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Loch Coire nan Arr: The dating of multiple cores using spheroidal carbonaceous particle data

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A Report from ENSIS Ltd to the AEA National Environment Technology Centre, Culham

March 1995

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Introduction

This report deals with the allocation of dates to 10 sediment cores taken from Loch Coire nan Arr in February 1994 under contract RC01513. An earlier report (Harlock & Rose, 1994) has given site details, sampling and analytical methodologies and they will not be repeated here.

The 10 cores (CNA1 to CNA10 inclusive) were analysed for percentage dry weight, percentage loss-on-ignition and spheroidal carbonaceous particle (SCP) concentration. These data were also presented in the earlier report. CNA9 was dated using a chronology constructed from the radioisotope ^{210}Pb and it is the aim of the present report to show how core correlations between CNA9 and the other cores enable dates to be allocated to the other 9 cores. This will then enable appropriate sediment levels to be amalgamated for subsequent dioxin analysis by AEA.

Methods

The ^{210}Pb chronology was supplied by the University of Liverpool under a separate contract. This is summarised for reference in Table 1.

For the purposes of correlating the sediment cores CNA1-8 and CNA10 with the dated core CNA9, three techniques were employed:

1) Dry weight / Loss-on-ignition.

There are many peaks and troughs in the dry weight (DW) and loss-on-ignition (LOI) profiles for CNA1-10. However, there are very few which occur consistently and which are significant enough that they can be identified unambiguously. Consequently, only a single dating horizon is used here, although others could almost certainly be determined using profile matching programmes.

In all cores except CNA1 (which turns out to be quite individual - see below) a DW peak and LOI trough occurs simultaneously between 10.5cm and 13.5cm. In CNA9 this feature occurs at a depth of 10.5-11.5cm corresponding to a date of 1857-1866 ± 18. As the cores were taken from a relatively small and flat area of the lake it may be assumed that a single event (e.g. mineral in-wash from the catchment) caused this feature in all cores at approximately the same time and it is therefore likely (but by no means certain) that this feature occurs at around this date in all the cores.

It should be noted that at this time the errors on ^{210}Pb dates give a time span of 36 years on this feature. It should therefore fall in the range 1840 - 1885. In comparing this dating to the SCP record it is not possible to place a consistent date on this feature although all cores except CNA1 and CNA6 would place it at the earlier end of this range i.e. 1840-1850. Both CNA1 and CNA6 are slightly unusual cores, CNA1 seemingly showing a compressed record and CNA6 having a very unusual SCP profile (see below).

The DW/LOI feature if it is to be used must be assumed to be occurring at the same time in all cores and a date of 1840-1850 will therefore be used for this feature. Where uncertainties and inconsistencies arise these are probably due to the coarse sampling interval for DW/LOI analysis giving broad peaks. This, in addition to the ^{210}Pb dating ranges, means that precise dates are not available for the feature. It could have been further defined by finer interval core extrusion followed by more detailed DW/LOI analysis but with the other information available to allocate dates this is probably unnecessary.

2) Spheroidal carbonaceous particle concentration profiles.

This is a technique that has been employed for over 10 years (Renberg & Wik, 1984; 1985) and relies on the fact that SCP profiles occur consistently in the sediments of lakes within a region. It also assumes that there is no transport or movement of particles (other than normal sediment processes) within the sediment column. Given the potential for disturbance in many lakes it is a technique which works remarkably well.

Once one or two SCP profiles within a region have been dated reliably (using ^{210}Pb or varve counting) then dates can be ascribed to other cores within that region using features of the SCP profile. In the U.K. and Ireland there are now three features of the SCP profile that can be used for dating (Rose et al., in press):

i) the start of the SCP record
ii) the start of the rapid increase in SCP concentration
iii) the near-surface SCP concentration peak.

For sediment cores taken from within Scotland these features have been allocated the dates of 1850-1860, 1960's and 1976 ± 2 respectively. However, Loch Coire nan Arr is known to be an exception to this general rule.

i) the start of the SCP record

In 1991, a sediment core (ARR5) was taken from Loch Coire nan Arr as part of the Acid Waters Monitoring Network repeat coring programme. This core was ^{210}Pb dated and analysed for SCP (Juggins et al., 1993). This showed that the start of the SCP record appeared to begin much earlier than for other sites in Scotland and also showed a 'second start' to the record i.e. the SCP profile reached a concentration of 0 gDM^{-1} (per gram dry mass sediment) at 11.5 cm increased slightly and then reached 0 gDM^{-1} again at a lower depth, 15.5cm. SCP concentrations of 0 gDM^{-1} only show that the concentration has fallen below the detection limit of the method which is usually about 50 gDM^{-1}. Where there is an 'upper 0' followed by an increase in SCP concentration at a lower sediment depth it maybe that SCP have just not been detected rather than there being a concentration of 0 gDM^{-1}. This is probably the explanation for the 'upper 0' in CNA4 (see below). However, at the base of the profile where a concentration of 0 gDM^{-1} is repeatedly found at successive sediment levels it can be concluded that the bottom of the SCP record has been reached. It must be remembered that profiles are highly dependant on the sampling and analysis interval for each core. For example, the lowest analysed sediment level in ARR5 above the upper 0 is 9.5cm and the 0 value is recorded at 11.5cm. Therefore, the start of the SCP record occurs at some point between the two rather than exactly at 11.5cm (i.e. between 1879 and 1830).

[The presence of SCP at a sediment depth below the 'first 0' is usually attributed to core smearing, whereby SCP from upper levels where concentrations are high are pushed down the side of the core tube to lower levels as the tube enters the sediment. However, this feature appears to occur quite frequently with Loch Coire nan Arr sediment cores (e.g. ARR5, CNA4, 7 & 9) and may be a feature of sediment accumulation peculiar to this loch.]

The date at which the SCP profile reaches 0 gDM^{-1} for the first time (from the top down) in CNA9 is 12.5cm which corresponds to a ^{210}Pb date of 1849 ± 16 (i.e. 1865 - 1833). In CNA9 contiguous samples have been analysed for SCP and so this is probably a fairly accurate date. This compares well with the ARR5 dates and therefore is also probably a good date for the start of the SCP record. This also compares well with other dated sediment cores in Scotland where this feature is usually allocated the date 1850's.

The upper 0 for cores CNA7 and 9 should therefore be used as the start of the SCP record.

ii) the start of the rapid increase in SCP concentration.

A rapid increase in SCP concentration occurs in virtually all analysed sediment cores and is generally attributed to the post-War boom in the electricity generating industry in the U.K. In Scotland this feature usually dates to the 1960's although it is sometimes a little earlier. There are profiles however, where the change from the slow, steady increase in SCP concentration in the early years of the 20th century to a post-War rapid increase could be ambiguous. In such cases the feature is usually ascribed to the depth at which the intercept of the extrapolated gradients of the slow steady increase and the rapid increase occurs (Rose et al, in press).

In CNA9 the rapid increase occurs at 5.0 - 5.5cm which corresponds to a ^{210}Pb date of 1930/1 ± 3 and this is considerably earlier than is generally the case in Scottish sites including the 1991 core ARR5 where the rapid increase occurs at 3.75cm corresponding to a ^{210}Pb date of 1960 ± 2. Why this occurs in CNA9 is unclear.

iii) the near-surface SCP concentration peak

In previous studies, this feature has proved to be the most useful as it is usually the least ambiguous of the three features and spans the smallest time period. The only time that there is confusion is when there are several peaks of similar concentration (e.g. CNA6) but these can still usually be sorted out fairly simply by considering the positions of the other features present within the profile.

In CNA9 this feature occurs at 1.5 - 2.0 cm depth corresponding to a ^{210}Pb date of 1976 ± 2 which agrees exactly with the date generally ascribed to this feature in Scottish cores (1976 ± 2) (Rose et al., in press). The 1991 ARR5 core also agrees on this feature and gives a ^{210}Pb peak date of 1974 ± 2.

A summary of these dates is given in Table 2.

3) Cumulative SCP concentration diagrams

No published work exists where multiple cores taken from the same site at the same time have been analysed for SCP. Renberg & Hultberg (1992) analysed two cores taken from a Swedish lake, Lysevatten, in March 1985 and February 1986 and this is the nearest to 'simultaneous' profiles to date. These cores showed similar profiles but differences in concentrations and differences in, for example, the depth of the peak and the start of the record by several cm. The 1985 core was ^{210}Pb dated and the SCP profiles used for correlation purposes.

The present study, with ten cores taken over a two day period, allows us to:

i) ascertain how consistent SCP profiles are when taken from a small area within the same lake over a very short period; and

ii) to show how useful such an approach is for cross correlation of cores and the allocation of dates.

All data and profiles for CNA1-10 are produced in the earlier report (Harlock & Rose, 1994) and will not be reproduced here. However, it is clear that although the SCP features described above are present in all cores (except the start of the record where the core is of insufficient length e.g. CNA1) the profiles show a remarkable variety of shapes. Taken in isolation dates could be allocated to any of these profiles using the SCP approach but the interest here is how these relate one to another. Concentrations between cores also vary considerably, for example, the peak concentration varies between 6,169 (CNA4) and 11,371 gDM^{-1} (CNA5).

The 10 cores were taken from a relatively small, flat area of Loch Coire nan Arr just north of the deepest part of the basin. There is no reason why the flux of SCP to any one part of this area should be very different from another, and it is likely that differences in the profile are due to sedimentary reasons such as variations in sediment accumulation rate rather than differences in numbers of SCP reaching the sediment.

An alternative method of correlation is to use comparisons of the cumulative concentration for each core by setting the start of the SCP record to 0% and adding each analysed level such that the surface then corresponds to 100%. This has the effect of 'smoothing' the data so that small peaks and troughs are less important and removes the influence of small sedimentary changes. The cumulative SCP diagram for CNA9 is shown in Figure 1. As this core has been ^{210}Pb dated it is possible to replace the sediment depth on the x-axis with ^{210}Pb dates so that, for example, 10% is reached at 5.5cm corresponding to 1929 ± 3. This has been done for each 10 percentile and the results are shown in Table 3.

10% is reached at 1929 ± 3 and 80% is reached at 1976 ± 2 the dates corresponding to the rapid increase in SCP concentration and the SCP concentration peak in CNA9.

Figure 2 shows how the cumulative SCP diagrams for cores CNA3, 4, 5, 6, & 7 compare with CNA9. The comparison for all of these cores is remarkably good and supports the idea that SCP deposition at these coring locations has been very similar over at least the last 70-80 years. Between 20% and 60% the curves for these cores are within ± 0.25cm (approximately corresponding to ± 3 years, very similar to ^{210}Pb error), but variance is larger both above (± 0.5cm between 70% and 90%, equivalent to about 5 ^{210}Pb years) and below (± 1cm at 10%, equivalent to ± 10 ^{210}Pb years). It should be noted that these errors are a maximum as they are the range between the highest and lowest curves. CNA9 appears to run through the centre of the range and so errors between individual core curves and the dated curve are lower.

Figure 3 shows how cores CNA2 and 10 compare to CNA9. CNA10 shows similar agreement to the cores shown in Figure 2, as does CNA2 below 5cm. However, CNA2 falls to 0 gDM^{-1} at 3.5 - 4cm and this effects the cumulative graph above this depth. The reason for this is unclear although other profiles (e.g. CNA8 & 10) also show marked troughs but do not fall to 0 and hence show better comparison with the CNA9 curve. This may be due to a sedimentary irregularity although nothing unusual can be seen on the DW/LOI diagrams. CNA1 has not been included on these profiles as being a shorter core different levels were analysed (see below) and CNA8 is not included as the top sample was lost and this would affect calculated cumulative percentages.

The similarities between these cores increases confidence in the allocation of dates using this approach. It means that more dates can be ascribed to each core (9 between 1929 and 1994) with known errors for each date. This is an improvement on 'traditional' SCP dating where only 3 dates are available.

Comparing the three approaches should enable a chronology to be constructed for each core and these are dealt with individually below.

The cores

CNA1

At only 10cm long CNA1 is considerably shorter than the other nine cores. The LOI trough / DW peak which falls between 10.5 and 13.5cm in CNA2 - 10 is therefore either below the base of CNA1 or is represented by the feature at 6 - 6.5cm. If the latter is true, then from (1) this dates to 1840 - 1885 making the record of the last 150 years quite compressed (cf. CNA2 - 10). As mentioned above CNA1 is unique amongst this set of cores and it is probably best not to place too much emphasis on this DW/LOI feature, but rely more on the SCP results.

The SCP concentration profile shows a peak at 1.1cm (≡ 1976 ± 2) and a rapid increase at 3.6cm (≡ 1930 ± 3). These dates are fairly self-consistent giving an accumulation rate of 0.56 - 0.60 mm yr^{-1}. The profile shows a long flat period towards the base of the core and the presence of SCP at the lower depths could be due to core smearing.

The cumulative SCP concentration is shown in Figure 4. Dates can be allocated by comparison with the CNA9 '10 percentiles' and the results are shown in Table 4. 80% is attained at 1.1cm (≡ 1976 ± 2) corresponding with the SCP peak at the same depth. 10% is reached at 3.9cm (≡ 1929 ± 3) which also agrees well with the rapid increase date of 1930 ± 3 at 3.6cm. Cumulative SCP diagrams only give dates back to 1929 and so it may be worth extrapolating back to obtain further dates from this approach, especially as the start of the SCP record is doubtful. Figure 5 shows that the depth/date relationship for cumulative SCP is a straight line suggesting that accumulation rate is consistent throughout CNA1 (cf. CNA9 where accumulation varies - see dating report). If this is true then 1840 -1885 falls in the depth range 8.5 - 6.5cm as for the SCP profiles.

A summary for CNA1 would then be as follows:

Depth (cm)	Date
0.0	1994
0.5	1986 ± 3
1.0	1977 ± 3
1.5	1969 ± 3
2.0	1957 ± 3
2.5	1950 ± 3
3.0	1940 ± 3
3.5	1934 ± 5
4.0	1925 ± 5
5.0	1905 ± 10
6.0	1890 ± 10
7.0	1870 ± 10

CNA2

The DW/LOI feature is very broad for CNA2 and falls between 12.5 and 14.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP profile is slightly unusual as the trough at 3.75cm (cf. CNA5, 8 & 10) falls to 0 gDM^{-1} and this also has an effect on the cumulative SCP diagram (see below). The start of the SCP record is between 9.5 and 12.5cm but is likely to be nearer to the lower end of this range if it is to agree with the DW/LOI feature. The rapid increase is at 3.5cm (≡ 1930 ± 3) but this is probably a little high due to the 0 anomaly. Without this 0 the rapid increase would be at a slightly lower level. The peak in SCP concentration is at 1.25cm (≡ 1976 ± 2) giving an accumulation rate of 0.69 mm yr^{-1}. This rate, if constant, would put 1930 (the proposed date of the rapid increase) at 4.4cm which would agree with the hypothesis that the 0 point has moved the rapid increase to a higher sediment level. However this accumulation rate would put 1850 (the date for the start of the SCP record) at 10cm which although falling within the range mentioned above is probably too close to 9.5cm to be realistic. In CNA9 there is an increase in accumulation rate between 1850 and 1875 and if this also occurs in CNA2 then that would place the start of the record lower than 10cm consistent with a DW/LOI date of 1840-1850.

The cumulative SCP diagram (Figure 6) is also effected by the 0 point on the profile resulting in a flat area on the curve between 3.25 and 4.25cm. This probably only effects the dating of the 20% level (≡ 1938 ± 3), currently 4.4cm, and the 10% level (≡ 1929 ± 3). The cumulative dating of these levels is therefore probably not accurate. 80% which is expected to coincide with the SCP peak does so, both occurring at the same depth 1.25cm (≡ 1976 ± 2). Dates must therefore be extrapolated between 1944 and 1850, and this can be done such that the accumulation rate variability is consistent with CNA9. A summary of CNA2 would then be as follows:

Depth (cm)	Date
0.0	1994
0.5	1987 ± 3
1.0	1981 ± 3
1.5	1970 ± 3
2.0	1958 ± 3
2.5	1951 ± 3
3.0	1944 ± 3
4.0	1932 ± 7
5.0	1919 ± 10
6.0	1907 ± 10
7.0	1894 ± 10?
8.0	1882 ± 10?
9.0	1874 ± 10?
10.0	1868 ± 10?
11.0	1860 ± 10?
12.0	1852 ± 10?

CNA3

The DW/LOI feature for CNA3 occurs at 13.5cm. This feature has been ascribed the date range 1840 - 1850.

There is no start to the SCP record at the base of the core and this may be due to core smearing. The rapid increase in SCP concentration occurs at 5.5cm (≡ 1930 ± 3) and the peak occurs at 2.75cm (≡ 1976 ± 2). These dates and depths cannot be consistent and give sediment accumulation rates of 0.85 and 1.52 mm yr^{-1} respectively suggesting variability in sediment accumulation rate through the period covered by the core.

The cumulative SCP concentration curve is shown in Figure 7 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 5.2cm which agrees fairly well with the SCP rapid increase. 1976 ± 2 (80%) is at 1.4cm which agrees well with the depth at which the peak should occur if the accumulation rate was consistent at 0.85mm yr^{-1}. This accumulation rate puts 1850 at 12-12.5cm but allowing for an increase in sediment accumulation bewteen 1880 and 1850 then this may be slightly lower, consistent with the DW/LOI feature. The dating is likely to be as follows:

Depth (cm)	Date
0.0	1994
0.5	1985 ± 3
1.0	1979 ± 3
1.5	1975 ± 3
2.0	1970 ± 3
2.5	1964 ± 3
3.0	1957 ± 3
4.0	1943 ± 5
5.0	1931 ± 10
6.0	1918 ± 10?
7.0	1905 ± 10?
8.0	1893 ± 10?
9.0	1880 ± 10?
10.0	1872 ± 10?
11.0	1864 ± 10?
12.0	1856 ± 10?
13.0	1845 ± 10?

CNA4

The DW/LOI feature for CNA4 occurs at 13.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP profile for CNA4 is unlike any other in this set of cores and it makes the rapid increase difficult to determine. The peak is at 0.5 - 1cm (≡ 1976 ± 2) and it is likely that the rapid increase occurs at about 5cm (≡ 1930 ± 3). In the 'Methods' described above it was suggested that the upper '0 concentration' would be allocated as the start of the record. In CNA4, however, this is unlikely to be the case as this would put 1850 at a maximum depth of 9.5cm which would mean a drastic reduction in sediment accumulation rate between 1930 and 1850. This is not impossible but is unlikely as other CNA cores suggest that sediment accumulation increases during this period. In CNA4 therefore the start of the SCP record is likely to be at the lower 0 i.e. between 12.5 and 15.5cm, consistent with the DW/LOI feature.

The cumulative SCP concentration curve is shown in Figure 8 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 6.3cm and 1938 ± 3 (20%) at 4.5cm, depths and dates which fall either side of the rapid increase depth and date of 1930 ± 3 at 5cm. 1976 ± 2 (80%) is placed at 1.2cm a little lower than the SCP peak (0.5 - 1cm). Generally though all the dates agree fairly well and a summary is likely to be:

Depth (cm)	Date
0.0	1994
0.5	1986 ± 3
1.0	1978 ± 3
1.5	1973 ± 3
2.0	1967 ± 3
2.5	1962 ± 3
3.0	1954 ± 3
4.0	1942 ± 5
5.0	1935 ± 10
6.0	1922 ± 10?
7.0	1909 ± 10?
8.0	1897 ± 10?
9.0	1884 ± 10?
10.0	1876 ± 10?
11.0	1868 ± 10?
12.0	1860 ± 10?
13.0	1852 ± 10?

CNA5

The DW/LOI feature for CNA5 occurs at 13.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP record begins between 13 and 15.5 cm (1850). The rapid increase (1930 ± 3) is at 5.5cm and the SCP peak (1976 ± 2) is at 2.5 - 3cm. These give sediment accumulation rates of 1.16 and 1.52 mm yr^{-1} respectively.

The cumulative SCP concentration curve is shown in Figure 9 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 5.5cm, which agrees well with the rapid increase depth/date of 1930 ± 3 at 5.5cm. 1976 ± 2 (80%) is placed at 1.9cm a little higher than the SCP peak (2.5 - 3cm), but close to the depth assigned to 1976 (2cm) with an accumulation rate of 1.16 mm yr^{-1}.

A summary for CNA5 is then as follows:

Depth (cm)	Date
0.0	1994
0.5	1988 ± 3
1.0	1983 ± 3
1.5	1978 ± 3
2.0	1974 ± 3
2.5	1970 ± 3
3.0	1958 ± 3
4.0	1944 ± 5
5.0	1935 ± 10
6.0	1921 ± 10?
7.0	1908 ± 10?
8.0	1894 ± 10?
9.0	1881 ± 10?
10.0	1872 ± 10?
11.0	1864 ± 10?
12.0	1858 ± 10?
13.0	1850 ± 10?

CNA6

The DW/LOI feature for CNA6 occurs at 11.5cm. This feature has been ascribed the date range 1840 - 1850 but as has been mentioned CNA6 shows a unique SCP profile and it may be that the coarse sampling interval has put this feature too high.

The SCP record begins between 13 and 15.5 cm (1850) and the rapid increase (≡ 1930 ± 3) is at 5cm. There are 3 peaks near the surface of the core but although the lowest one is the maximum concentration it is unlikely to be at 1976 as it is so close to the rapid increase. The rapid increase depth/date gives an accumulation rate of 0.78 mm yr^{-1} which would put the start of the record (1850) at 11-11.5cm and 1976 at 1.5cm. Although this depth for the start agrees well with the DW/LOI date, it is too high for the SCP profile, although it has not taken into account the increased sediment accumulation between 1880 and 1850 seen in CNA9. This depth for the peak means the middle peak is most likely to correspond to 1976.

The cumulative SCP concentration curve is shown in Figure 10 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 6.9cm which is considerably lower than the SCP rapid increase depth of 5.5cm (1930 ± 3). 1976 ± 2 (80%) is placed at 1.7cm which agrees well with the middle SCP peak.

Taking the middle peak (1.75cm) at 1976 ± 2, this gives an accumulation rate of 0.94 mm yr^{-1}, which if consistent would put the rapid increase at about 6cm and a start to the SCP record of 13.5cm, within the range suggested by the SCP profile and not too inconsistent with the DW/LOI feature if this is at the upper end of the 1844-1880 range (cf. CNA1). However, this does not take into account the increase in accumulation rate between 1850 and 1880. A summary for CNA6 is therefore likely to be:

Depth (cm)	Date
0.0	1994
0.5	1989 ± 3
1.0	1983 ± 3
1.5	1978 ± 3
2.0	1971 ± 3
2.5	1965 ± 3
3.0	1959 ± 3
4.0	1946 ± 5
5.0	1936 ± 10
6.0	1923 ± 10?
7.0	1910 ± 10?
8.0	1897 ± 10?
9.0	1885 ± 10?
10.0	1877 ± 10?
11.0	1869 ± 10?
12.0	1861 ± 10?
13.0	1853 ± 10?

CNA7

The DW/LOI feature for CNA7 occurs at 13.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP record begins between 9.5 and 12.5 cm (1850) which is consistent with the DW/LOI feature. The most distinctive feature, the rapid increase (≡ 1930 ± 3), is at 5cm. The maximum SCP concentration is at 4.5 - 5.0cm which is very close to the rapid increase. It may therefore be that 1976 is represented by a second peak, although smaller, at 1.25cm (cf. CNA6). The rapid increase depth/date gives a sediment accumulation rate of 0.78 mm yr^{-1} which would put 1976 at 1.4cm, agreeing with the smaller near surface peak.

The cumulative SCP concentration curve is shown in Figure 11 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 5.8cm and 1938 ± 3 (20%) either side of the 1930 rapid increase. 80% (1976) is attained at 1.6cm, also agreeing with the SCP profile if the smaller peak represents 1976. A summary of CNA7 dating would therefore be:

Depth (cm)	Date
0.0	1994
0.5	1988 ± 3
1.0	1982 ± 3
1.5	1977 ± 3
2.0	1972 ± 3
2.5	1966 ± 3
3.0	1959 ± 3
4.0	1945 ± 5
5.0	1933 ± 10
6.0	1920 ± 10?
7.0	1906 ± 10?
8.0	1892 ± 10?
9.0	1878 ± 10?
10.0	1870 ± 10?
11.0	1862 ± 10?
12.0	1853 ± 10?

CNA8

The DW/LOI feature for CNA8 occurs at 10.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP profile for CNA8 is similar to those of CNA2 & 10. The surface sample was lost for this core and so no cumulative diagram is available. However, CNA2 and CNA10 cumulative diagrams closely match CNA9 and so CNA8 is expected to date in a similar way.

The start of the SCP record (1850) is between 7.5 and 9.5cm although the SCP profile is such that it is probably nearer to the bottom of this range and therefore agrees quite well with the DW/LOI feature. The rapid increase (1930 ± 3) is at 3.5 - 4.0cm and the peak (1976 ± 2) at 1.5-1.75cm. These give sediment accumulation rates of 0.58 mm yr^{-1} and 0.90 mm yr^{-1} respectively and it is the former which more closely agrees with the rest of the SCP profile. However, it must be considered that this is a shorter core than most of the others and also the sediment accumulation rate may vary.

Extrapolating these dates, the most likely dating for CNA8 is therefore:

Depth (cm)	Date
0.0	1994
0.5	1987 ± 3
1.0	1980 ± 3
1.5	1972 ± 3
2.0	1963 ± 3
2.5	1954 ± 3
3.0	1945 ± 3
4.0	1927 ± 5
5.0	1913 ± 10
6.0	1899 ± 10?
7.0	1885 ± 10?
8.0	1873 ± 10?
9.0	1861 ± 10?
10.0	1854 ± 10?
11.0	1846 ± 10?

CNA10

The DW/LOI feature for CNA10 occurs at 12.5cm. This feature has been ascribed the date range 1840 - 1850.

The SCP record begins between 9.5 and 12.5 cm (1850) but from the profile shape and the DW/LOI feature is more likely to be towards the bottom of this range. The rapid increase (≡ 1930 ± 3) is at 4.5 - 5cm and the SCP peak is at 1.5 - 2.0cm.

The cumulative SCP concentration curve is shown in Figure 12 and the depths for each 10 percentile shown in Table 4. This places 1929 ± 3 (10%) at 7.9cm which is considerably lower than the SCP rapid increase depth of 4.5 - 5cm (1930 ± 3). 1976 ± 2 (80%) is placed at 1.6cm which agrees well with the SCP peak at 1.5 - 2.0cm. The large, broad lower peak in the SCP profile may effect the cumulative profile and allocated dates for the 10% and 20% levels may have larger errors than usual associated with them. A summary for CNA10 is as follows:

Depth (cm)	Date
0.0	1994
0.5	1987 ± 3
1.0	1981 ± 3
1.5	1975 ± 3
2.0	1968 ± 3
2.5	1960 ± 3
3.0	1954 ± 3
4.0	1942 ± 5
5.0	1927 ± 10
6.0	1915 ± 10?
7.0	1903 ± 10?
8.0	1890 ± 10?
9.0	1876 ± 10?
10.0	1867 ± 10?
11.0	1858 ± 10?
12.0	1850 ± 10?

Summary

Combining three approaches, the use of DW/LOI diagrams, the SCP record, and the use of SCP cumulative concentration diagrams, 10 cores taken from the same small area of a lake over a two day period can be cross-correlated and dated. This is the first time that this approach has been used for multiple cores taken from a lake over such a short period and it shows that despite variation within SCP profiles the cumulative concentration approach is potentially a very powerful one. It not only 'smooths' minor variations within the SCP profile making them easier to interpret (see CNA4) but also adds significantly to the number of dates that can be confidently allocated to a core.

A summary of the allocated dates is shown in Table 5.

References

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Juggins, S., Shaw, C., Patrick, S., Monteith, D.T., Beaumont, W.R.C. & Reed, J. (1993). *The United Kingdom Acid Waters Monitoring Network Data Report for 1992-1993 (Year 5).* Report to the Department of the Environment and the Department of the Environment Northern Ireland. ENSIS Publishing. 126pp.

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Table 1. ^{210}Pb chronology of CNA9 - Summary table.

Depth (cm)	Date	±
0.00	1994	0
0.25	1992	2
0.50	1990	2
0.75	1988	2
1.00	1985	2
1.25	1983	2
1.50	1980	2
1.75	1976	2
2.00	1973	2
2.25	1970	2
2.50	1967	2
2.75	1963	2
3.00	1960	2
3.25	1956	2
3.50	1953	2
3.75	1950	2
4.00	1947	2
4.25	1944	2
4.50	1941	3
4.75	1938	3
5.00	1935	3
5.50	1929	3
6.00	1922	4
6.50	1915	5
7.00	1908	6
7.50	1900	8
8.00	1892	10
8.50	1884	12
9.00	1879	14
9.50	1875	16
10.00	1870	17
10.50	1866	19
11.00	1862	18
11.50	1857	18
12.00	1853	17
12.50	1849	16
13.00	1830	17

Table 2. Summary of dates for features allocated to SCP profiles, for CNA9, the 1991 core ARR5 (Juggins et al., 1993) and generally for Scotland (Rose et al., in press).

	CNA9	ARR5	Scotland
Start of SCP record	1833 - 1865	1830 - 1879	1850's
Rapid increase	1930 ± 3	1960 ± 2	1960's
Near-surface peak	1976 ± 2	1974 ± 2	1976 ± 2

Table 3. ^{210}Pb dates for each '10 percentile' of the CNA9 cumulative SCP diagram (Figure 1).

10 percentile	Sediment depth (cm)	^{210}Pb date
10	5.5	1929 ± 3
20	4.7	1938 ± 3
30	4.1	1945 ± 2
40	3.6	1951 ± 2
50	3.1	1958 ± 2
60	2.7	1963 ± 2
70	2.3	1970 ± 2
80	1.8	1976 ± 2
90	1.4	1981 ± 2
100	0.0	1994 ± 0

Table 4 Sediment depths and dates for each 10 percentile for the CNA cores.

CNA9		CNA 1	CNA 2	CNA 3	CNA 4	CNA 5	CNA 6	CNA 7	CNA 10
%	Date								
10	1929	3.9	6.6	5.2	6.3	5.5	6.9	5.8	7.9
20	1938	3.1	4.4	4.3	4.5	4.7	4.7	4.5	5.2
30	1945	2.8	2.9	3.9	3.8	4.0	4.1	4.1	3.4
40	1951	2.4	2.5	3.4	3.3	3.5	3.7	3.7	3.2
50	1958	2.0	2.1	3.0	2.8	3.1	3.2	3.2	2.7
60	1963	1.7	1.7	2.6	2.4	2.8	2.6	2.7	2.3
70	1970	1.4	1.5	2.0	1.7	2.5	2.1	2.2	1.9
80	1976	1.1	1.3	1.4	1.2	1.9	1.7	1.6	1.6
90	1981	0.8	0.9	0.7	0.8	1.1	1.1	1.0	0.9
100	1994	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5. Summary dating table for CNA1-10. Errors are included in individual core summaries (see text).

	CNA 1	CNA 2	CNA 3	CNA 4	CNA 5	CNA 6	CNA 7	CNA 8	CNA 9	CNA 10
0.0	1994	1994	1994	1994	1994	1994	1994	1994	1994	1994
0.5	1986	1987	1985	1986	1988	1989	1988	1987	1990	1987
1.0	1977	1981	1979	1978	1983	1983	1982	1980	1985	1981
1.5	1969	1970	1975	1973	1978	1978	1977	1972	1980	1975
2.0	1957	1958	1970	1967	1974	1971	1972	1963	1973	1968
2.5	1950	1951	1964	1962	1970	1965	1966	1954	1967	1960
3.0	1940	1944	1957	1954	1958	1959	1959	1945	1960	1954
4.0	1925	1932	1943	1942	1944	1946	1945	1927	1947	1942
5.0	1905	1919	1931	1935	1935	1936	1933	1913	1935	1927
6.0	1890	1907	1918	1922	1921	1923	1920	1899	1922	1915
7.0	1870	1894	1905	1909	1908	1910	1906	1885	1908	1903
8.0		1882	1893	1897	1894	1897	1892	1873	1892	1890
9.0		1874	1880	1884	1881	1885	1878	1861	1879	1876
10.0		1868	1872	1876	1872	1877	1870	1854	1870	1867
11.0		1860	1864	1868	1864	1869	1862	1846	1862	1858
12.0		1852	1856	1860	1858	1861	1853		1853	1850
13.0			1845	1852	1850	1853			1830	

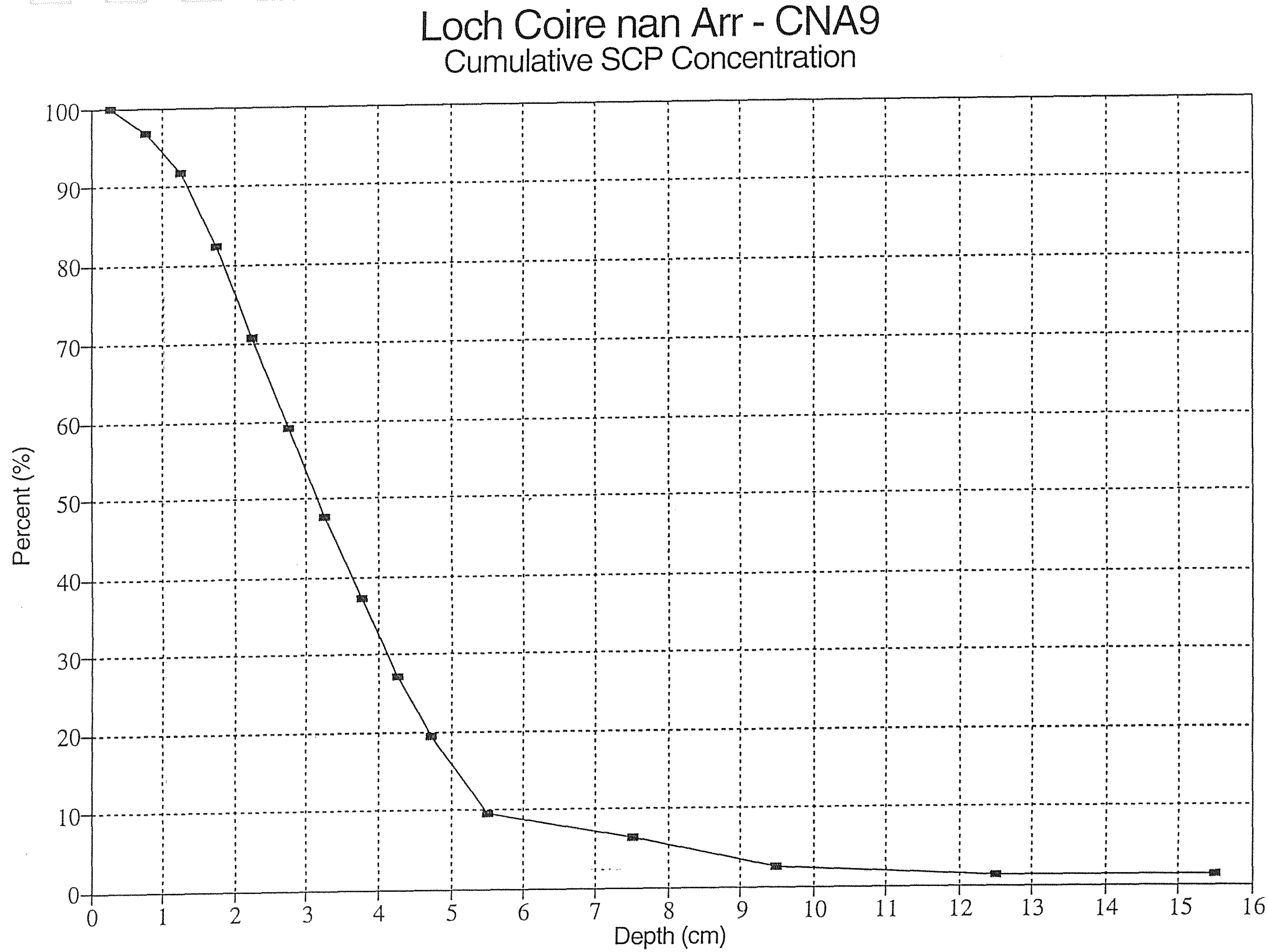
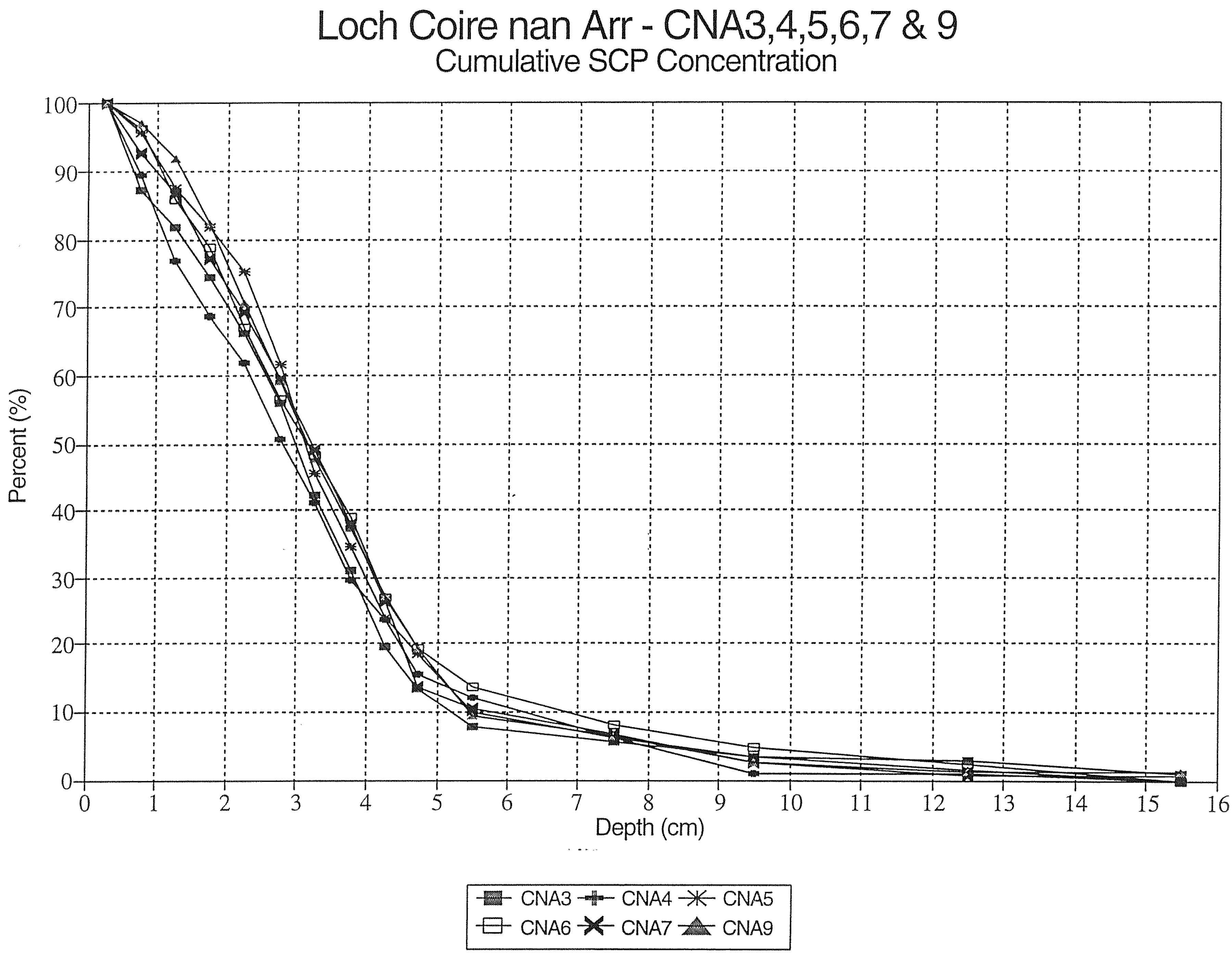

Loch Coire nan Arr - CNA9
Cumulative SCP Concentration
Percent (%)
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 1



Loch Coire nan Arr - CNA3,4,5,6,7 & 9
Cumulative SCP Concentration
Percent (%)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Depth (cm)
CNA3
CNA4
CNA5
CNA6
CNA7
CNA9

Figure 2

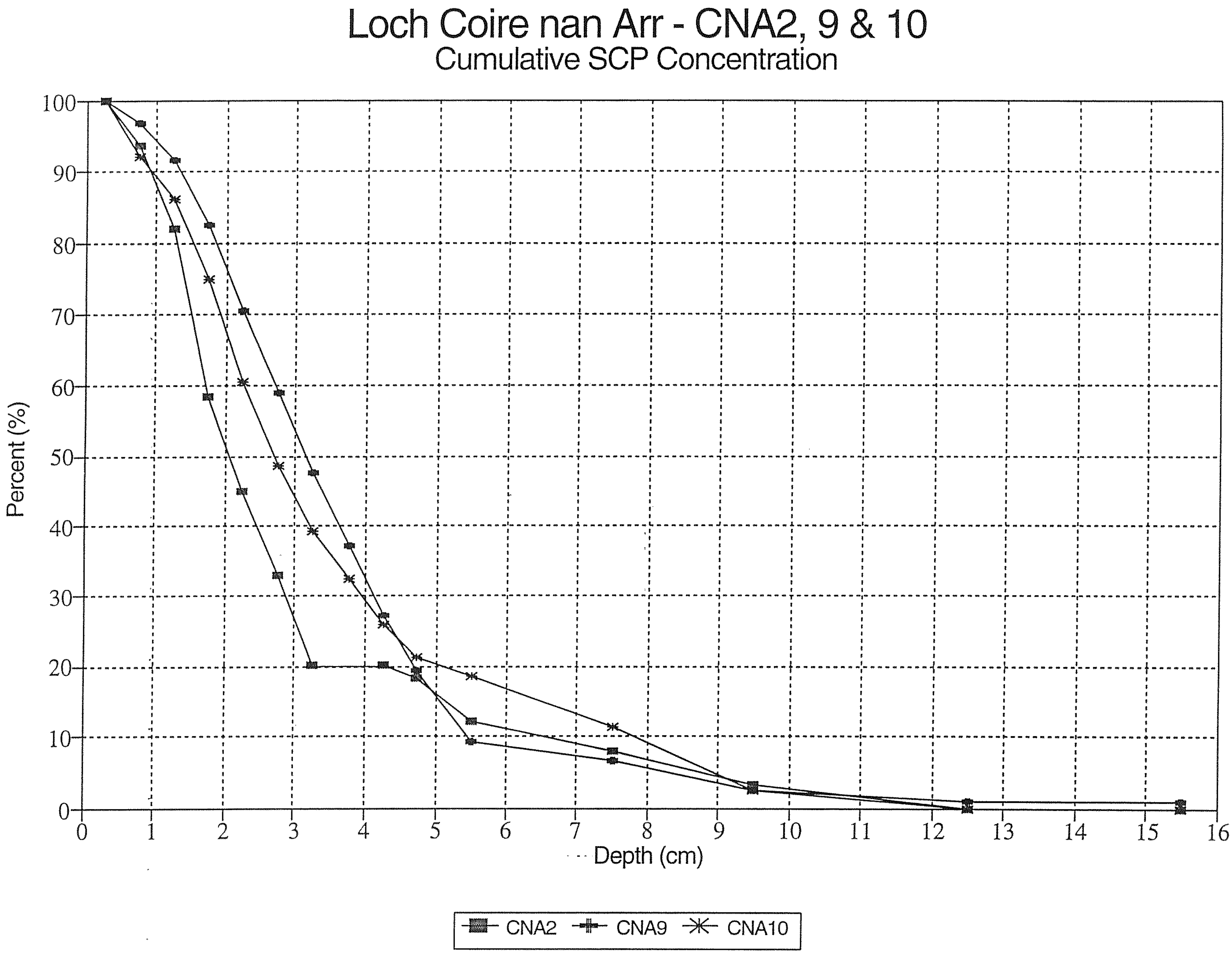
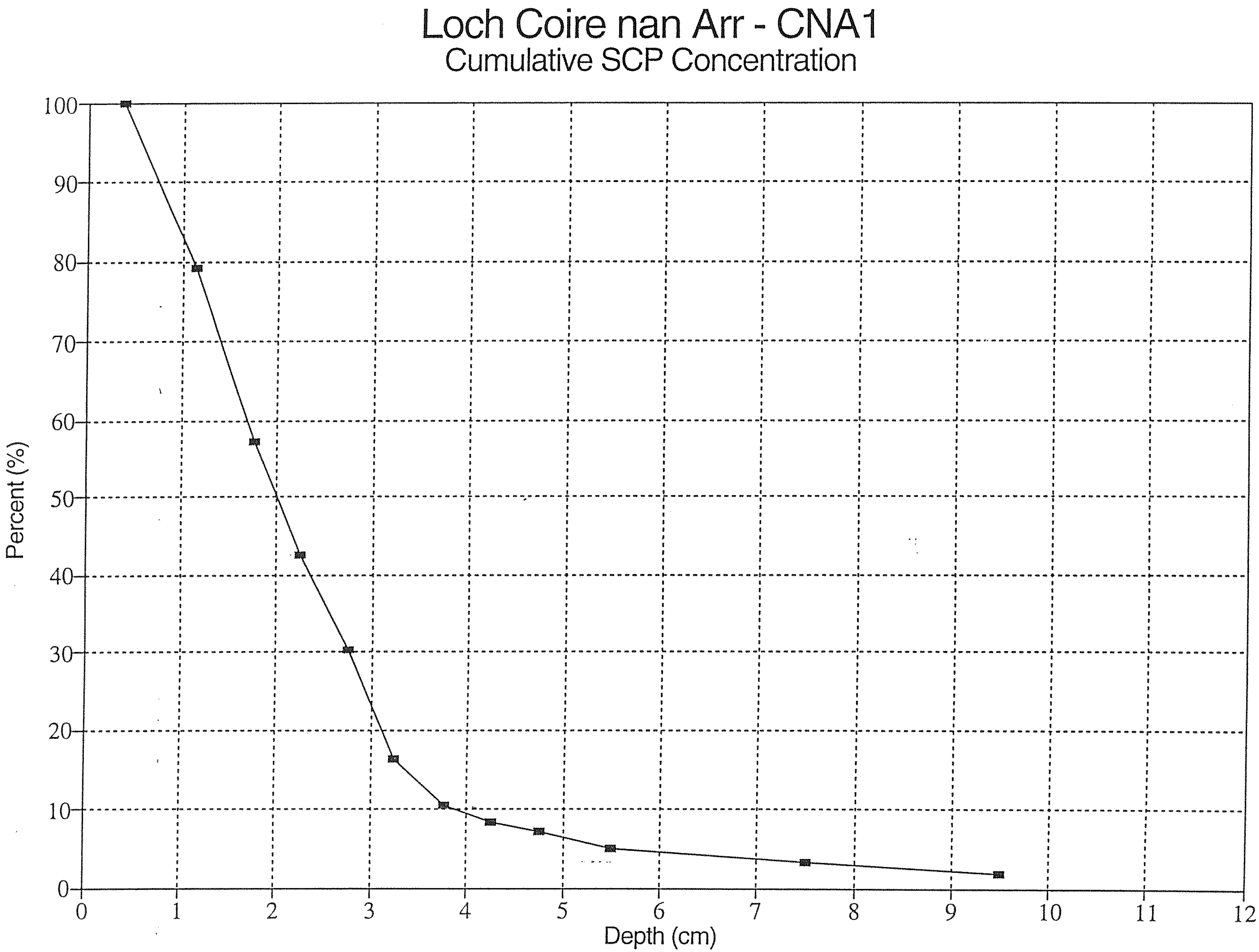

Loch Coire nan Arr - CNA2, 9 & 10
Cumulative SCP Concentration
Percent (%)
0
10
20
30
40
50
60
70
80
90
100
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
CNA2
CNA9
CNA10

Figure 3



Loch Coire nan Arr - CNA1
Cumulative SCP Concentration
Percent (%)
0
10
20
30
40
50
60
70
80
90
100
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12

Figure 4

Loch Coire nan Arr (CNA1)
Depth/Date Graph

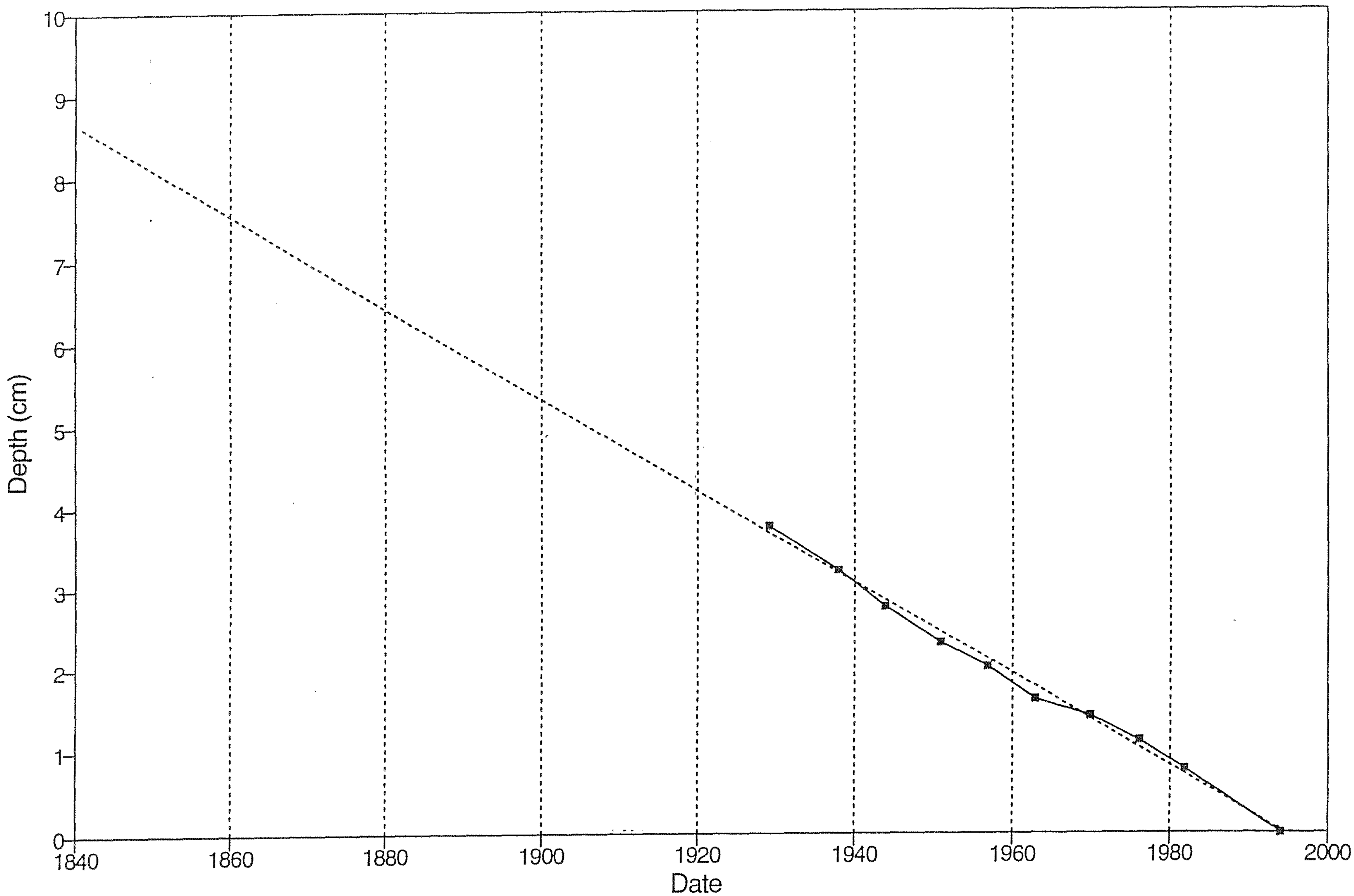


Figure 5

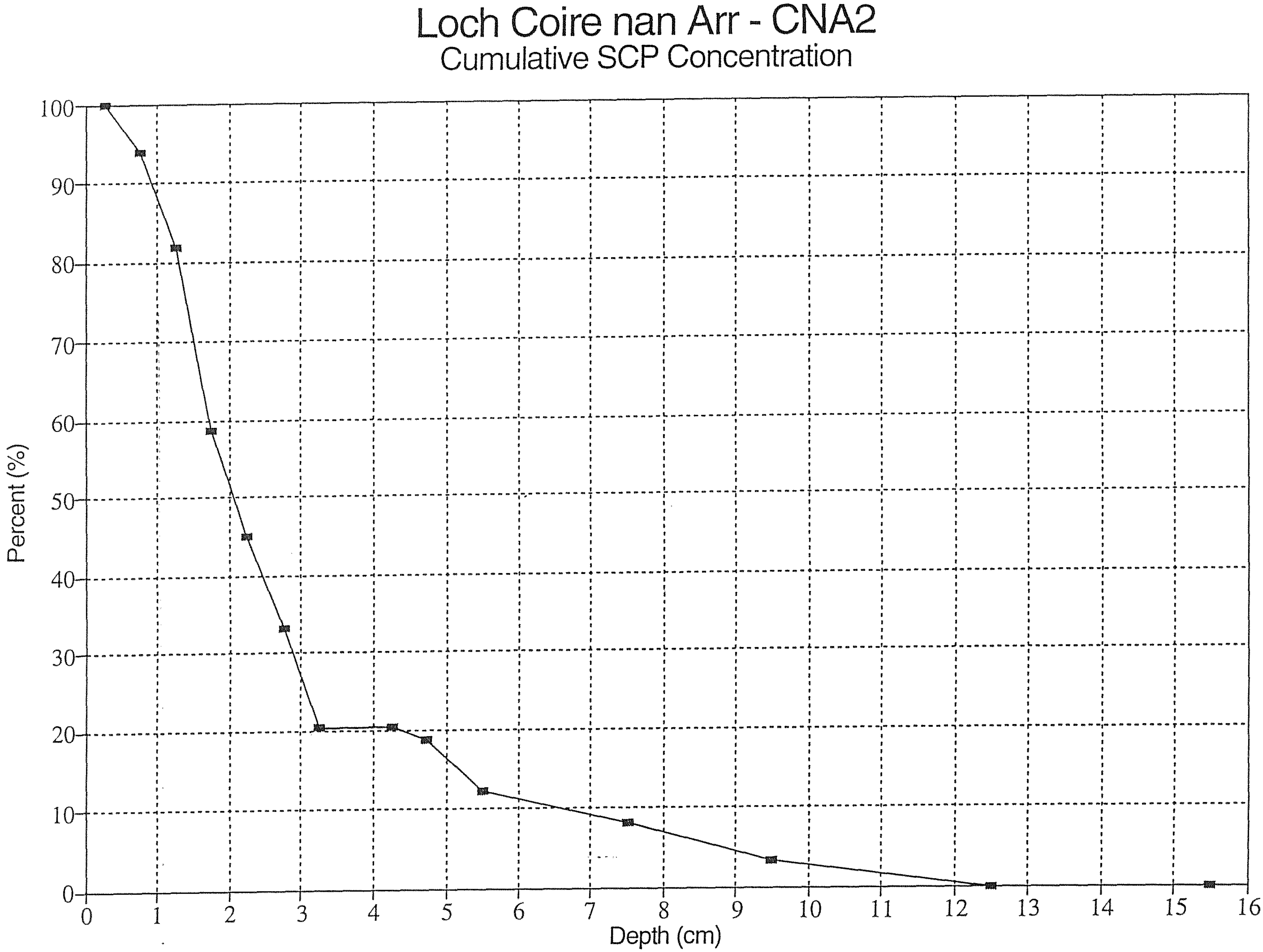

Loch Coire nan Arr - CNA2
Cumulative SCP Concentration
Percent (%)
100
90
80
70
60
50
40
30
20
10
0
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 6

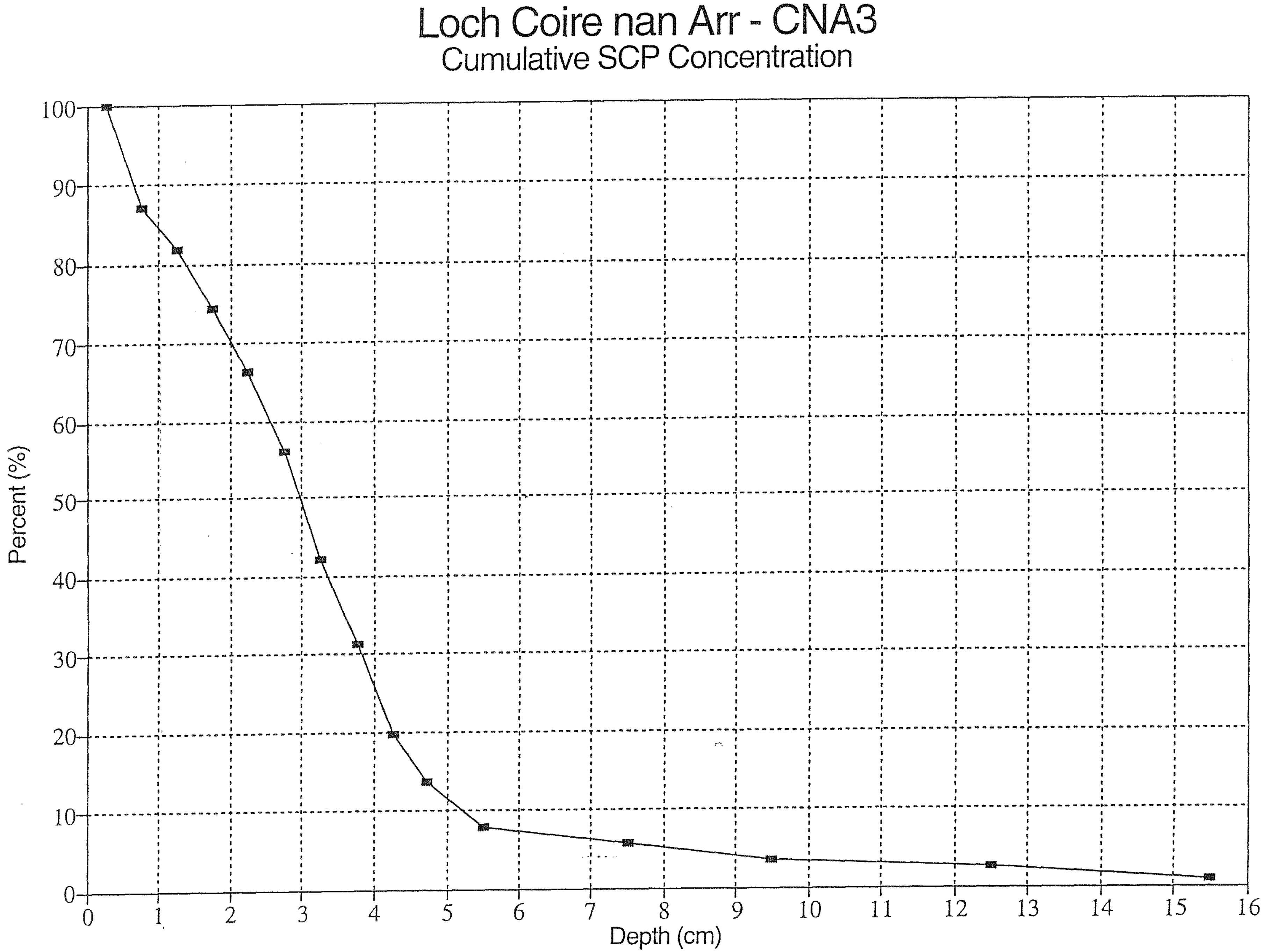

Loch Coire nan Arr - CNA3
Cumulative SCP Concentration
Percent (%)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Depth (cm)

Figure 7

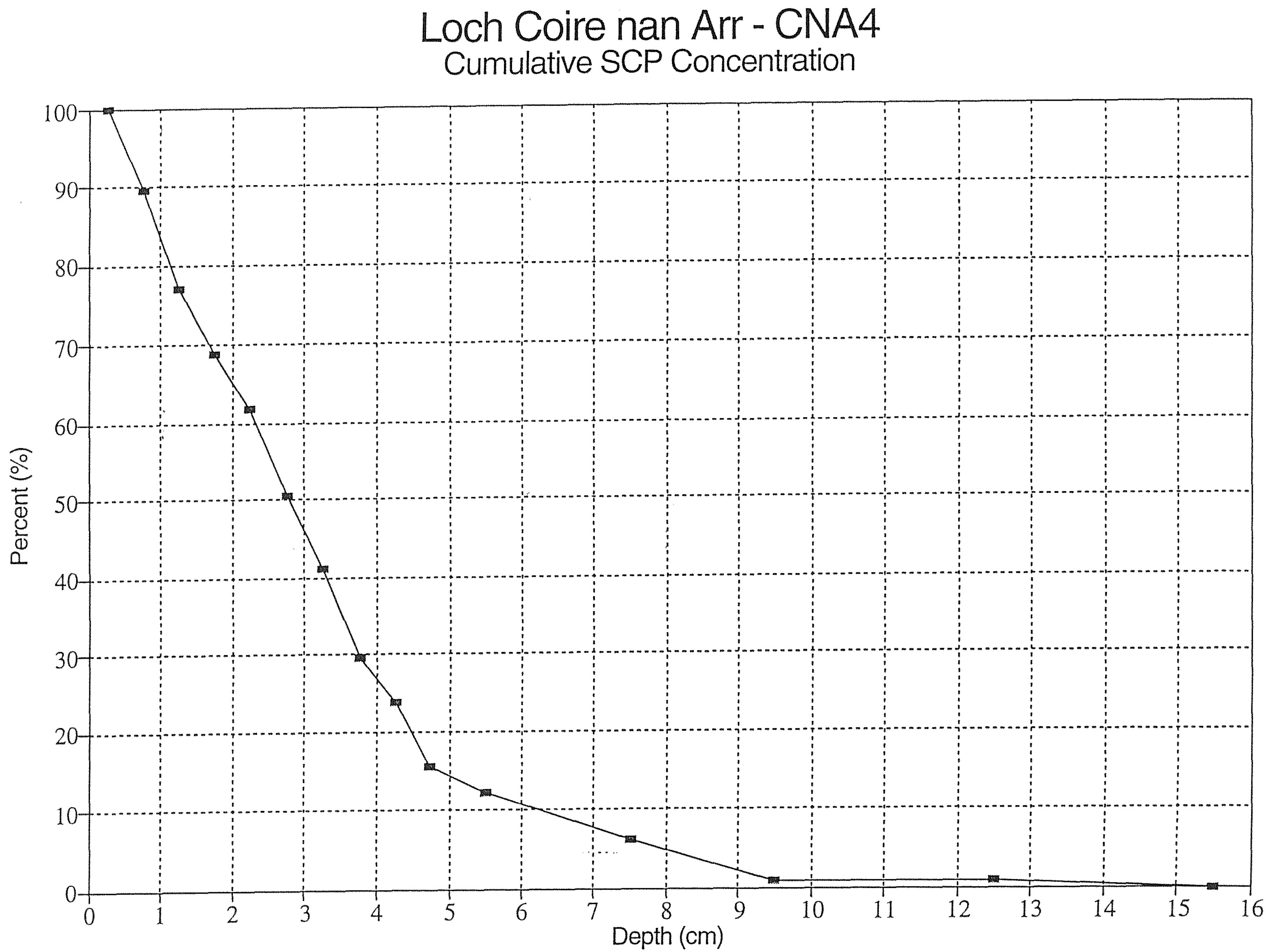

Loch Coire nan Arr - CNA4
Cumulative SCP Concentration
Percent (%)
Depth (cm)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 8

Loch Coire nan Arr - CNA5
Cumulative SCP Concentration

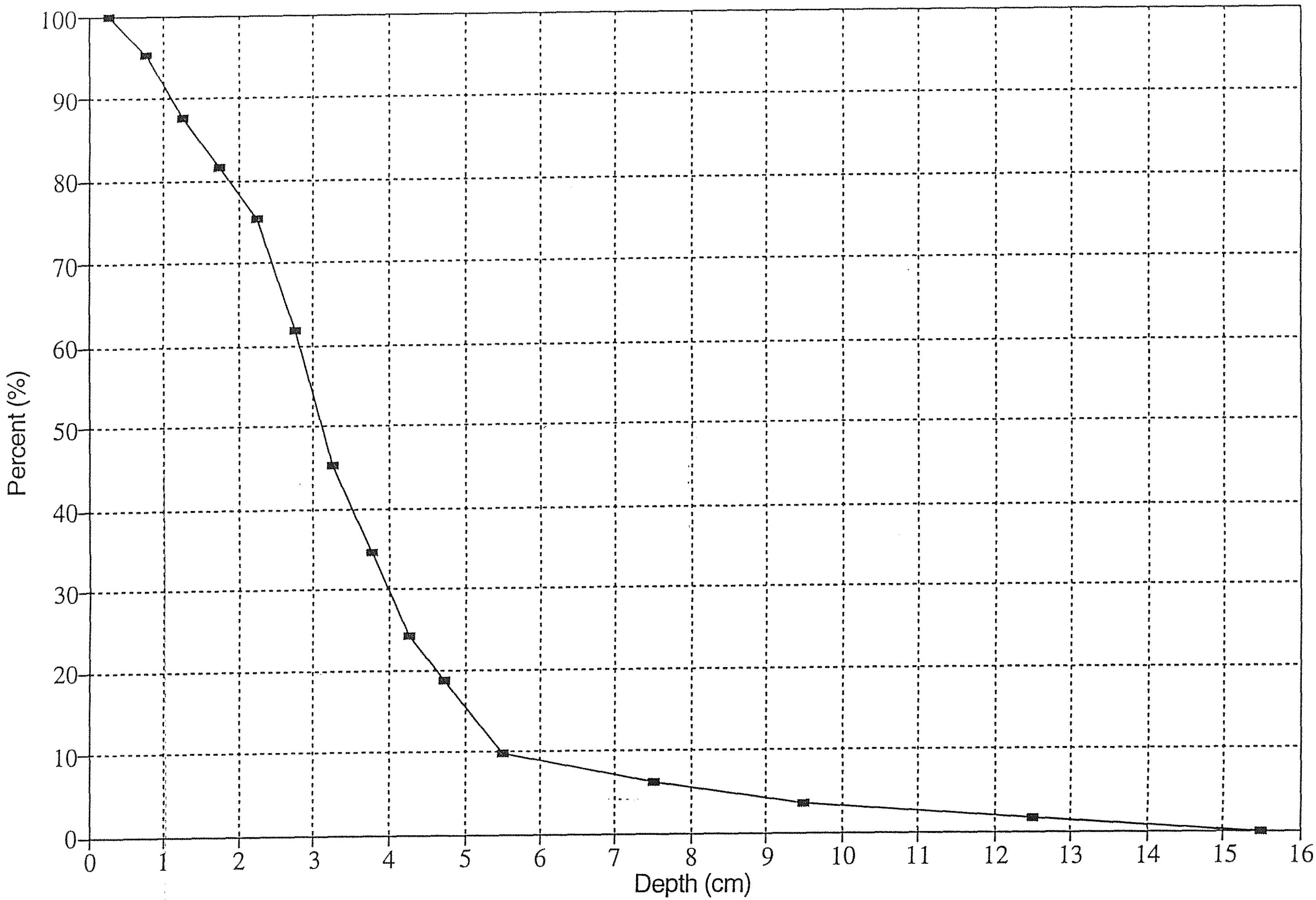
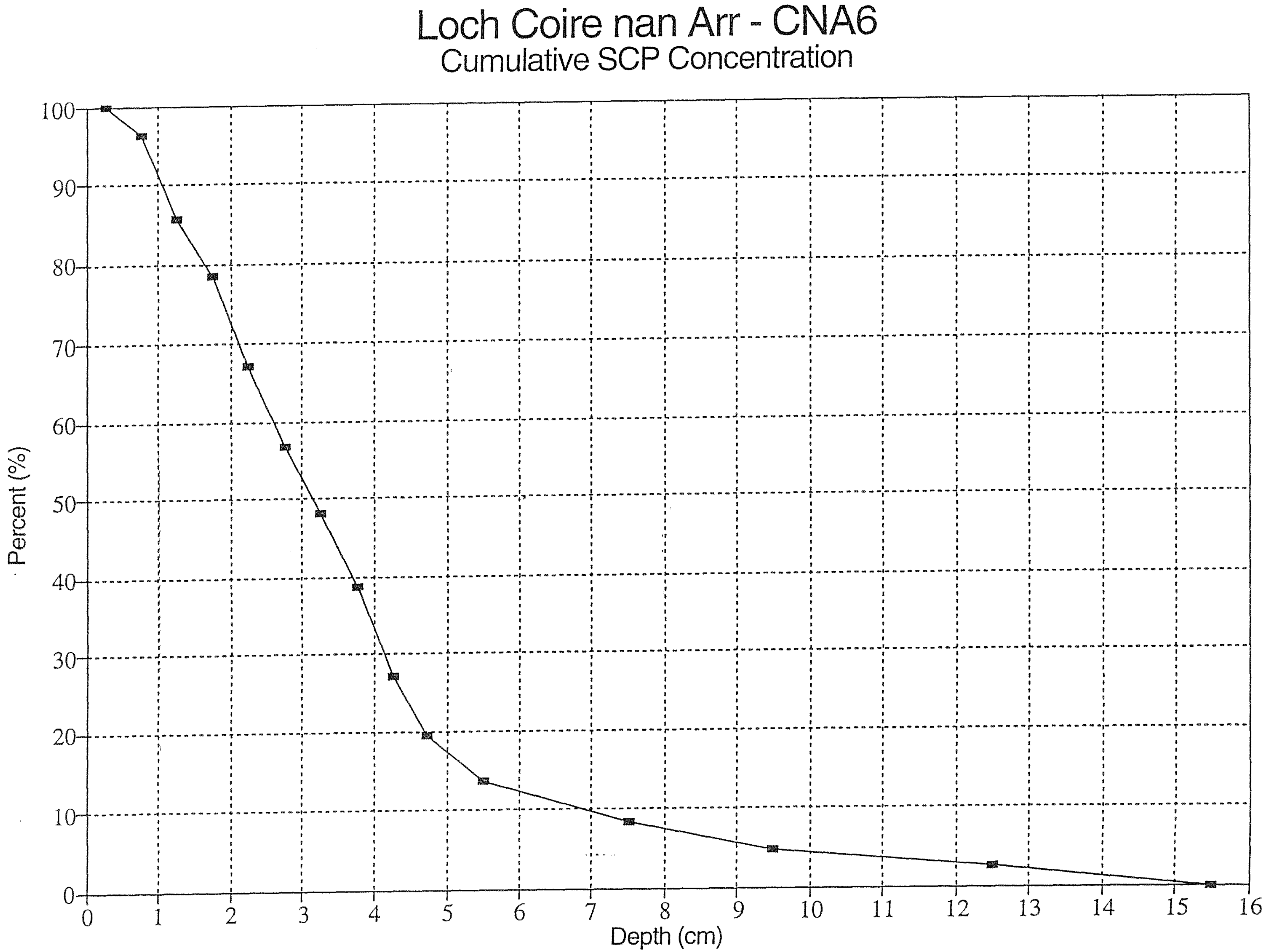


Figure 9



Loch Coire nan Arr - CNA6
Cumulative SCP Concentration
Percent (%)
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 10

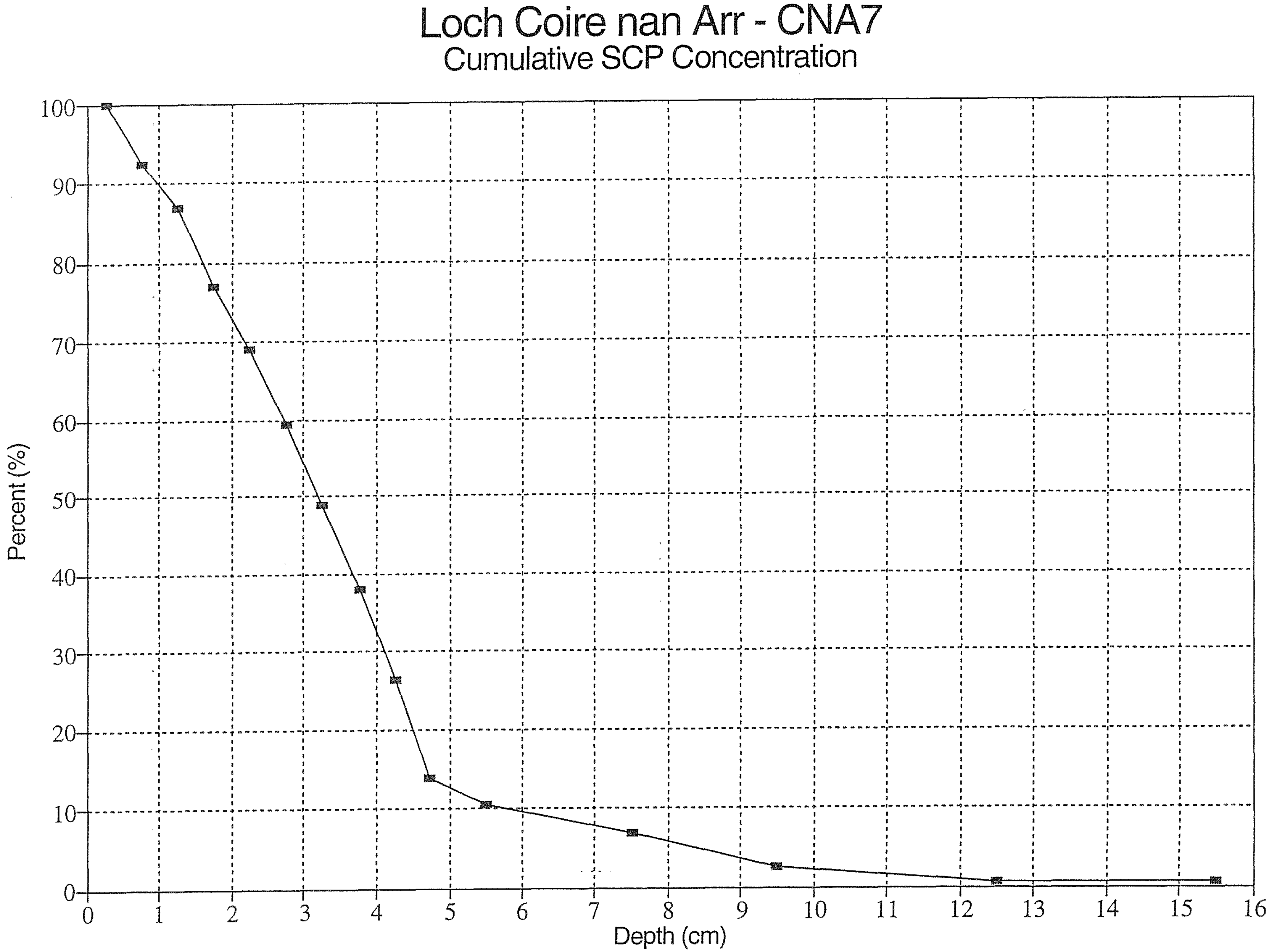
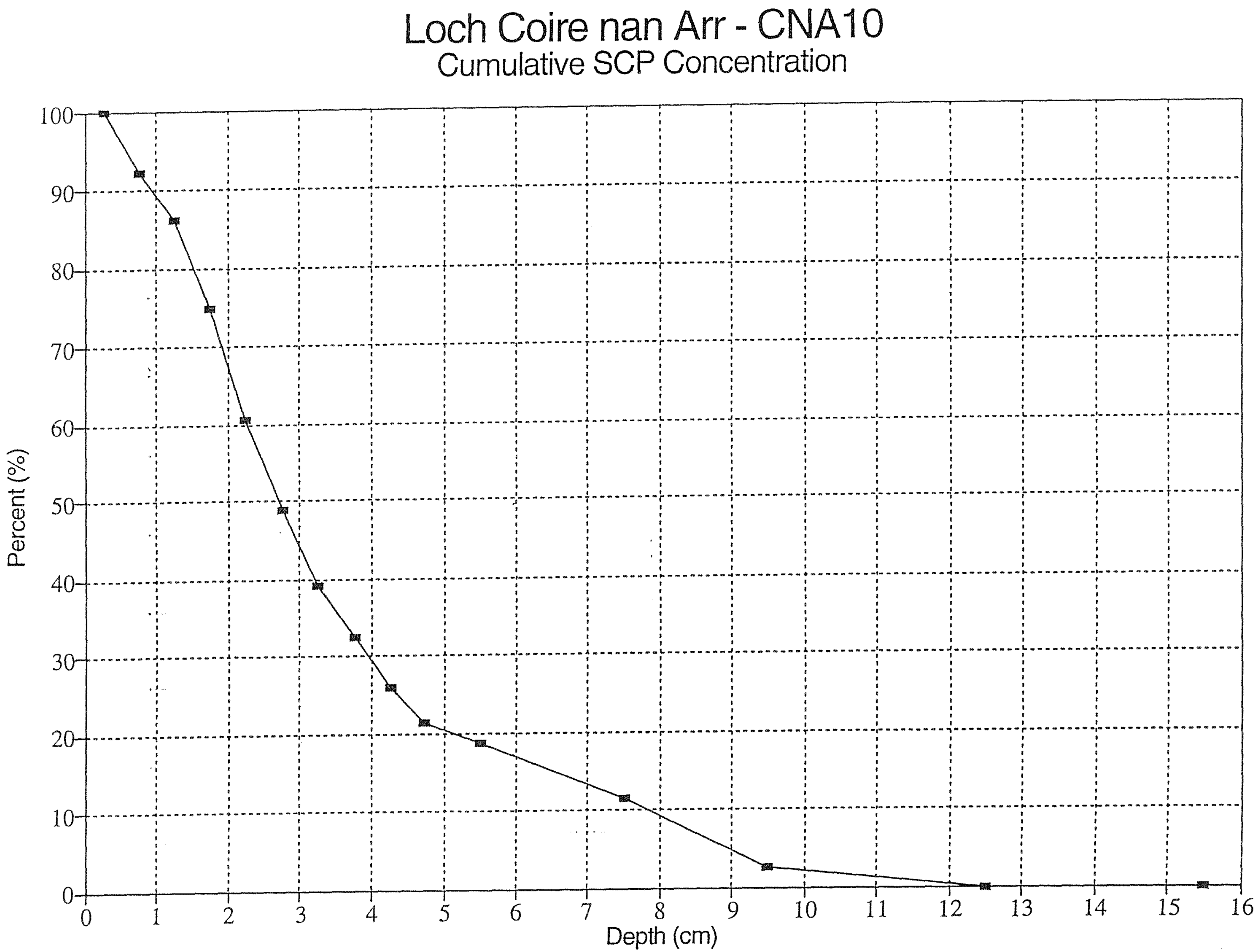

Loch Coire nan Arr - CNA7
Cumulative SCP Concentration
Percent (%)
0
10
20
30
40
50
60
70
80
90
100
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 11



Loch Coire nan Arr - CNA10
Cumulative SCP Concentration
Percent (%)
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 12