s^{-1} (see Paper I for details). We used the same linelist as the one used for abundance determinations (see Section 3 for details). Heliocentric corrections were obtained with the IRAF task r\text{correct}, with a negligible uncertainty of smaller than 0.005 km s^{-1}

dance determinations (see Section 3 for details). Heliocentric velocities resulting from each exposure of the same star, are listed in Table 2. Our determinations are generally in close agreement with literature values to within 3\sigma, except for star 208 in NGC 752, which has a slightly smaller44 radial veloc-

ty than other objects in this cluster. The fact that this star was recognised as a spectroscopic binary (see Paper I for details). Mermilliod et al. (2007) explains the disagreement. According to its radial velocity curve (Mermilliod et al., 2007), we observed this binary near minimum, which implies that we observed only one of the components of the system. For this rea-

### Table 2. Heliocentric radial velocity measurements and 1\sigma errors (\(V_r \pm \delta V_r\)) for each programme star. Literature measurements are also reported with their uncertainties (\(V_r \pm \sigma V_r\)).

| Cluster      | Star | \(V_r \pm \delta V_r\) (km s^{-1}) | \(V_r \pm \sigma V_r\) (km s^{-1}) |
|--------------|------|----------------------------------|---------------------------------|
| Be 32        | 0456 | 105.59\pm 0.54                   | 110.0\pm 1.2                   |
|              | 1948 | 104.78\pm 0.35                   | 105.5\pm 4.9                   |
| NGC 752c     | 001  | 5.49\pm 0.44                     | 4.79\pm 0.15                   |
|              | 208  | 1.10\pm 0.23                     | 4.86\pm 0.06                   |
|              | 213  | 5.11\pm 0.42                     | 5.50\pm 0.10                   |
|              | 311  | 6.00\pm 0.30                     | 5.28\pm 0.08                   |
| Hyadesd      | 028  | 38.15\pm 0.43                    | 39.28\pm 0.12                  |
|              | 041  | 38.56\pm 0.36                    | 39.65\pm 0.08                  |
|              | 070  | 38.26\pm 0.35                    | 39.37\pm 0.07                  |
| Praesepe\_NGC 2632 | 212  | 35.96\pm 0.36                    | 34.81\pm 0.21                  |
|              | 253  | 34.39\pm 0.27                    | 33.67\pm 0.22                  |
|              | 283  | 34.67\pm 0.39                    | 34.35\pm 0.20                  |

\(a\) D'Orazi et al. (2008).
\(b\) Mermilliod et al. (1998).
\(c\) Spectroscopic binary according to Pourbaix et al. (2004).
\(d\) Griffin et al. (1988).
\(e\) Famaey et al. (2005).

2.3. Photometric parameters

First guesses of the atmospheric parameters effective temperature (\(T_{\text{eff}}\)), logarithmic gravity (\(\log g\)), and microturbulent velocity (\(v_t\)), for our target stars were derived from a photometric data listed in Table 3 as described in Paper I. In brief, \(T_{\text{eff}}\) were obtained using the Alonso et al. (1999) and Montegriffo et al. (1998) colour-temperature relations, both theoretical and empirical, and the reddened colours (B-V)_0, (V-J)_0, and (V-K_s)_0. We assumed the E(B-V) values listed in Table 3 and the reddening laws of Cardelli et al. (1989). In the case of Be 32, we have I_c magnitudes instead of I_0 ones, so we reddened (V-I_c) with the law of Dean et al. (1978), and converted it into (V-I_0) with the transformations by Bessell (1979). The 1\sigma errors in each \(T_{\text{eff}}\) estimate were computed using the magnitude and reddening uncertainties together with the standard deviation in the colour-temperature relationships used. The photometric \(T_{\text{eff}}\) estimates, listed in Table 4 are the weighted mean of the different values obtained from each considered colour and colour-temperature relations.

Photometric gravity estimates were derived from the above \(T_{\text{eff}}\) and the bolometric corrections, BC_g, derived using the Alonso et al. (1999) prescriptions and the fundamental relationships

\[
\log \frac{g}{g_0} = \log \frac{M}{M_0} + 2 \log \frac{R}{R_0}.
\]
Table 3. Adopted cluster parameters. When more than one determination exists, the average is shown with 1 σ errors.

| Cluster | (B−V) | (m-M)₀ | Age (Gyr) |
|---------|-------|--------|-----------|
| Be 32   | 0.15±0.05 | 12.62±0.18 | 4.8±1.5 |
| NGC 752 | 0.03±0.002 | 8.04±0.23 | 1.59±0.45 |
| Hyades  | ≤0.001   | 3.34±0.01   | 0.70±0.07 |
| Praesepe| 0.027±0.004 | 6.22±0.02 | 0.65±0.25 |

a. Averages of measurements by Kaluzny & Mazur (1991), Carraro & Chiosi (1994), Duarte & Bica (2000), Richtler & Sagati (2001), Tadross (2001), Lata et al. (2002), Salaris et al. (2004), D'Orazi et al. (2006), and Tosi et al. (2007).

b. Averages of measurements by Johnson (1953), Roman (1953), Johnson (1961), Rohlfs & Vanysek (1962), Ario (1962), Eggen (1963), Crawford & Barnes (1970), Patenaude (1978), Harding (1979), Nicolest (1981), Twomey (1983), Barri et al. (1987), Nissen (1988), Marzeli & Pigatto (1988), Eggen (1989), Franci (1989), Boesgaard (1991), Derviti & Pauneri (1993), Carraro & Chiosi (1993), Meynet et al. (1993), Daniel et al. (1994), Piatti et al. (1994), Dinescu et al. (1995), Milone et al. (1995), Claria et al. (1996), Duarte & Bica (2000), Loktin & Beshenov (2001), Blake (2002), Blake & Rucinski (2004), Salaris et al. (2004), Bartasiti et al. (2007), Taylor (2007), and Giardino et al. (2008).

c. Derived by Taylor (2008) from a review of published values.

d. Averages of measurements obtained from the Hipparcos parallaxes by Pinsonneault et al. (1998), Perryman et al. (1998), Narayanan & Gould (1999), Loktin & Beshenov (2001), and Percival et al. (2003).

e. Averages of measurements by Eggen (1998), Loktin & Beshenov (2001), Salaris et al. (2004), Jameson et al. (2008), and Bouvier et al. (2008).

f. Averages of measurements obtained from the Hipparcos parallaxes by Pinsonneault et al. (1998), Perryman et al. (1998), Van Leeuwen (1999), Loktin (2000), Loktin & Beshenov (2001), and Percival et al. (2003).

The relative error δEW/EW and the...
quality parameter $Q$ can be used to distinguish good and bad lines, and they were indeed used to select the highest quality lines for the abundance analysis, as described in detail in Paper I. The measured EW for our program stars are shown in the electronic version of Table 5 along with the $\delta$EW and $Q$ parameter estimated by DAOSPEC.

Four of our target stars have published EW measurements from high-resolution spectra. These consist of three stars (namely, 028, 041, and 070) observed in the Hyades by Boyarchuk et al. (2000) with $R \sim 45000$, and star 0456 in Be 32 studied by Bragaglia et al. (2008) with $R \sim 40000$. We have a total of 100, 92, and 51 lines in common for stars 028, 041, and 070 in the Hyades, respectively, and 51 lines for star 0456 in Be 32. Figure 2 compares the comparison between the EW determined with DAOSPEC with the values published by Bragaglia et al. (2008) and Boyarchuk et al. (2000). The differences (see Figure 2) are negligible within the uncertainties; we find a small offset of 5.6 mA in the case of star 041 in the Hyades, which is however still within 1 $\sigma$. We can therefore consider our measurements in good agreement with similar studies.

### 3.2. Abundance analysis

Abundance calculations and spectral synthesis (for oxygen) were performed using the latest version of the abundance calculation code originally described by Spite (1967). We used the MARCS model atmospheres developed by Edvardsson et al. (1993). We also used of ABOMAN, a tool developed by E. Rossetti at the INAF, Bologna Observatory, Italy, which allows the semi-automatic processing of data for several objects, using the aforementioned abundance calculation code. The tool ABOMAN performs all the steps needed to choose the best-fit model automatically (see below) and compute abundance ratios for all elements, and provides all the graphical tools required to analyse the results.

The detailed procedure followed to derive the chemical abundances is described in depth in Paper I. In brief, we calculated Fe I and Fe II abundances for a set of models with parameters extending $\pm 3\sigma$ around the photometric estimates of Table 4. We chose the model that satisfied simultaneously the following conditions: (i) the abundance of Fe I lines should not vary with excitation potential $\chi_{\text{exc}}$; (ii) the abundance of Fe I lines should not vary significantly with EW, i.e., strong and weak lines should infer the same abundance; (iii) the abundance of Fe II lines should not differ significantly from the abundance of Fe I lines; and (iv) the abundance of Fe I lines should not vary significantly with wavelength.

Once the best-fit model has been found, abundance ratios of all the measured elements were determined, as shown in Table 6 as the average of abundances given by single lines. The internal (random) errors were then computed as $\sigma / \sqrt{n_{\text{line}}}$, where $n_{\text{line}}$ is the number of lines.

### Table 4. Stellar atmosphere parameters for the programme stars (see text).

| Cluster | Star | $T_{\text{eff}}$ (K) | $T_{\text{clump}}$ (K) | log $g$ (cgs) | log $g_{\text{clump}}$ (cgs) | $v_{\text{t}}$ (km s$^{-1}$) | $v_{\text{t,clump}}$ (km s$^{-1}$) | $M_{\text{clump}}$ (M$_\odot$) |
|---------|------|----------------------|------------------------|-------------|---------------------------|----------------|-----------------------------|--------------------------|
| Be 32   | 0456 | 4759±92              | 4650                   | 2.6±0.14    | 2.1                       | 1.7±0.30      | 1.16±0.10                  | 1.4                      | 1.2±0.1                  |
|         | 1948 | 4706±99              | 4700                   | 2.47±0.14   | 2.3                       | 1.72±0.30     | 1.18±0.10                  | 1.5                      | 1.2±0.1                  |
| NGC 752 | 001  | 4949±80              | 5050                   | 3.02±0.14   | 3.1                       | 1.60±0.30     | 1.11±0.10                  | 1.3                      | 1.9±0.2                  |
| 208     | 4698±110 | 4600 | 2.73±0.14 | 2.9          | 1.73±0.31                | 1.15±0.10     | 1.2                      | 1.9±0.2                  |
| 213     | 4841±86  | 4900 | 2.81±14  | 3.0          | 1.65±0.30                | 1.13±0.10    | 1.4                      | 1.9±0.2                  |
| 311     | 4793±74  | 4800 | 2.80±14  | 3.2          | 1.68±0.30                | 1.14±0.10    | 1.2                      | 1.9±0.2                  |
| Hyades  | 028   | 4865±73              | 4750                   | 2.67±0.14   | 2.7                       | 1.64±0.30     | 1.15±0.10                  | 1.4                      | 2.5±0.1                  |
| 041     | 4871±79  | 4800 | 2.71±05  | 2.8          | 1.64±0.30                | 1.15±0.10    | 1.4                      | 2.5±0.1                  |
| 070     | 4858±95  | 4850 | 2.62±05  | 2.8          | 1.65±0.30                | 1.16±0.10    | 1.6                      | 2.5±0.1                  |
| Praesepe| 212    | 4901±35              | 4900                   | 2.70±07     | 2.8                      | 1.62±0.30     | 1.15±0.14                 | 1.5                      | 2.6±0.3                  |
| 253     | 4869±23  | 4900 | 2.60±07  | 2.8          | 1.64±0.30                | 1.16±0.14    | 1.6                      | 2.6±0.3                  |
| 283     | 4841±29  | 4800 | 2.61±07  | 2.9          | 1.65±0.30                | 1.16±0.14    | 1.4                      | 2.6±0.3                  |

### Table 5. Equivalent widths and atomic data of the programme stars. The complete version of the table is available at the CDS. Here we show a few lines to illustrate its contents.

| A         | Elem | $\chi_{\text{exc}}$ (eV) | log $gf$ (dex) | EW (mÅ) | $\delta$EW (mÅ) | Q   | EW (mÅ) | $\delta$EW (mÅ) | Q   | EW (mÅ) | $\delta$EW (mÅ) | Q   |
|-----------|------|-------------------------|---------------|---------|-----------------|-----|---------|-----------------|-----|---------|-----------------|-----|
| 6696.79   | AL1  | 4.02                    | -1.42         | 165.3   | 3.9             | 0.361 | 25.3    | 3.9             | 0.481 | 30.0    | 5.0             | 0.585 |
| 6698.67   | AL1  | 3.14                    | -1.65         | 47.8    | 2.7             | 0.434 | 43.4    | 2.6             | 0.501 | ...     | ...             | ...  |
| 7361.57   | AL1  | 4.02                    | -0.90         | 33.8    | 3.9             | 0.633 | 33.2    | 6.5             | 0.946 | ...     | ...             | ...  |
| 7362.30   | AL1  | 4.02                    | -0.75         | 48.6    | 4.3             | 0.346 | 39.7    | 2.9             | 0.737 | ...     | ...             | ...  |
| 7835.31   | AL1  | 4.02                    | -0.65         | 53.7    | 3.7             | 0.393 | 48.4    | 3.9             | 0.611 | ...     | ...             | ...  |
| 7836.13   | AL1  | 4.02                    | -0.49         | 66.0    | 7.8             | 1.279 | 68.4    | 5.1             | 0.783 | ...     | ...             | ...  |
| 8772.86   | AL1  | 4.02                    | -0.32         | ...     | ...             | ...   | ...     | ...             | ...  | ...     | ...             | ...  |
| 8773.90   | AL1  | 4.02                    | -0.16         | 115.0   | 8.6             | 1.151 | 111.9   | 8.3             | 1.111 | ...     | ...             | ...  |
| 5853.67   | BA2  | 0.60                    | -1.00         | 119.7   | 3.9             | 1.098 | 102.0   | 2.6             | 0.343 | ...     | ...             | ...  |
Table 6. Abundance ratios for single cluster stars, with their internal and external (last column) uncertainties.

| Ratio       | Berkeley 32 | NGC 752 | External Uncertainty |
|-------------|-------------|---------|----------------------|
|             | Star 456    | Star 1948 | Star 001 | Star 208 | Star 213 | Star 311 |
| [Fe/H]      | -0.33±0.02  | -0.27±0.02 | +0.07±0.01 | +0.07±0.01 | +0.14±0.01 | ±0.03 |
| [Fe/H]      | -0.30±0.06  | -0.29±0.06 | +0.06±0.03 | +0.05±0.04 | +0.18±0.12 | ±0.03 |
| [O/Fe]      | -0.29±0.21  | -0.25±0.09 | +0.07±0.04 | +0.05±0.12 | +0.07±0.12 | +0.14±0.09 | ±0.07 |
| [Al/Fe]     | +0.15±0.06  | +0.08±0.07 | -0.11±0.04 | -0.06±0.06 | -0.28±0.06 | ±0.05 |
| [Ba/Fe]     | +0.52±0.05  | +0.35±0.17 | +0.55±0.04 | +0.52±0.04 | +0.51±0.01 | +0.57±0.06 | ±0.04 |
| [Ca/Fe]     | -0.06±0.08  | -0.05±0.04 | -0.02±0.03 | -0.12±0.02 | -0.09±0.03 | -0.17±0.05 | ±0.06 |
| [Co/Fe]     | +0.02±0.05  | +0.09±0.04 | -0.03±0.03 | +0.06±0.04 | +0.00±0.03 | +0.05±0.05 | ±0.04 |
| [Cr/Fe]     | -0.25±0.07  | +0.04±0.07 | +0.02±0.03 | +0.00±0.03 | -0.01±0.03 | -0.01±0.04 | ±0.05 |
| [La/Fe]     | -0.14±0.02  | -0.04±0.08 | +0.14±0.06 | +0.18±0.03 | +0.18±0.09 | +0.32±0.13 | ±0.04 |
| [Mg/Fe]     | +0.38±0.12  | +0.24±0.16 | -0.13±0.06 | +0.16±0.05 | +0.20±0.04 | +0.06±0.03 | ±0.09 |
| [Na/Fe]     | -0.14±0.08  | -0.08±0.10 | +0.05±0.01 | -0.07±0.02 | -0.03±0.05 | -0.10±0.05 | ±0.04 |
| [Nd/Fe]     | -0.05±0.13  | +0.04±0.03 | +0.29±0.14 | +0.27±0.23 | +0.34±0.11 | +0.46±0.18 | ±0.13 |
| [Ni/Fe]     | -0.04±0.03  | -0.01±0.03 | -0.04±0.02 | +0.00±0.02 | -0.02±0.02 | +0.03±0.03 | ±0.02 |
| [O/Fe]      | -0.16±0.13  | +0.15±0.11 | +0.15±0.06 | -0.06±0.05 | +0.02±0.08 | +0.00±0.06 | ±0.08 |
| [Sc/Fe]     | +0.02±0.05  | -0.02±0.05 | -0.02±0.05 | +0.04±0.06 | +0.05±0.06 | +0.09±0.08 | ±0.05 |
| [Si/Fe]     | +0.18±0.04  | +0.11±0.04 | -0.03±0.03 | +0.04±0.03 | +0.04±0.03 | +0.01±0.04 | ±0.04 |
| [Ti/Fe]     | -0.10±0.05  | -0.04±0.05 | +0.00±0.02 | -0.03±0.02 | -0.08±0.02 | -0.13±0.03 | ±0.03 |
| [Tl/Fe]     | -0.17±0.05  | +0.01±0.07 | +0.03±0.02 | +0.08±0.07 | +0.07±0.06 | +0.15±0.13 | ±0.03 |
| [V/Fe]      | -0.14±0.10  | -0.07±0.05 | +0.00±0.02 | +0.16±0.05 | -0.04±0.03 | +0.05±0.06 | ±0.06 |
| [Y/Fe]      | -0.41±N.A.  | -0.09±N.A. | -0.12±0.06 | -0.03±0.10 | +0.03±0.07 | +0.05±0.05 | ±0.04 |

Comparison of our results with available literature is discussed in details in Section 4.

3.3. Abundance uncertainties and the Sun

The internal (random) uncertainty described above includes uncertainties related to the measurement of EW and to the atomic parameters (dominated by loggf determinations). We must consider other sources of uncertainty (see Paper I for details) such as: the uncertainty owing to the choice of atmospheric parameters; the uncertainty owing to the continuum normalization procedure; the uncertainty in the reference solar abundance values.

Uncertainties due to the choice of stellar parameters were evaluated with the method proposed by Cayrel et al. [2004]. In brief, we altered the predominant atmospheric parameter, T eff, within its uncertainty (∼100 K) and re-optimizing the other parameters for the hottest and coolest stars in our sample. We re-calculated abundances with the procedure described in the previous Section. The external uncertainties, listed in the last column of Table 6, are estimated by averaging errors calculated with the higher and lower temperatures for the warmest and coolest stars in our sample (namely, stars 001 and 208 in NGC 752).

Uncertainties due to the continuum normalization procedure might also affect the obtained EW and, therefore, the derived abundances. Their contribution is estimated by averaging the differences between the EW obtained with the “best-fit” continuum and those derived by lowering and raising the continuum level by the continuum placement uncertainty. This is calculated from Equation 7 of Stetson & Panczyk [2008]. The typical uncertainty caused by the continuum placement is ∆EW ≈ 1 mÅ and almost independent of the EW. This small uncertainty has a negligible impact on the derived abundances in comparison with other sources of uncertainty described above. Therefore, they have not been explicitly included in the error budget.

To validate the whole procedure used here, in Paper I we performed an abundance analysis of the ESO HARPS solar spectrum reflected by Ganymede. We used the same line list, model
4. Cluster-by-cluster discussion

4.1. Berkeley 32

Berkeley 32 (α2000 = 06h58m07.4s and δ2000 = +06°25′43″) is a distant OC (Rc = 1.16 kpc) situated 260 pc above the disc plane. Its distance makes it one of the crucial clusters for a correct determination of the metallicity gradient along the Galactic disc, and therefore one of the key OC to the understanding of disc formation and evolution. The color-magnitude diagram of this cluster is well-populated by early F-type stars, the low main-sequence appears to be sparsely populated (Figure 1). This, together with the age of this cluster, may be an indication of the dynamic escape of low mass stars. Stellar evolution models also predict a well-populated red giant branch, which is not observed. All the known red giants are located in the red clump region (Bartasūtė et al. 2007), which has a peculiar morphology because it has a faint extension slightly to the blue of its main concentration, which cannot be reproduced by stellar evolution models (Girardi et al. 2000).

Photometry and low/medium resolution spectroscopy studies (see Bartasūtė et al. 2007, and references therein) determined a slightly subsolar metallicity (i.e. [Fe/H] = −0.16 ± 0.05, Friel & Janes 1993). A similar result was found with high-resolution abundance analysis by Friel et al. (2010), based on two recent papers (Bragaglia et al. 2008 and Sestito et al. 2006). This suggests that the metallicity of Berkeley 32 is consistent with the general trend of the Galactic disc.

Table 8. High-resolution average Be 32 abundances.

| Ratio  | Be 32 | NGC 752 | Hyades | Praesepe (M 44) |
|--------|-------|---------|--------|-----------------|
| [Fe/H] | −0.30 ± 0.02 (±0.03) | +0.08 ± 0.04 (±0.03) | +0.11 ± 0.01 (±0.03) | +0.16 ± 0.05 (±0.03) |
| [α/Fe] | −0.04 ± 0.14 (±0.07) | +0.02 ± 0.06 (±0.07) | +0.00 ± 0.12 (±0.07) | +0.00 ± 0.14 (±0.07) |
| [Al/Fe] | +0.12 ± 0.05 (±0.05) | −0.12 ± 0.06 (±0.05) | +0.00 ± 0.02 (±0.05) | −0.00 ± 0.03 (±0.05) |
| [Ba/Fe] | +0.51 ± 0.12 (±0.04) | +0.52 ± 0.03 (±0.04) | −0.36 ± 0.04 (±0.04) | +0.33 ± 0.05 (±0.04) |
| [Ca/Fe] | −0.05 ± 0.01 (±0.06) | −0.09 ± 0.06 (±0.06) | −0.07 ± 0.01 (±0.06) | −0.08 ± 0.02 (±0.06) |
| [Co/Fe] | +0.07 ± 0.05 (±0.04) | +0.01 ± 0.04 (±0.04) | −0.03 ± 0.03 (±0.04) | +0.04 ± 0.02 (±0.04) |
| [Cr/Fe] | −0.11 ± 0.21 (±0.05) | +0.00 ± 0.01 (±0.05) | +0.04 ± 0.03 (±0.05) | +0.05 ± 0.01 (±0.05) |
| [La/Fe] | +0.14 ± 0.07 (±0.04) | +0.18 ± 0.08 (±0.04) | −0.08 ± 0.04 (±0.04) | −0.05 ± 0.02 (±0.04) |
| [Mg/Fe] | +0.33 ± 0.10 (±0.09) | +0.12 ± 0.06 (±0.09) | +0.10 ± 0.08 (±0.09) | +0.27 ± 0.05 (±0.09) |
| [Na/Fe] | −0.12 ± 0.04 (±0.04) | +0.01 ± 0.07 (±0.04) | +0.18 ± 0.01 (±0.04) | +0.25 ± 0.06 (±0.04) |
| [Nd/Fe] | +0.03 ± 0.06 (±0.13) | +0.34 ± 0.09 (±0.13) | +0.07 ± 0.02 (±0.13) | +0.04 ± 0.05 (±0.13) |
| [Ni/Fe] | −0.03 ± 0.02 (±0.02) | −0.01 ± 0.03 (±0.02) | −0.03 ± 0.01 (±0.02) | +0.02 ± 0.02 (±0.02) |
| [O/Fe] | +0.00 ± 0.16 (±0.08) | +0.03 ± 0.04 (±0.08) | −0.27 ± 0.04 (±0.08) | −0.11 ± 0.03 (±0.08) |
| [Sc/Fe] | +0.00 ± 0.03 (±0.05) | +0.03 ± 0.05 (±0.05) | −0.02 ± 0.02 (±0.05) | −0.04 ± 0.05 (±0.05) |
| [Si/Fe] | +0.14 ± 0.05 (±0.04) | +0.02 ± 0.03 (±0.04) | +0.09 ± 0.01 (±0.04) | +0.06 ± 0.02 (±0.04) |
| [Ti/Fe] | −0.08 ± 0.07 (±0.03) | −0.03 ± 0.06 (±0.03) | −0.09 ± 0.04 (±0.03) | −0.07 ± 0.03 (±0.07) |
| [V/Fe] | −0.08 ± 0.05 (±0.06) | +0.01 ± 0.09 (±0.06) | +0.04 ± 0.05 (±0.06) | +0.06 ± 0.03 (±0.06) |
| [Y/Fe] | −0.23 ± 0.23 (±0.04) | −0.03 ± 0.08 (±0.04) | −0.09 ± 0.03 (±0.04) | −0.11 ± 0.01 (±0.04) |

NGC 752 (α2000 = 01h57m41.0s, δ2000 = +37°47'06") is an old (~1.6 Gyr) OC located in the solar neighbourhood at a distance of ~400 pc. This cluster has a low central concentration and contains a relatively small number of members. Its color-magnitude diagram (e.g. Johnson 1953) has a still poorly understood morphology. The turn-off area is well-populated by early F-type stars, while the low main-sequence appears to be sparsely populated (Figure 1). This, together with the age of this cluster, may be an indication of the dynamic escape of low mass stars. Stellar evolution models also predict a well-populated red giant branch, which is not observed. All the known red giants are located in the red clump region (Bartasūtė et al. 2007), which has a peculiar morphology because it has a faint extension slightly to the blue of its main concentration, which cannot be reproduced by stellar evolution models (Girardi et al. 2000).

Photometry and low/medium resolution spectroscopy studies (see Bartasūtė et al. 2007, and references therein) determined a slightly subsolar metallicity (i.e. [Fe/H] = −0.16 ± 0.05, Friel & Janes 1993). A similar result was found with high-resolution abundance analysis by Friel et al. (2010), based on two recent papers (Bragaglia et al. 2008 and Sestito et al. 2006). This suggests that the metallicity of NGC 752 is consistent with the general trend of the Galactic disc.
Table 9. Abundance comparison of individual Hyades stars (see text).

| Parameter | Here | S09/S06 | M07/M06 | P07 | Bo00 | LC05 |
|-----------|------|---------|---------|-----|------|------|
| Resolution | 30000 | 60000 | 42000 | 30000 | 45000 | 30000 |
| S/N | 300–600 | ~500 | 100–350 | 175 | 100–300 | >100 |

| Star | T_eff (K) | log g (dex) | Vsin (km s⁻¹) | [Fe/H] | [FeII/H] |
|------|-----------|-------------|----------------|--------|---------|
|      | 4750      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |
|      | 4965      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |
|      | 4955      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |
|      | 4823      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |
|      | 4956      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |
|      | 4900      | 2.7         | 1.4            | +0.12±0.01+0.14±0.08 | +0.011 | +0.011±0.08 |

| Star | T_eff (K) | log g (dex) | Vsin (km s⁻¹) | [Fe/H] | [FeII/H] |
|------|-----------|-------------|----------------|--------|---------|
|      | 4800      | 2.8         | 1.4            | +0.01±0.01+0.20±0.01 | +0.19±0.07 | +0.12±0.00 |
|      | 4938      | 2.9         | 1.4            | +0.01±0.01+0.20±0.01 | +0.19±0.07 | +0.12±0.00 |
|      | 4975      | 2.9         | 1.4            | +0.01±0.01+0.20±0.01 | +0.19±0.07 | +0.12±0.00 |
|      | 4980      | 2.9         | 1.4            | +0.01±0.01+0.20±0.01 | +0.19±0.07 | +0.12±0.00 |
|      | 4985      | 2.9         | 1.4            | +0.01±0.01+0.20±0.01 | +0.19±0.07 | +0.12±0.00 |

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resolution spectroscopy (R = 40,000, S/N = 80–150) in eight F-type stars around the main sequence turn-off ([Fe/H] = −0.09 ± 0.03; Hubbs & Thorburn, 1992). However, an investigation based on high-resolution spectroscopy (R = 57,000, S/N = 30–80) of 18 G giant stars obtained a solar [Fe/H] ratio ([Fe/H] = +0.01 ± 0.04; Sestito et al., 2004) in closer agreement with the value determined here. To our knowledge, we are the first to publish abundance ratios of elements other than [Fe/H] for this cluster.

### 4.3. Hyades

The Hyades cluster (Melotte 25, α2000 = 04h 26m 54s and δ2000 = +15°52'00") is the closest OC to the Sun (~45 pc) located in the constellation of Taurus. Its proximity has motivated an extensive study lasting more than a century (starting with Hertzsprung, 1905). The OC is embedded into a moving group with the same name, which suggests that it would be part of a dynamical stream coming from the inner Galaxy or a disrupting cluster (Famaey et al., 2007). Being one of the most studied clusters, both photometrically and spectroscopically, it is the ideal cluster for abundance analysis comparisons. The color-magnitude diagram of this young OC (~0.7 Gyr, see Table 3) e.g. Johnson & Knuckles, 1955 contains only four red giant stars that have been confirmed as members from their parallaxes, proper motions, and radial velocities. Most of the existing abundance studies are focused on main sequence stars (see e.g. Paulson et al., 2003; Varenne & Monier, 1999; and references therein). A comparison of the Hyades average abundances determined from some (or all) of the known four red giants are shown in Table 10. The averages of the abundances compiled until 1999 by Varenne & Monier (1999) are shown in the last column of Table 10 for reference. In general, [Fe/H] appears slightly supersolar, while all other abundance ratios are solar, and our abundance ratios agree well with literature values.

### 4.4. Praesepe (NGC 2632)

The cluster popularly known as Praesepe or Beehive (also called M 44, NGC 2632 or Melotte 88; α2000 = 08h 40m 24s and δ2000 = +19°40'00") is an old OC (0.65 Gyr, see Table 3) well known from the antiquity. It is located in the Cancer constellation at a distance of ~175 pc, computed from Hipparcos parallaxes. Its metal content was derived with different methods (e.g. Friel & Boesgaard, 1992; Komarov & Basak, 1993; Claria et al., 1996; Hui-Bon-Hoa & Alecian, 1998; Burkhart & Croupy, 1998; Dias et al., 2002; Pace et al., 2008). In general, all the quoted studies obtained a metallicity either barely or definitely supersolar. Of these, the high-resolution abundance determinations were derived mainly for dwarfs or early-type giants (e.g. Friel & Boesgaard, 1992; Burkhart & Croupy, 1998; An et al., 2007; Pace et al., 2008). Surprisingly, to our knowledge, there are no recent high-resolution abundance determinations of late-type giants in this cluster.

Table 11 shows a comparison of our results with some of the most recent high-resolution studies. In general, the [Fe/H] we derived in our late-type giants lies in-between those of Pace et al. (2008) and An et al. (2007), suggesting that the proposed dichotomy of literature values (barely supersolar versus definitely supersolar) should be interpreted rather as an above average uncertainty. This larger than usual uncertainty could naturally...
5. Discussion of abundance ratios

As in Paper I, we compared our abundance ratios (and those from Paper I) with both others in the literature and the abundances of the Galactic disc field stars from Reddy et al. (2006, 2003), in Figures 3 to 6. We extended the open cluster abundance compilation of Paper I (see Table 12) with both recent published works and old studies that were not included in the previous version. In both cases, as in Paper I, we included only studies based on high-resolution (R ≥ 18000) spectroscopy. When more than one determination was available for one cluster, we simply plotted them all to give a realistic idea of the uncertainties involved in the compilation, and we did not attempt to correct for differences between the abundance analysis procedures (log gf, solar reference, and so on), because this would be beyond the scope of the present article.

5.1. Iron-peak element ratios

Figure 3 shows the abundance ratios of iron-peak elements. Our OC with abundances close to solar (i.e., Hyades, Praesepe, and NGC 752) are in very good agreement with the results obtained in other OC studied with high-resolution spectra and in disc stars of similar metallicity. A larger scatter or marginal discrepancies are sometimes observed for the odd elements Sc, V, and Co, but this is because of the well-known hyperfine structure (HFS) of the lines usually employed in the analysis. The element that appears to suffer more from these effects is vanadium. This scatter is due, at least in part, to the different procedures used in the literature for treating the HFS splitting. We stress that in our case, we do not attempt any HFS correction.

The most metal-poor and oldest OC in our sample, Be 32, has a puzzling behaviour. While all its iron-peak abundance ratios are still compatible with the literature values for OC and field stars of similar metallicity (uncertainties are large), some underlying discrepancy could be present. For example, HFS should cause an overestimate (and not an underestimate) of vanadium. In addition, chromium appears to be lower than solar. We note that (see Table 8) the literature Co and Cr determinations by Friel et al. (2010), Sestito et al. (2006), and Bragaglia et al. (2008) are very similar to ours. In the case of our [Cr/Fe] measurement for Be 32, we must note that our two giants appear to exhibit quite different [Cr/Fe] abundances, resulting in a large scatter in the cluster average value. This large scatter is most probably due to a measurement uncertainty, and should not be considered significant.

In Paper I, we noticed a peculiar behaviour in the Ni abundance ratios of literature OC determinations: they appear to be slightly richer in Ni than field stars by roughly 0.05 dex. Our [Ni/Fe] ratios are in closer agreement with the field star determinations than with the OC ones. Although this difference is small (within the uncertainties), it appears systematic in nature, and we were unable to find any easy explanation, such as the choice of either solar reference abundances or the log gf system, of this discrepancy.

5.2. Alpha-element ratios

Figure 2 shows the abundance ratios of α-elements. As for iron-peak elements, our measurements are always compatible with the literature values, within their uncertainties. Generally speaking, all our OC show roughly solar α-enhancements, even Be 32, which has a lower metallicity.

However, some elements deserve some more discussion, as was noted in Paper I. For example, the log gf of calcium are quite uncertain, and we chose the VALD reference atomic data, which explains why our [Ca/Fe] ratios are slightly lower than the bulk of literature determinations for cluster and disc stars. A similar problem affects the Mg lines, as can clearly be appreciated from the large spread of literature values. Our Mg/Fe determinations tend to lie on the upper envelope of literature ratios for OC. A deeper discussion of Mg abundances can be found in Paper I.
In the case of oxygen, the problem is instead in the difficulty in measuring its small lines. The forbidden [O I] line at 6300 Å, which we used in this paper, suffers from contamination by a Ni line and by telluric absorption features, while the O triplet around 7770 Å (used by some other studies) suffers from NLTE effects. This is reflected by the large scatter in literature values.

5.3. Heavy element ratios

We determined abundances for three heavy s-process elements: Ba, La, and Nd; and one light s-process element: Y (Figure 5). Literature determinations for these elements are not numerous. D’Orazi et al. (2009) measured Ba in several OC using spectral synthesis to take into account HFS. The [Ba/Fe] abundances derived by D’Orazi et al. (2009) taking into account HFS do not differ significantly from other literature determinations (including ours). The [Ba/Fe] ratios are clearly above solar for most of the clusters and they show a scatter larger than $\sim$0.5. D’Orazi et al. (2009) found this scatter to be due to age: the Ba content appears to increase for younger clusters. The available lanthanum and neodymium lines were unfortunately relatively small, and we were able to find fewer published studies to compare with. As a result, the solar clusters (Hyades, Praesepe, and NGC 752) have La and Nd ratios in good agreement with the literature, while Be 32 appears to have lower [La/Fe] and [Nd/Fe] than the few studied OC at a similar metallicity, which are Mel 66 (Gratton & Contarini 1994) and NGC 2243 (Smith & Suntzeff 1987). However, our [Nd/Fe] agrees well with the field star solar ratios. The only light s-process element we could measure, Y, relies on a couple of weak lines that provide uncertain abundances (see the large errorbar in Figure 5). Our Y ratio appears to be lower than all literature estimates, although still compatible with the solar values of field stars of similar metallicity, within the large uncertainties.

In summary, we can say that all the studied clusters appear to have roughly solar s-process enhancements, but it would be extremely interesting to attempt a more detailed study of s-process elements in OC, as done by D’Orazi et al. (2009) for barium.
5.4. Ratios of Na and Al and anticorrelations

As discussed in Paper I, the study of light elements in OC is quite interesting. The elements Al and Na, together with Mg, O, C, and N, show puzzling (anti-)correlations in almost all of the studied globular clusters, in the Milky Way (see, e.g., Carretta et al. 2010, Pancino et al. 2010, and references therein) and outside (e.g., Mucciarelli et al. 2009, Letarte et al. 2006). No (anti-)correlations were observed in either field stars (but see Martell & Grebel 2010) or OC (Martell & Smith 2009; de Silva et al. 2009; Smiljanic et al. 2009, and Paper I) so far. This suggests that metallicity, cluster size and age, or the environment must play a rôle, and therefore finding (anti-)correlations in some OC would be of enormous importance to put tighter constraints on the phenomenon.

We determined abundances of Al and Na and compared them with published results in Figure 6. While in the case of Alumium the agreement with literature values is good, we find a significantly lower [Na/Fe] scatter in this clusters. Often affected by NLTE effects (Gratton et al. 1999), although no such scatter is observed among field stars. However, a few clusters have [Na/Fe] lower than our Be 32 determination, and NLTE corrections (Gratton et al. 1999) could make the discrepancy of our Be 32 Na determination even worse. Unfortunately, given the large scatter and the difficulty of measurement, it is difficult to either confirm or exclude the presence of some (small) intrinsic [Na/Fe] scatter in this clusters.

In Figure 7 all the studied stars occupy the “normal stars” loci, which is around solar for Na and Al, and slightly α-enhanced for O and Mg (see Section 5.2). There is a hint of correlation between [Al/Fe] and [Na/Fe], which was also observed for objects studied in Paper I. Of course, small variations in T_eff could induce artificial correlations between element pairs, so the observed trend is most probably not-significant. However, we again note that the Na spread is very large (see above), suggesting that a small degree of chemical anomalies (barely hidden within the present observational uncertainties) cannot be completely excluded.

6. Galactic trends

The existence of trends in the chemical abundances with Galacticocentric distance, R_g, vertical distance to the Galactic plane, z, and age, are key to understanding Galactic disc formation and evolution because they provide fundamental constraints on chemical evolution models. Different tracers have been used to investigate trends in the Galactic disc: OB stars (e.g. Daflon & Cunha 2004), Cepheids (e.g. Lemaitre et al. 2008), H II regions (e.g. Deharveng et al. 2000), and planetary nebulae (e.g. Costa et al. 2004). However, as coeval groups of stars at the same distance and with a homogeneous chemical composition, OC are the ideal test particles to investigate the existence of radial and vertical gradients and of an age-metallicity relation in the disc.

We complement the small sample of abundance ratios obtained here and in Paper I with a revised version of the literature data first presented in Paper I (Table 12). When a cluster had two or more abundance determinations available in the literature, we averaged them to make the figures easily readable and the error bars are, simply, calculated as the standard deviation. For those clusters with only one abundance determina-
Fig. 8. Trends of [Fe/H] (top panel) and [$\alpha$/Fe] (bottom panel) with galactocentric radius. Grey dots are OC compiled in Table 12, while black dots are the ones analysed here and in Paper I. A global linear fit is drawn in both panels (long-dashed line). Two separate linear fits of OC inside and outside 12.5 kpc are also shown (solid lines).

2002; Magrini et al. 2009; Friel et al. 2010; Jacobson et al. 2011a,b; Friel 1995) reviewed the first investigations in this field. Since then, a great effort has been performed to obtain both homogeneous (e.g., Friel et al. 2002; Sestito et al. 2008; Friel et al. 2010) and/or larger samples (e.g., Twarog et al. 1997; Jacobson et al. 2011a,b). All these investigations agree on the fact that the iron content decreases with increasing radius (e.g., Friel et al. 2002). This behaviour has been generally considered linear with a slope between −0.05 and −0.09 dex kpc$^{-1}$, depending on the cluster sample used. Similar trends were obtained for other different tracers of the disc (e.g., Andrievsky et al. 2004; Lemusle et al. 2008). Most of these works were limited to the inner $R_{gc}$ $< 15$ kpc. However, investigations based on samples containing clusters at larger distances (e.g., Twarog et al. 1997; Yong et al. 2005; Sestito et al. 2008) found that the [Fe/H] ratio decreases as a function of increasing radius to $R_{gc}$ $\approx 12.5$ kpc and appears to flatten from there outwards.

The variation in [Fe/H] with $R_{gc}$ in our compilation has been plotted in the top panel of Figure 8. The whole sample is well fitted by a line with a slope of $-0.046\pm0.005$ dex kpc$^{-1}$ (long-dashed line), in concordance with the result obtained in Paper I from a smaller sample ($-0.05\pm0.01$ dex kpc$^{-1}$) and in other investigations in the literature (e.g., $-0.06\pm0.02$ dex kpc$^{-1}$; Friel et al. 2002). The sample used here contains more clusters with distances larger than $R_{gc}$ $\geq 12$ kpc. This allows us to investigate the discontinuity observed by some authors at $R_{gc}$ $\approx 12$–13 kpc. At first sight, no clear discontinuity in slope appears, partly because of the large range of [Fe/H] at this radius ($\approx 0.5$ dex) and partly as a possible consequence of the heterogeneity of our sample. However, when we fit separately clusters inwards and outwards of 12.5 kpc, we find two significantly different slopes: the metallicity in the inner disc decreases with a slope of $-0.07\pm0.01$ dex kpc$^{-1}$, while in the outer disc the slope is $-0.01\pm0.01$ dex kpc$^{-1}$. The obtained slopes change within the uncertainties if the cut radius varies between 11.5 and 13.5 kpc. This is also in very good agreement with the recent results by Andreuzzi et al. (2011), who find $-0.07$ dex kpc$^{-1}$ in the inner 12 kpc. This bimodal behaviour can be explained by a different chemical enrichment and star formation in the inner and outer disc; (e.g., Chiappini et al. 2001; Magrini et al. 2009), however, a sharp discontinuity between the inner and outer disc is not expected theoretically.

The ratio [$\alpha$/Fe] reflects the relative contributions of Type Ia and II supernovae: chemical evolution models predict an increase of this ratio with $R_{gc}$ (e.g., Chiappini et al. 2001; Magrini et al. 2009). This tendency was indeed observed in OC by, e.g., Yong et al. (2005), Magrini et al. (2009), and in Paper I. The bottom panel of Figure 8 shows the variation in [$\alpha$/Fe] with $R_{gc}$ for our compilation: a weak increase in $\alpha$-element abundances with radius is apparent. However, the slope is still compatible with a flat distribution at the 1σ level, as in Paper I, especially if the two outermost clusters are removed. The discontinuity observed for [Fe/H] is not evident at all in [$\alpha$/Fe].

An accretion of a satellite into the outer disc could also explain the trend observed (e.g., Chiappini et al. 2001; Yong et al. 2005). In this case, we would expect to find some inhomogeneities corresponding to the trajectory of the merger. Carraro & Bensby (2009) indeed found evidence that two OC, Berkeley 29 and Sauer 1, are related to the Sagittarius dwarf galaxy. Our compiled sample unfortunately do not allow us to investigate this question in depth.
6.2. Time evolution of the radial gradient

Chemical evolution models of the Galactic disc predict a variation in the metallicity gradient with time, but they disagree about the direction of this gradient variation (see Maciel et al. [2007] for a recent review), some predicting a steepening and some a flattening of the gradient with time. Studies based on metallicities derived from low-resolution spectroscopy found that old OC (≥1 Gyr) followed a steeper radial gradient, −0.08 dex kpc−1, than the younger ones, ~0.02 dex kpc−1 (Friel et al. 2003, Chen et al. 2003). Only recently have chemical abundances been derived from high-resolution spectroscopy for a sufficient number of OC to significantly investigate the variation in the radial gradient with time. As for studies based on low-resolution spectra, they agree that the gradient was steeper in the past and has flattened with time (Magrini et al. 2009, Andreuzzi et al. 2011). For example, on the basis of a sample of ~70 OC Andreuzzi et al. (2011) found that all objects younger than 4 Gyr display a similar gradient with a slope -0.07 dex kpc−1 in the inner 12 kpc, while the one for older objects is steeper, -0.15 dex kpc−1.

Other tracers have been used to study the time variation in radial gradients. Studies based on planetary nebulae found more puzzling results: while Magiel et al. (2003) found a flattening of the gradient with time, as generally observed for OC, Stanghellini & Haywood (2010) found that the gradient steepens with time. At the moment, there is no explanation of this contradictory result. Comparisons among the slopes of the radial gradients derived by populations of different ages also show that the gradient has flattened out in the past few Gyr (see Maciel & Costa 2009, for a recent review).

To investigate the behaviour of the radial gradient in our compiled sample of high-resolution abundances, we plotted in Figure 9 the gradient in [Fe/H] as a function of $R_{gc}$ in four different age bins. We obtained a linear fit in each age bin for the inner 12.5 kpc, and for the outer range we simply used the same fit as in Figure 8 owing to the paucity of OC after age binning in this region. We found that the slope of the [Fe/H] gradient increases as we go back in time from −0.02±0.01 dex kpc−1 for objects younger than 0.1 Gyr to −0.10±0.01 dex kpc−1 for clusters older than 2.5 Gyr.

6.3. Trends with the disc scale–height

Another interesting trend that could be investigated is the behaviour of [Fe/H] with the vertical scale–height of the disc $z$, i.e., the vertical [Fe/H] gradient. Although the formation of the thick discs remains an open question, the existence of vertical gradients can help us to discriminate among the mechanisms proposed to their formation. No vertical chemical gradients are expected in thick discs formed by heating caused by accretion events or major mergers. In contrast, vertical gradients may exist in discs thickened by gradual heating of the thin disc or before the gas has settled to form a thin disc (see Mould 2005, for a review). Up to now, there is no conclusive agreement about the existence of a vertical metallicity gradient in the Galactic disk. The existence of a vertical gradient for field stars have been claimed by several authors, although they cover only about 1 kpc above and below the disc plane (Bartaššute et al. 2003, Marsakov & Borkova 2005, 2006, Soubiran et al. 2008). Studies covering large ranges of $z$ do not find any evidence of a vertical gradient (Gilmore et al. 1995, Soubiran & Girard 2005, Navarro et al. 2011) among the field populations. Studies using OCs have found a vertical gradient of ~0.3 dex kpc−1 (Piatti et al. 1995, Carraro et al. 1998, Chen et al. 2003), although, these studies do not distinguish the effects of the radial gradient, which can mask any vertical trend. This effects were taken into account by Jacobson et al. (2011a) who found no evidence of a vertical gradient.

To investigate the presence of trends with $z$ in our compilation, we firstly had to remove the contribution of the radial metallicity gradient. We plotted in Figure 10 the variation in [Fe/H] with $z$ in four different annuli of $R_{gc}$. We note that OC with high $z$ are preferentially located at large $R_{gc}$; this is not unexpected because the disc thickens in its external regions. Moreover, an intrinsic bias caused by obscuration in the plane appears: clusters at large Galactocentric radii are found and observed preferentially higher above the plane. This could explain why the two outermost annuli studied uncover a possible weak decrease in [Fe/H] as $z$ increases. This trend is however still compatible with no gradient at the 1 σ level and, once again, larger samples of homogeneous data are necessary to investigate this result in detail.

6.4. Is there an age–metallicity relation for open clusters?

Another important prediction of the chemical evolution models is the existence of an age-metallicity relation for disc populations. It is still unclear whether or not the field disc stars follow an age-metallicity relation. Some works find it (e.g. Reddy et al. 2003, Bensby et al. 2004, Reid et al. 2007), but others do not (e.g. Feltzing et al. 2001, Nordström et al. 2004, Karataş et al. 2005). Again, no clear trend of chemical abundances with age has been clearly observed in the case of Galactic OC (e.g. Friel 1995). Although Friel et al. (2010) notices a trend of [Al/Fe] and [O/Fe] ratios with age, again larger and homogeneous samples
are necessary to confirm this result. If an age-metallicity relation is confirmed for the field population but not for OC, this would imply that they might have followed a different chemical evolution \cite{Yong2005}.

The evolution of the radial gradient as a function of time, described above, indicates that the chemical enrichment of OC is modulated by their location in the Galaxy and not by the moment at which they formed. To investigate whether an age-metallicity relationship exists at a given $R_{gc}$, we plotted in Figure 11 the evolution of [Fe/H] with age in four different radial annuli. There is no clear trend in any of the studied annuli, although not all of them contain clusters covering the same age range. Only in the outermost annulus is a weak trend observed, although it is still not very significant. Again, we conclude that a larger sample of homogeneous data are necessary to investigate this point in depth.

7. Summary and conclusions

We have enlarged our sample of homogeneous high-resolution abundance measurements from the five clusters of Paper I to a total of nine, analysing here spectra of red clump giants in the Hyades, Praesepe, NGC 752, and Be 32. Our main results can be summarized as follows:

- We provide the first high-resolution based abundance ratios (other than [Fe/H], see \cite{Sestito2008} for NGC 752, which turned out to be mostly of solar composition;
- We have presented the abundance ratios of Praesepe red clump giants, which appear to solve a puzzling dichotomy of literature determinations for stars of different evolutionary stages;
- We have found that our abundance ratios for the Hyades and Berkeley 32 are in good agreement with other literature determinations;

- We have confirmed the absence of light elements (anti-)correlations in the OC studied so far.

We have updated our compilation of previous literature data for 57 clusters of Paper I to a total of 89 clusters presented here. With this updated compilation and our homogeneous measurements in hand, we have investigated Galactic trends in [Fe/H] (and [$\alpha$/Fe]) with age, Galactocentric radius, and height above the Galactic plane. Our findings are in substantial agreement with other similar investigations, where the abundance gradient appears to indeed flatten out outside $R_{gc}$ ~12.5 kpc, and the inner disk slope appears to flatten for younger ages as well, although the age bins are not too well-sampled. At the same time, [$\alpha$/Fe] shows a weak increase with $R_{gc}$. No significant gradients are observed with $|z|$ or age, except for a weak tendency of [Fe/H] to decrease with increasing $|z|$ and decrease with age in the outermost disc annulus studied. None of our measured weak trends have any significance above 1 $\sigma$. Larger samples of homogeneous data are still necessary to investigate the existence of any dependence on age and $|z|$ in the Galactic disc.

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Table 12. Literature sources of high-resolution (R\(\geq\)1500) [Fe/H] ratios of open clusters together with the resolution, signal-to-noise ratios, number of stars, and method used in each of them.

| Cluster     | [Fe/H] | Resolution | S/N | N. Star | Method | References     |
|-------------|--------|------------|-----|---------|--------|----------------|
| Be 17       | -0.10±0.09 | 25000       | ≥80 | 3 giant | EW\(^1\) | Friel et al. (2005) |
| Be 20       | -0.48±0.08 | 28000       | ≥50 | 2 giant | EW     | Yong et al. (2005) |
|             | -0.30±0.02 | 45000       | ≥35 | 2 giant | EW     | Sestito et al. (2008) |
| Be 21       | -0.54±0.02 | 48000       | ~20 | 4 giants | EW     | Hill & Pasquini (1999) |
| Be 22       | -0.32±0.04 | 34000       | 20–25 | 2 K giant | EW     | Villanova et al. (2005) |
| Be 25       | -0.20±0.05 | 40000       | 25–40 | 4 giant | EW     | Carraro et al. (2007b) |
| Be 29       | -0.44±0.02 | 34000       | ~70 | 2 G giant | EW     | Carraro et al. (2004) |
|             | -0.52±0.03 | 28000       | ≥100 | 2 giant | EW     | Yong et al. (2005) |
|             | -0.31±0.03 | 45000       | ≥25 | 6 giant | EW     | Sestito et al. (2008) |
| Be 31       | -0.54±0.06 | 28000       | ≥60 | 1 giant | EW     | Yong et al. (2005) |
|             | -0.31±0.06 | 28000       | ~100 | 2 giant | EW\(^1\) | Friel et al. (2010) |
| Be 32       | -0.29±0.04 | 45000       | ≥50 | 9 giant | EW     | Bragaglia et al. (2008) |
|             | -0.30±0.02 | 28000       | ~100 | 2 giant | EW\(^1\) | Friel et al. (2010) |
| Be 39       | -0.21±0.01 | 28000       | 70–115 | 3 giant | EW\(^1\) | Friel et al. (2010) |
| Be 66       | -0.48±0.24 | 34000       | 5–15 | 2 K giant | EW     | Villanova et al. (2005) |
| Be 73       | -0.22±0.10 | 40000       | 25–40 | 2 giant | EW     | Carraro et al. (2007b) |
| Be 75       | -0.22±0.20 | 40000       | 25–40 | 1 giant | EW     | Carraro et al. (2007b) |
| Blanco 1    | +0.04±0.02 | 50000       | ≥70 | 8 F-G dwarf | Syn   | Ford et al. (2005) |
|             | +0.20±0.03 | 28000       | 100–400 | 4 dwarf | EW     | Edvardsson et al. (1995) |
| Cr 121      | +0.25     | 20000       |       | 1 supergiant | EW     | Mallik (1998) |
|             | -0.22±0.11 | 25000       | ≥75 | 4 giant | EW\(^1\) | Friel et al. (2003) |
|             | -0.03±0.04 | 40000       | 70–130 | 6 giant | EW     | Carretta et al. (2005) |
|             | -0.01±0.02 | 47000       | 80–100 | 12 giant | EW     | De Silva et al. (2007) |
|             | +0.13±0.05 | 45000       | ≥60 | 7 giant | EW     | Sestito et al. (2008) |
| Hyades      | +0.13±0.02 | 45000       | 200 | 14 F dwarf | EW     | Boesgaard & Friel (1990) |
| Mel 25      | +0.05±0.03 | 60000       | ~200 | 29 F 19 A dwarf | Syn   | Varenne & Monier (1999) |
|             | +0.12±0.06 | 40000       | 100–300 | 3 giant | EW     | Bovarchuk et al. (2000) |
|             | +0.13±0.08 | 40000       | ~100 | 2 F-K dwarf | EW     | Sestito et al. (2003) |
|             | +0.13±0.06 | 60000       | 100–200 | 55 F-M dwarf | EW     | Paulson et al. (2003) |
|             | +0.13±0.05 | 60000       | 100–200 | 46 F-K dwarf | EW/Syn | De Silva et al. (2006) |
|             | +0.14±0.04 | 40000       | 100 | 1 dwarf | EW     | D’Orazi & Randich (2009) |
|             | +0.21±0.04 | 60000       | 175–225 | 3 G dwarf/4 giant | Syn    | Schuler et al. (2009, 2006) |
| IC 2391     | -0.03±0.07 | 18000–44000 | 30–100 | 4 dwarf | EW     | Randich et al. (2001) |
|             | -0.01±0.02 | 40000       | 70–280 | 7 G–K dwarf | EW     | D’Orazi & Randich (2009) |
| IC 2581     | -0.34±0.02 | 18000       | ≥100 | 1 F supergiant | EW     | Luck (1994) |
| IC 2602     | -0.05±0.05 | 18000–44000 | 30–100 | 9 dwarf | EW     | Randich et al. (2001) |
|             | +0.00±0.01 | 40000       | 100–250 | 8 G–K dwarf | EW     | D’Orazi & Randich (2009) |
| IC 2714     | +0.12±0.09 | 48000       | 180 | 1 giant | EW\(^2\) | Smailianic et al. (2009) |
|             | -0.01±0.01 | 50000       | 200–300 | 3 giant | EW     | Santos et al. (2009) |
| IC 4651     | +0.11±0.01 | 40000       | ≥100 | 5 giant | EW     | Carretta et al. (2004) |

1 Spectral synthesis for O.
2 Spectral synthesis for C, N, O.
| Cluster          | [Fe/H]  | Resolution | S/N  | N. Star          | Method | References         |
|------------------|---------|------------|------|------------------|--------|--------------------|
|                  | +0.10±0.03 | 45000     | 70–120 | 5 giant/18 dwarf | EW     | Pasquini et al. (2004) |
|                  | +0.12±0.05 | 100000 | ~80     | 5 G dwarf        | EW     | Pace et al. (2008)    |
|                  | +0.15±0.01 | 50000   | 200–300 | 3 giant/3 dwarf  | EW     | Santos et al. (2009)  |
|                  | +0.11±0.01 | 48000   | ≥100    | 5 giant          | EW/Syn | Mikolaitis et al. (2011) |
| IC 4665          | -0.03±0.04 | 60000   | 30–150  | 18 F–K dwarf     | Syn    | Shen et al. (2005)    |
| IC 4725          | +0.18±0.08 | 18000   | ≥100    | 2 supergiant/1 giant | EW     | Luck (1994)           |
| IC 4756          | -0.02±0.05 | 18000   | ≥100    | 4 supergiant     | EW     | Luck (1994)           |
|                  | -0.15±0.04 | 15000   | 70–150  | 7 giant          | EW²    | Jacobson et al. (2007) |
|                  | +0.04±0.04 | 48000   | ≥170    | 5 giant          | EW²    | Smiljanic et al. (2009) |
|                  | +0.02±0.03 | 50000   | 200–300 | 3 giant/3 dwarf  | EW     | Santos et al. (2009)  |
|                  | +0.01±0.09 | 100000 | 50–100  | 3 dwarf          | EW     | Pace et al. (2010)    |
|                  | +0.08±0.11 | 100000 | 50–100  | 3 giant          | EW     | Pace et al. (2010)    |
|                  | +0.03±0.04 | 28000   | 20–50   | 4 F dwarf        | EW     | Friel & Boesgaard (1992) |
|                  | -0.03±0.03 | 30000   | ≥100    | 9 giant          | EW     | Yong et al. (2005)    |
|                  | -0.01±0.04 | 28000   | ≥200    | 3 giant          | EW     | Tautvaisiene et al. (2000) |
|                  | +0.03±0.01 | 45000   | 80–180  | 8 dwarf/2subgiant | EW     | Randich et al. (2006) |
|                  | +0.03±0.04 | 100000 | ~80     | 6 G dwarf        | EW     | Pace et al. (2008)    |
|                  | +0.02±0.02 | 50000   | 200–300 | 3 giant/3 dwarf  | EW     | Santos et al. (2009)  |
|                  | +0.03±0.07 | 28000   | 150–180 | 3 giant          | EW¹    | Friel et al. (2010)   |
|                  | -0.01±0.05 | 21000   | >70     | 19 giants        | EW¹    | Jacobson et al. (2011b) |
|                  | +0.23±0.08 | 45000   | 300–450 | 1 supergiant/1 dwarf | EW     | Gonzalez & Lambert (1996) |
|                  | -0.33±0.03 | 45000   | 80–115  | 5 giant          | EW     | Boesgaard & Friel (1990) |
|                  | -0.30±0.01 | 34000   | ~100    | 2 giant          | EW     | Gratton & Contarini (1994) |
|                  | -0.05±0.05 | 28000   | ≥150    | 14 F dwarf       | EW     | Friel & Boesgaard (1992) |
|                  | +0.06±0.10 | 42000   | 150–400 | 11 A 11 F dwarf  | Syn    | Gebran et al. (2008)  |
| NGC 1883         | +0.01±0.08 | 35000   | 20–35   | 11 G dwarf       | EW     | Randich et al. (2003) |
|                  | +0.12±0.02 | 28000   | 120–140 | 4 giant          | EW¹    | Friel et al. (2010)   |
|                  | -0.03±0.04 | 21000   | >70     | 27 giants        | EW¹    | Jacobson et al. (2011b) |
|                  | +0.01±0.04 | 57000   | 30–80   | 18 G dwarf       | EW     | Hobbs & Thorburn (1992) |
|                  | +0.03±0.04 | 28000   | 100     | 1 giant          | EW¹    | Friel et al. (2010)   |
|                  | -0.04±0.05 | 21000   | >70     | 13 giants        | EW¹    | Jacobson et al. (2011b) |
|                  | -0.07±0.04 | 28000   | 120     | 2 giant          | EW¹    | Jacobson et al. (2009) |
|                  | -0.16±0.03 | 21000   | >70     | 28 giants        | EW¹    | Jacobson et al. (2011b) |
|                  | -0.20±0.22 | 20000   | ~20    | 5 giant          | EW     | Villanova et al. (2007) |
|                  | -0.01±0.01 | 28000   | ~100    | 3 giant          | EW¹    | Jacobson et al. (2009) |
|                  | -0.08±0.01 | 33000-64000 | 50–80 | 1 subgiant      | EW¹    | Carraro et al. (2007a) |

¹ Spectral synthesis for Al, Na, O.
² Spectral synthesis for C, N, Eu.
Table 12. Continued.

| Cluster   | [Fe/H]     | Resolution | S/N | N. Star | Method | References                  |
|-----------|------------|------------|-----|---------|--------|-----------------------------|
| NGC 2112  | -0.09±0.10 | 16000–34000 | 80  | 2 giant | EW     | Brown et al. (1996)         |
|           | +0.16±0.03 | 33000      | 80–100 | 3 giant | EW     | Carraro et al. (2008)      |
| NGC 2141  | -0.26      | 28000      | ≥130 | 1 giant | EW     | Yong et al. (2005)         |
|           | +0.00±0.16 | 28000      | 75  | 1 giant | EW     | Jacobson et al. (2009)     |
| NGC 2158  | -0.03±0.14 | 28000      | 75  | 1 giant | EW     | Jacobson et al. (2009)     |
|           | -0.28±0.05 | 21000      | >70 | 15 giants | EW     | Jacobson et al. (2011b)    |
| NGC 2194  | -0.08±0.08 | 21000      | >70 | 6 giants | EW     | Jacobson et al. (2011b)    |
| NGC 2204  | -0.23±0.04 | 20000      | ≥60 | 13 giant | EW     | Jacobson et al. (2011a)    |
| NGC 2232  | +0.22±0.09  | 16000      | 70–300 | 5 dwarf | EW     | Monroe & Pilachowski (2010) |
|           | +0.32±0.08  | 16000      | 70–300 | 5 dwarf | EW     | Monroe & Pilachowski (2010) |
| NGC 2243  | -0.48±0.01 | 30000      | ~100 | 2 giant | EW     | Gratton & Contarini (1994)  |
|           | -0.42±0.05 | 20000      | ≥60 | 10 giant | EW     | Jacobson et al. (2011a)    |
| NGC 2264  | -0.18±0.08 | 45000      | 45–75 | 4 dwarf | EW     | King et al. (2000)         |
|           | -0.17±0.05 | 45000      | ≥80 | 7 giant | EW     | Bragaglia et al. (2008)    |
| NGC 2324  | 0.08±0.08  | 21000      | >70 | 5 giants | EW     | Jacobson et al. (2011b)    |
| NGC 2355  | +0.07±0.06 | 28000      | 50–200 | 4 giant | EW     | Hamdani et al. (2000)      |
|           | +0.04±0.09 | 28000      | ≥70 | 4 giant | EW     | Smiljanic et al. (2009)    |
| NGC 2360  | -0.03±0.01 | 50000      | 200–300 | 3 giant | EW     | Santos et al. (2009)       |
|           | -0.10±0.03 | 50000      | 100–300 | 3 giant | EW     | Santos et al. (2009)       |
| NGC 2420  | -0.57±0.08 | 20000      | 4 giant | Syn    | Smith & Suntzeff (1987)    |
|           | -0.20±0.06 | 21000      | >70 | 9 giants | EW     | Jacobson et al. (2011b)    |
| NGC 2423  | +0.14±0.06 | 50000      | 200–300 | 3 giant | EW     | Santos et al. (2009)       |
|           | -0.15±0.09 | 21000      | >70 | 4 giants | EW     | Jacobson et al. (2011b)    |
| NGC 2425  | +0.03±0.03 | 28000      | 50–2000 | 3 giant | EW     | Hamdani et al. (2000)      |
|           | -0.01±0.01 | 28000      | ≥70 | 3 giant | EW     | Smiljanic et al. (2009)    |
| NGC 2447  | -0.10±0.03 | 50000      | 100–300 | 3 giant| EW     | Santos et al. (2009)       |
| M 93      | +0.03±0.03 | 28000      | ≥70 | 3 giant | EW     | Santos et al. (2009)       |
|           | -0.10±0.03 | 50000      | 100–300 | 3 giant| EW     | Santos et al. (2009)       |
| NGC 2477  | +0.07±0.03 | 45000      | ≥80 | 6 giant | EW     | Bragaglia et al. (2008)    |
| NGC 2506  | -0.20±0.02 | 40000      | ≥35 | 4 giant | EW     | Carretta et al. (2004)     |
|           | -0.24±0.05 | 48000      | ≥35 | 4 giant | EW     | Mikolaitis et al. (2011)   |
| NGC 2516  | +0.01±0.07 | 47000      | 70  | 2 F dwarf | EW     | Tundrup et al. (2002)      |
| NGC 2539  | +0.13±0.09 | 50000      | 200–300 | 3 giant | EW     | Santos et al. (2009)       |
| NGC 2660  | +0.04±0.04 | 45000      | ≥45 | 5 giant | EW     | Bragaglia et al. (2008)    |
| NGC 3114  | +0.05±0.13 | 48000      | ≥45 | 7 giant | EW     | Pereira & Quezada (2010)   |
|           | +0.02±0.09 | 50000      | 200–300 | 3 giant| EW     | Santos et al. (2009)       |
| NGC 3532  | +0.10±0.17 | 18000      | ≥100 | 5 giant/1 supergiant | EW     | Luck (1994)                |
|           | +0.04±0.05 | 48000      | ≥170 | 6 giant | EW     | Smiljanic et al. (2009)    |
| NGC 3680  | -0.04±0.03 | 100000     | ~80 | 2 G dwarf | EW     | Pace et al. (2008)         |
|           | +0.04±0.10 | 48000      | 200 | 1 giant  | EW     | Smiljanic et al. (2009)    |
| NGC 3960  | +0.02±0.04 | 45000      | ≥95 | 6 giant | EW     | Santos et al. (2009)       |
| NGC 4349  | -0.12±0.06 | 50000      | 200–300 | 3 giant | EW     | Santos et al. (2009)       |
| NGC 5460  | +0.05±0.24 | 25000      | ≥100 | 21 A B F | Syn   | Fossati et al. (2011)      |
| NGC 5822  | +0.07±0.02 | 18000      | ≥100 | 1 giant | EW     | Luck (1994)                |

5 Depending on the adopted temperature scale.
Table 12. Continued.

| Cluster     | [Fe/H]       | Resolution | S/N | N. Star              | Method | References                  |
|-------------|--------------|------------|-----|----------------------|--------|-----------------------------|
|             | +0.04±0.08   | 48000      | ≥130| 5 giant              | EW^2   | Smiljanic et al. (2009)     |
|             | +0.05±0.04   | 50000      | 200–300| 3 giant/3 dwarf       | EW     | Santos et al. (2009)        |
| NGC 6067    | +0.05±0.09   | 100000     | 50–100| 2 dwarf              | EW     | Pace et al. (2010)          |
|             | +0.15±0.11   | 100000     | 50–100| 3 giant              | EW     | Pace et al. (2010)          |
|             | +0.02±0.12   | 18000      | ≥100 | 1 supergiant         | EW     | Luck (1994)                 |
| NGC 6087    | +0.06±0.20   | 18000      | ≥100 | 2 supergiant/1 giant | EW     | Luck (1994)                 |
|             | +0.12±0.09   | 48000      | ≥150 | 3 giant              | EW^2   | Smiljanic et al. (2009)     |
|             | +0.15±0.05   | 45000      | ≥150 | 6 giant              | EW     | Mikolaitis et al. (2010)    |
| NGC 6134    | +0.12±0.04   | 47000      | ≥140 | 4 giant              | EW     | Magrini et al. (2010)       |
|             | +0.46±0.03   | 48000      | 85–180| 5 giant              | Syn    | Carretta et al. (2007)      |
| NGC 6192    | +0.36±0.07   | 47000      | 65–140| 2 giant/1 subgiant/1 dwarf | EW     | Sestito et al. (2007)      |
|             | +0.14±0.06   | 48000      | 50–150| 13 F–K dwarf         | EW^2   | Smiljanic et al. (2009)     |
| NGC 6475 M 7| +0.03±0.02   | 18000      | ≥200 | 2 B 3 F–K dwarf/2 G–K giant | EW     | Magrini et al. (2010)       |
|             | +0.37±0.03   | 47000      | ≥80  | 2 giant              | EW     | Carretta et al. (2007)      |
|             | +0.07±0.05   | 48000      | ≥160 | 2 giant              | EW     | Sestito et al. (2007)       |
|             | +0.12±0.04   | 47000      | ≥140 | 4 giant              | EW     | Magrini et al. (2010)       |
| NGC 6633    | +0.20±0.05   | 50000      | 200–300| 3 giant              | EW     | Sestito et al. (2007)       |
| NGC 6791    | +0.37±0.03   | 20000      | 30   | 1 hot HB             | EW/Syn | Peterson & Green (1998)     |
|             | +0.35±0.02   | 25000      | ≥40  | 6 giant              | Syn    | Orišić et al. (2006)        |
|             | +0.38±0.02   | 20000      | 30–60| 10 giant             | Syn    | Carraro et al. (2006)       |
|             | +0.47±0.07   | 29000      | 40–85| 4 giant              | Syn    | Carretta et al. (2007)      |
|             | +0.09±0.08   | 45000      | ~40  | 2 dwarf              | EW     | Sestito et al. (2007)       |
| NGC 6819    | +0.09±0.03   | 40000      | 130  | 3 giant              | EW     | Magrini et al. (2010)       |
| NGC 6882/5 | +0.03±0.01   | 18000      | ≥100 | 1 supergiant/1 dwarf | EW^2   | Magrini et al. (2010)       |
| NGC 6939    | +0.00±0.10   | 15000      | 70–150| 9 giant              | EW^3   | Jacobson et al. (2007)      |
| NGC 7142    | +0.08±0.06   | 15000      | 150  | 6 giant              | EW^3   | Jacobson et al. (2007)      |
|             | +0.16±0.01   | 30000      | 100–130| 4 giant              | EW     | Jacobson et al. (2008)      |
| NGC 7160    | +0.16±0.03   | 16000      | 70–300| 16 F–G dwarf         | EW     | Magrini et al. (2010)       |
| NGC 7789    | −0.04±0.05   | 30000      | ≥50  | 9 giant              | EW/Syn | Magrini et al. (2010)       |
| Pleiades M 45| +0.02±0.04   | 21000      | >70  | 28 giants            | EW^1   | Jacobson et al. (2011b)     |
|             | −0.03±0.02   | 45000      | 150  | 12 F dwarf           | EW     | Boesgaard & Friel (1990)    |
|             | −0.03±0.10   | 18000–44000| 30–100| 2 dwarf              | EW     | Randich et al. (2001)       |
|             | +0.06±0.02   | 42000–75000| 100–300| 16 A giant/5 F dwarf | Syn    | Gebran & Monier (2008)      |
| Praesepe M 44| +0.07±0.03   | 45000      | 70   | 2 dwarf              | EW     | King et al. (2000)          |
| Mel 88      | +0.07±0.05   | 40000      | 20 F–G–K dwarf       | EW     | Boesgaard & Friel (1990)    |
|             | +0.04±0.04   | 28000      | 60–190| 6 F dwarf            | EW     | Pace et al. (2008)          |
| Rup 4       | −0.09±0.04   | 40000      | 25–40 | 3 giant              | EW     | Carraro et al. (2007b)      |
| Rup 7       | −0.26±0.05   | 40000      | 25–40 | 5 giant              | EW     | Carraro et al. (2007b)      |
| Sauerer 1   | −0.38±0.01   | 34000      | ~80  | 2 G giant            | EW     | Carraro et al. (2004)       |
| To 2        | −0.50±0.10   | 34000      | 50–60 | 3 giant              | EW     | Brown et al. (1996)         |
|             | −0.28±0.01   | 21000–40000| 15–70 | 18 giant             | EW     | Frinchaboy et al. (2008)    |
Table 12. Continued.

| Cluster | [Fe/H]   | Resolution | S/N   | N. Star | Method | References                  |
|---------|----------|------------|-------|---------|--------|-----------------------------|
|          | −0.31 ±0.02 | 17000      | 60–80 | 13 giant | EW     | Villanova et al. (2010)     |
| Tr 20   | −0.11 ±0.13 | 50000      | 65    | 1 giant  | EW     | Platais et al. (2008)       |