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THE INFLUENCE OF PLANT SPECIES AND PRETREATMENT ON THE ^{14}C AGE OF *CAREX*-DOMINATED PEAT PLANTS OF A PEAT CORE FROM JINCHUAN MIRE, NE CHINA

Satabdi Misra[1] • Sneha Kashyap[1] • Chun-Yen Chou[1] • Tingyi Chang[1] • Hong-Chun Li[1,2]* • Xiaoyan Ning[2] • Jing-Jing Sun[3] • Jie Wang[3] • Meixun Zhao[2]

[1]Department of Geosciences, National Taiwan University, Taipei 10617, Taiwan, ROC
[2]Frontiers Science Center for Deep Ocean Multispheres and Earth System, and Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, Qingdao, China
[3]School of Geographical Science, Northeast Normal University, Changchun, Jilin, 130024, China

ABSTRACT. The comparisons among 126 ^{14}C dates of *Carex* samples including separated leaf and root parts with acid (A)-treatment and acid-base-acid (ABA)-treatment, and 48 published ^{14}C dates of bulk peat plants on a 92-cm core from Jinchuan Mire in NE China, indicate old carbon influence (OCI) on the ^{14}C dates. The OCI varies with plant species, pretreatment and peat depth. In vascular peat plants such as *Carex*, humin fractions (remains after ABA treatment) and humic acids are representative of the original plant precursor, while fulvic acids are regarded as the secondary mobile product which should be removed for ^{14}C dating. ABA- treatment removes both fulvic acids and humic acids, whereas A-treatment gets rid of only fulvic acids. *Carex* roots uptake more dissolved CO_2 in peat water. *Carex* leaves may use more CO_2 (involving degassing CO_2) above the peat surface. By removing humic acids throughout ABA treatment, the OCI may vary differently over depth (time). ABA treatment cannot eliminate the fixed OCI in humin fractions of vascular peat plants, instead, this treatment may enhance OCI by removing humic acid which may represent the true age of the plants. In addition, Bacon model results on this core could not show rapid changes in accumulation rate.

KEYWORDS: *Carex lehmanii*, Jinchuan peat Mire China, peat core, pretreatment, species-definite AMS ^{14}C dating.

1. INTRODUCTION

Peatland ecosystems are an imperative variety of wetland bionetwork, comprising around 3–6% of the Earth's land surface and 50–70% of the global wetland area (Clymo 1984; Gorham 1991). They play a key role in the global carbon (C) cycle and are influenced by global climate change (Lal 2004; Zhang et al. 2008). Peats can be considered as an excellent terrestrial archive for preserving geological records (including natural and anthropogenic environmental changes) and the ability for palaeoclimate reconstruction (Langdon and Barber 2005; Nichols et al. 2010). The chemical and biological proxies stored in peats can provide precious information regarding environmental changes and pollution loads (Shotyk et al. 1998; Hendon and Charman 2004). Radiocarbon (^{14}C) is the most widely utilized as a geochronometer to investigate geological, biological and geochemical alterations in peat cores. Precise and accurate chronologies of peat sequences are essential for the estimation of carbon accumulation rates and interpretation of palaeoclimatic reconstruction (Garnett et al. 2000; Turetsky et al. 2007; Parry et al. 2013; Baskaran et al. 2017; Yang et al. 2017; Sun et al. 2019; Xia et al. 2019). However, radiocarbon dates can be altered by different factors such as accumulation rates, degradational pathways and geochemistry (Shore et al. 1995; Turetsky et al. 2004).

Bulk peat can be described as a heterogeneous mixture of organic matter of different origins and different ages with varying stages of biological degradation and humification level (Brock et al. 2011; Hatté and Jull 2013). Previous studies suggested that above-ground growing mosses in a peat

*Corresponding author. Email: hcli1960@ntu.edu.tw

mire should be used for ^{14}C dating to avoid the influence of old carbon (van der Plicht et al. 2013). However, above-ground growing mosses (mainly *Sphagnum* species) do not exist or are very difficult to pick up in many horizons from a peat core owing to three reasons: (1) They grow mainly in bog peat mires or hummocks in fen peat mires; (2) They are decomposed easier than other peat plants such as herbs and wood fragments; (3) In comparison to herb and woody species in a peat mire, their growth is more sensitive to climate conditions such as water level and temperature. For instance, the *Sphagnum* species in Jinchuan Mire appeared only in two short periods: 1150~1350 CE and after 1950 CE over the past 1000 years (Sun et al. 2019). Hence, to select above-ground growing mosses in a peat core for ^{14}C dating requires not only professional skills, but also depends on their availability. Such a task is more difficult for a fen-type peat mire. Up to date, what plant species other than above-ground growing mosses in a long-term peat sequence (>1000 years) is suitable for ^{14}C dating remains unclear. If a peat plant species exists throughout a core and is suitable for ^{14}C dating, the reliability of the core chronology can be enhanced significantly.

The Changbai Mountain range is a renowned mountain chain in northeastern (NE) China and is considered to be susceptible to global environmental alterations (Bao et al. 2010). The climatic dynamics of NE China are predominantly controlled by the East Asian Summer Monsoon (EASM; Li et al. 2017; Zhang et al. 2019). Previous investigations on this area were mostly performed on bulk peat samples for ^{14}C dating (Li et al. 2017; Zheng et al. 2018; Li et al. 2019). Li et al. (2019) published a detailed AMS ^{14}C study on two peat cores from Jinchuan Mire: JC1 and JCA. For the 92 cm long core JCA, a total of 52 AMS ^{14}C dates from 30 horizons including 28 bulk plant samples and 2 sediment samples were generated, showing 1000 year deposition. Among those samples, 15 samples had gone through acid (A)-treatment (0.5N HCl) and acid (0.5N HCl)-base (0.5 mol NaOH)-acid (0.5N HCl) (ABA) treatment (Brock et al. 2010; Santos and Xu 2017), respectively. In Li et al. (2019), although the bulk plant samples denoted "Non-ABA", they were cleaned in a 60 mesh sieve with deionized water (DIW) and treated with 0.5N HCl. Therefore, detrital materials, carbonates and fulvic acids were removed from the so called "Non-ABA" samples. And, the bulk plant samples were small leaf materials. In that previous study, Li et al. (2019) concluded that (1) peat plants absorbed and fixed dissolved CO_2 in the water caused old carbon influence (OCI) in ^{14}C dates; (2) The ABA treatment cannot remove OCI influence; and (3) older age shift for the ABA-treated samples. However, the reason for the older shift of ^{14}C ages in ABA-treated samples remains unsolved. Based on the above conclusions, one should realize that the ^{14}C chronology of peat plants is quite different from the tree-ring ^{14}C chronology. If a specified plant species in a peat sequence can be selected in different depths and studied in detail, we may understand the mechanism of OCI in peat samples and choose a proper plant species and suitable treatment method for ^{14}C dating.

The Jinchuan peat mire is considered as an herbaceous mire and *Carex* species can be traced in every layer. Therefore, *Carex* has been selected from JCA (92-cm-long core) for the present investigation. The novelty of the present study is to present a comprehensive outlook on the significance of species-definite ^{14}C dating. Both the *Carex* leaves (CL) and *Carex* roots (CR) from the same depth have been evaluated for more precise information regarding the carbon fractionation in different plant parts during photosynthesis. Moreover, both A-treated and ABA-treated samples at the same depths have been assessed for better insights into the utility of pretreatment methods. In addition, the Bacon model (Blaauw and Christen 2011) has been applied to different sets of ^{14}C ages to detect OCI variations. The discrepancies of depositional changes between the modelled ^{14}C ages and the obtained ^{14}C ages based on the nuclear bomb ^{14}C chronology will be discussed. The present study aims to uncover the carbon cycle in peat plants and proper treatment for ^{14}C dating, which in turn provides accurate species-definite chronologies of the peat sequences.

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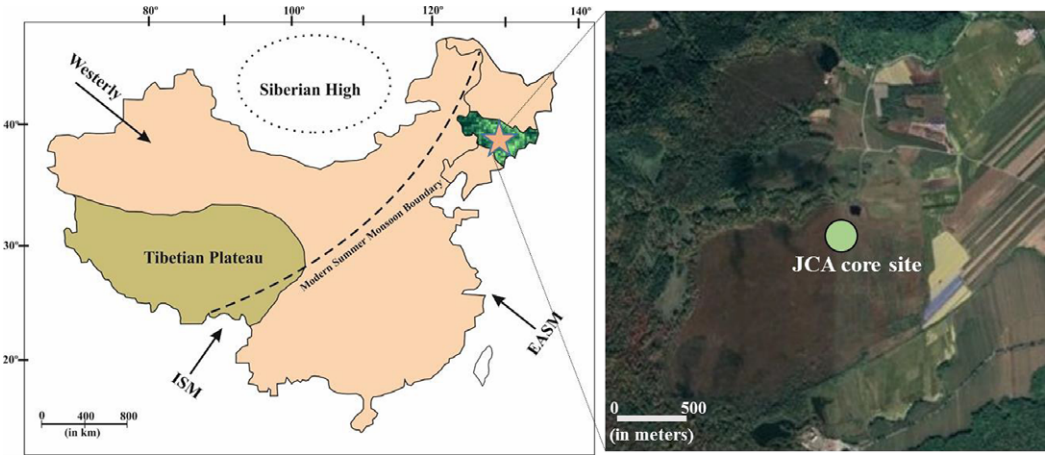

Figure 1 Location of the study area. Jinchuan (JC) Mire (42°20′48″N, 126°21′48″E; ~9.86 km^2 area) is located at the flank of Changbai mountain, NE China. EASM and ISM denote East Asian Summer Monsoon and Indian Summer Monsoon, respectively.

2. STUDY AREA

Jinchuan Mire (42°20′48″N; 126°21′48″E) is located on the western verge of Changbai Mountain in Huinan County, Jilin Province, China (Figure 1). The area is characterized by a dormant volcano and a subtropical continental monsoon climate with long, cold winters and short, cool summers (Bao et al. 2010). This peat mire is a fen-type mire with an area of 9.86 km^2 and was developed in a Quaternary volcanic lake adjacent to the middle valley of the Longgang Volcanic field (Hong et al. 2000). Jinchuan peat mire is termed as herbaceous mire as it was predominantly comprised of plant remains of the *Carex* genus of Cyperaceae family. This peat mire is embodied by successive deposits, concentrated organic matter distribution owing to cold and wet weather conditions and high accumulation rates because of topographical features (Zhao et al. 2002).

Jinchuan Mire is a herbaceous mire and contains *Carex* species more than 70% by volume. Previous studies have been carried out in terms of physical, chemical and biological properties (Li et al. 2019; Sun et al. 2019) as well as geomorphology (Zhang et al. 2019). JC1 (50 cm long) and JCA (92 cm long) were collected from different sites in Jinchuan Mire, JC1 from a *Sphagnum palustre* hummock and JCA from a lawn site near the water pond (Figure 1). The pH, water level and plant distribution have been monitored for recent years. Thus, the geological, hydrological, chemical and biological background information of modern Jinchuan Mire are well known.

The present study focuses on the JCA core collected in 2018. The measured porosity (H_2O%), dry bulk density (DBD), ash content, mineralogical compositions and plant microfossils analyses of JCA core were previously published by Sun et al. (2019). Additionally, 52 ^{14}C dates of the bulk peat samples and fallout radionuclide activities (natural ^{210}Pb and artificial ^{137}Cs) were formerly documented by Li et al. (2019). The present study will compare the ^{14}C dates of bulk peat plants, bulk *Carex*, *Carex* leaves and *Carex* roots with A- and ABA-treated samples from JCA to interpret the mechanism of OCI on peat plants and the significance of species-definite ^{14}C dating method.

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3. METHODOLOGY

3.1. Collection and Pretreatment of *Carex* Samples

For bulk *Carex* samples, the fresh peat samples of JCA were taken out from a freezer. An aliquot of peat (about 0.3~0.5 g) was first washed with deionized water and sieved by using a 125 μm sieve for the removal of detrital materials. The wet peat plants were placed in a glass petri dish filled with DIW. *Carex lehmanni* (*Carex*) species were identified under a microscope and picked up for ^{14}C dating. During 2020~2021 CE, a total of 84 *Carex* samples were selected from 84 horizons out of the 91 subsamples from this core. Those *Carex* samples were then treated either by A-treatment or ABA-treatment. Unfortunately, we did not separate the leaf and root of those *Carex* samples, mainly due to the small amount of picked-up *Carex* samples in many layers. Those samples can be considered as bulk *Carex*. During the revision of this paper in 2023, we choose peat plant samples from 14 horizons for selecting *Carex* leaves and roots. This time, about 0.5 g of wet peat underwent ABA treatment first (following Mauquoy and Van Geel 2007). Then, the *Carex* leaves and *Carex* roots were carefully picked up separately. Only 12 samples were able to deliver enough *Carex* leaves and *Carex* roots. The two samples which were unable to identify *Carex* species are considered as bulk plants.

All *Carex* (bulk, leaf, and root) samples are detrital-free. All samples were placed into 50 mL glass beakers and treated with 10 mL 0.5N HCl to remove potential carbonate content and fulvic acids. For the 84 bulk *Carex* samples, only 16 samples with relatively large amounts were treated by ABA procedure to remove carbonates, fulvic acids and humic acids (Brock et al. 2010; Santos and Xu 2017). For the ABA treatment, the first Acid (A) treatment was the same as the above description. In the Base (B) treatment procedure, the samples were centrifuged after the first A treatment. Then, the solution was discarded, and the plant remains were washed by DIW. Then, 10 mL 0.5 mol NaOH was added into the beaker and subsequently placed in a hot plate for 30 minutes base (B) treatment at 70°C. After the B treatment, the samples were again centrifuged and discarded the solution afterwards. The plant remains were washed again with DIW. Quickly, 10 mL 0.5N HCl was added into the sample tubes to acidify the plant remains for avoiding the absorption of the atmospheric CO_2. All A-treated and ABA- treated samples were finally washed with DIW and freeze-dried. The dried plant remains were ready for AMS ^{14}C dating.

3.2. AMS ^{14}C Dating

The AMS ^{14}C dating of the most JCA peat samples were accomplished in the NTUAMS laboratory with a 1.0 MV Tandetron Model 4110 BO-Accelerator Mass Spectrometer (AMS). The AMS ^{14}C dating procedures of the NTUAMS Lab have been described in Li et al. (2022). In 2020, for cross-checking seven *Carex* samples were sent to the OUC-CAMS Lab at Ocean University of China for AMS ^{14}C dating using an automated graphitization equipment (AGE) connected with a mini radiocarbon dating system (MICADAS) made by *Ionplus* (Lab code of 1032.1 and Sample ID with OUC in Supplement Table S1). Six samples were made into graphite in the NTUAMS Lab but measured by the OUC-CAMS Lab (Lab code of NTUAMS- and Sample ID with AGER in Supplement Table S1). More than 100,000 counts for ^{14}C age measurements were taken by the MICADAS for each sample for the reduction of statistical error. Previously published 52 ^{14}C dates in Li et al. (2019) were also included for comparison. All ^{14}C ages (1σ error) were newly calibrated with IntCal 20 database (Reimer et al. 2020). The calibrated ^{14}C ages are with 2σ uncertainty (96% probability in the age range).

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Supplement Table S1 contains a total of 178 ^{14}C dates from the JCA core, including A- treated 33 bulk plants and 90 bulk *Carex* samples, ABA-treated 51 samples (17 bulk plants, 16 bulk *Carex* samples, 12 *Carex* roots and 6 *Carex* leaves) and 4 sediment ^{14}C dates. Selected from the 178 ^{14}C dates in the Supplement Table S1, Table 1 presents the ^{14}C date comparisons of each depth throughout the core with different plant types (including bulk plant, bulk *Carex*, *Carex* leaves and *Carex* roots) with different treatments (A- and ABA-treatment). Those 137 ^{14}C dates are from 49 horizons. Based on the comparisons of the ^{14}C ages from the same samples under different treatments, we will discuss the old carbon influence (OCI) and its variation with different treatments and plant species.

The measured ^{14}C ages were calculated from pMC (percentage of modern carbon) which is listed in Supplement Table S1, T (BP) = -8033ln(pMC/100). $F^{14}C$ (fraction of modern carbon) and $D^{14}C$ can be easily calculated from pMC, being $F^{14}C$ = pMC/100 and $D^{14}C$ (‰) = (pMC/100 − 1)*1000. If pMC > 100% (or $F^{14}C$ >1, or $D^{14}C$ > 0) in a sample, it contains nuclear bomb ^{14}C and its calculated ^{14}C age should be negative. The sample should be formed after 1950 CE.

4. RESULTS AND DISCUSSION

4.1. Old Carbon Influence (OCI) in ^{14}C age of peat plants

Figure 2 exhibits 174 measured ^{14}C ages (not calibrated) of all plant samples from JCA, including bulk plants, bulk *Carex*, *Carex* leaves and *Carex* roots with A- or ABA treatment, respectively. Figure 2 shows clearly: (1) "the nuclear bomb ^{14}C curve" in the upper 20 cm depth, but the ^{14}C activities in the peat samples were significantly lower than that of the atmospheric CO_2 when the plant grew. This phenomenon was also reported by previous researchers for Hani Mire (Yang et al. 2017) and Jinchuan Mire (Li et al. 2019). In Figure 2, the maximum ^{14}C peak at 5.5 cm depth corresponded to a pMC of 121.682% (or $F^{14}C$ = 1.2168) (Supplement Table S1). However, the atmospheric CO_2 at that time (1964 CE) should have a pMC of 194% (or $F^{14}C$ = 1.94) (Hua et al. 2013). This means that $^{14}C/^{12}C$ of peat plants in Jinchuan Mire is lower than that of the atmospheric CO_2 when they grew. Therefore CALIBomb (http://calib.org/CALIBomb/) should be used with caution for obtaining the dates for post-bomb peats. (2) "The nuclear bomb ^{14}C curve" indicates that the 1964-peak was at 5.5 cm depth, which provides a controlling age point. (3) Although the ^{14}C chronology of the core has stratigraphic order on >20 cm intervals, there are many age reversals regardless of plant type and pretreatment. These age reversals were caused by the OCI in the peatland, and could not be eliminated by pretreatment in the laboratory procedure. Sometimes, the effect of OCI on the ^{14}C ages is quite significant, e.g., the OCI shifts the ^{14}C age at 72.5 cm depth 500 years older than the true depositional age which was about 800 year BP. Thus, if the dating interval is greater than 20 cm for a peat sequence, which is a common case, the OCI and age reversal may not be observed. Therefore, a high-resolution ^{14}C chronology should be obtained for a better understanding of OCI in peatland.

The ^{14}C age reversals and the age difference between A-treated and ABA-treated samples shown in Figure 2 provide significant insights into the 'radiocarbon reservoir effects' (Nilsson et al. 2001; Turetsky et al. 2004; Ascough 2014). Previous researchers reported multiple reasons for radiocarbon reservoir effects: dissolution of geological carbonates (Shotton 1972); old carbon influence because of the percolating dissolved organic compounds including humic acids through peat profile (Nilsson et al. 2001; Turetsky et al. 2004); up taking of old carbons or ^{14}C depleted carbons through groundwater or overland flow (Edwards and Rowntree 1980)

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Table 1 Comparisons of AMS ^{14}C dates from the same depth samples throughout the JCA core. Symbol # in Sample ID denotes the measurements in COU AMS Lab. BP = bulk peat; C = bulk *Carex*; CL = *Carex* leaves; CR = *Carex* roots; A = acid-treated; ABA = acid-base-acid treated.

Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)	Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)
−4320	JC-A-1 0-1	0.5	BP	A	−183±79	−4444	JC-A-1 29-30	29.5	BP	A	311±75
−4321	JC-A-2 0-1	0.5	BP	ABA	−112±71	−6120	JCA-30-C-A	29.5	C	A	371±81
−5569	JCA-1-C-A	0.5	C	A	−335±62	−8857	JCA-30-C-ABA-R	29.5	CR	ABA	333±71
−4446	JC-A-1 1-2	1.5	BP	A	−407±76	−8858	JCA-30-C-ABA-L	29.5	CL	ABA	367±71
−5570	JCA-2-C-A	1.5	C	A	−310±58	−4349	JC-A-1 30-31	30.5	BP	A	295±67
−4448	JC-A-1 2-3	2.5	BP	A	−422±69	−4350	JC-A-2 30-31	30.5	BP	ABA	303±75
−5590	JCA-3-C-A#	2.5	C	A	−651±59	−8859	JCA-31-C-ABA-L	30.5	CL	ABA	138±63
−5571	JCA-3-C-A	2.5	C	A	−613±61	−8860	JCA-31-C-ABA-R	30.5	CR	ABA	276±60
−4450	JC-A-1 3-4	3.5	BP	A	−744±88	−4310	JC-A-1 31-32	31.5	BP	A	154±74
−5591	JCA-4-C-A#	3.5	C	A	−180±60	−6192	JCA-32-C-A	31.5	C	A	382±67
−5572	JCA-4-C-A	3.5	C	A	−375±59	−6350	JCA-32-C-ABA	31.5	C	ABA	396±54
−4434	JC-A-1 4-5	4.5	BP	A	−1137±63	1032.1.5	JCA-36-C-A OUC#	35.5	C	A	267±39
−4435	JC-A-2 4-5	4.5	BP	ABA	−1074±77	−6142	JCA-36-C-ABA	35.5	C	ABA	557±80
−5592	JCA-5-C-A#	4.5	C	A	−565±62	−5751	JCA-40-C-A	39.5	C	A	480±69
−5573	JCA-5-C-A	4.5	C	A	−514±80	−8861	JCA-40-C-ABA-R	39.5	CR	ABA	477±63
−4312	JC-A-1 5-6	5.5	BP	A	−860±72	−4351	JC-A-1 40-41	40.5	BP	A	420±68
−5574	JCA-6-C-A	5.5	C	A	−1576±63	−4352	JC-A-2 40-41	40.5	BP	ABA	278±75
−4311	JC-A-1 6-7	6.5	BP	A	−1220±76	−6146	JCA-41-C-A	40.5	C	A	376±84
−5575	JCA-7-C-A	6.5	C	A	−984±68	1032.1.4	JCA-42-C-A OUC#	41.5	C	A	338±35
−4449	JC-A-1 7-8	7.5	BP	A	−925±72	−6147	JCA-42-C-ABA	41.5	C	ABA	508±75
−5593	JCA-8-C-A#	7.5	C	A	−745±60	1032.1.3	JCA-43-C-A OUC#	42.5	C	A	434±38
−5576	JCA-8-C-A	7.5	C	A	−877±64	−6148	JCA-43-C-ABA	42.5	C	ABA	498±69
−4361	JC-A-1 8-9	8.5	BP	A	−506±83	1032.1.2	JCA-44-C-A OUC#	43.5	C	A	428±36

Table 1 (*Continued*)

Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)	Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)
−5577	JCA-9-C-A	8.5	C	A	−1015±65	−6149	JCA-44-C-ABA	43.5	C	ABA	482±73
−4436	JC-A-1 9-10	9.5	BP	A	−588±67	−5509	JCA-50-C-A	49.5	C	A	646±69
−4437	JC-A-2 9-10	9.5	BP	ABA	−261±78	−8862	JCA-50-C-ABA-R	49.5	CR	ABA	646±61
−5578	JCA-10-C-A	9.5	C	A	28±55	−4353	JC-A-1 50-51	50.5	BP	A	480±77
−4340	JC-A-1 10-11	10.5	BP	A	−269±85	−4353	JC-A-1 50-51	50.5	BP	A	345±75
−4341	JC-A-2 10-11	10.5	BP	ABA	−377±69	−4354	JC-A-2 50-51	50.5	BP	ABA	454±77
−5594	JCA-11-C-A#	10.5	C	A	−23±62	−5741	JCA-51-C-A	50.5	C	A	663±76
−6136	JCA-11-C-ABA	10.5	C	ABA	107±63	−5742	JCA-53-C-A	52.5	C	A	583±69
−4475	JC-A-1 11-12	11.5	BP	A	−498±83	−6151	JCA-53-C-ABA	52.5	C	ABA	611±71
−5579	JCA-12-C-A	11.5	C	A	−705±51	−5554	JCA-60-C-A	59.5	C	A	667±60
−4313	JC-A-1 12-13	12.5	BP	A	−198±78	−8863	JCA-60-C-ABA-R	59.5	CR	ABA	650±61
−6188	JCA-13-C-A	12.5	C	A	63±67	−4355	JC-A-1 60-61	60.5	BP	A	566±78
−6347	JCA-13-C-ABA	12.5	C	ABA	228±58	−4356	JC-A-2 60-61	60.5	BP	ABA	714±79
−4529	JC-A-1 13-14	13.5	BP	A	−56±80	−5512	JCA-61-C-A	60.5	C	A	747±75
−6189	JCA-14-C-A	13.5	C	A	98±57	−5698	JCA-61-C-A	60.5	C	A	650±69
−6348	JCA-14-C-ABA	13.5	C	ABA	264±87	−5557	JCA-66-C-A	65.5	C	A	868±61
−4440	JC-A-1 14-15	14.5	BP	A	−88±79	−8864	JCA-66-C-ABA-R	65.5	CR	ABA	797±61
−5595	JCA-15-C-A#	14.5	C	A	151±68	−4357	JC-A-1 70-71	70.5	BP	A	766±62
−5582	JCA-16-C-A	15.5	C	A	61±51	−4357	JC-A-1 70-71	70.5	BP	A	802±62
−8844	JCA-16-C-ABA-R	15.5	CR	ABA	−28±61	−4357	JC-A-1 70-71	70.5	BP	A	722±70
−8855	JCA-16-C-ABA-L	15.5	CL	ABA	108±66	−4358	JC-A-2 70-71	70.5	BP	ABA	873±81
−4531	JC-A-1 16-17	16.5	BP	A	81±73	−5621	JCA-72-C-A	71.5	C	A	851±55
−5583	JCA-17-C-A	16.5	C	A	26±49	−8865	JCA-72 ABA	71.5	BP	ABA	900±74
−8845	JCA-17-C-ABA-L	16.5	CL	ABA	212±59	−6194	JCA-78-C-A	77.5	C	A	924±64

(*Continued*)

Table 1 (*Continued*)

Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)	Lab code	Sample ID	Depth (cm)	Type	Treatment	^{14}C age (BP)
−8856	JCA-17-C-ABA-R	16.5	CR	ABA	50±71	−6351s	JCA-78-C-ABA	77.5	C	ABA	1250±73
−4532	JC-A-1 17-18	17.5	BP	A	228±74	−6195	JCA-80-C-A	79.5	C	A	875±57
−5747	JCA-18-C-A	17.5	C	A	220±71	−6352	JCA-80-C-ABA	79.5	C	ABA	942±55
−8846	JCA-18-C-ABA-L	17.5	CL	ABA	266±85	−8867	JCA-80-C-ABA-R	79.5	CR	ABA	999±69
−8847	JCA-18-C-ABA-R	17.5	CR	ABA	170±60	−4359	JC-A-1 80-81	80.5	BP	A	891±72
−4533	JC-A-1 18-19	18.5	BP	A	170±74	−4360	JC-A-2 80-81	80.5	BP	ABA	1119±74
−6190	JCA-19-C-A	18.5	C	A	145±67	−5620	JCA-81-C-A	80.5	C	A	1065±50
−4452	JC-A-1 19-20	19.5	BP	A	48±89	−5617	JCA-84-C-A	83.5	C	A	964±52
−4453	JC-A-2 19-20	19.5	BP	ABA	320±75	−5617	JCA-84-C-ABA	83.5	C	ABA	1048±48
−5748	JCA-20-C-A	19.5	C	A	90±58	−6196	JCA-85-C-A	84.5	C	A	951±59
−8848	JCA-20-C-ABA-R	19.5	CR	ABA	109±60	−6353	JCA-85-C-ABA	84.5	C	ABA	994±60
−4347	JC-A-1 20-21	20.5	BP	A	−64±72	−4322	JC-A-1 87-88	87.5	BP	A	972±73
−4348	JC-A-2 20-21	20.5	BP	ABA	56±65	−4323	JC-A-2 87-88	87.5	BP	ABA	972±73
−4348	JC-A-2 20-21	20.5	BP	ABA	32±73	−6197	JCA-88-C-A	87.5	C	A	861±62
1032.1.7	JCA-21-C-A OUC	20.5	C	A	125±38	−6354	JCA-88-C-ABA	87.5	C	ABA	953±60
−6137	JCA-21-C-ABA	20.5	C	ABA	235±65	−5613	JCA-89-C-A	88.5	C	A	936±51
−6191	JCA-24-C-A	23.5	C	A	202±75	−5613-1	JCA-89-C-A-1	88.5	C	A	930±57
−6349	JCA-24-C-ABA	23.5	C	ABA	377±56	−5612	JCA-90-C-A	89.5	C	A	887±55
−4442	JC-A-1 24-25	24.5	BP	A	56±73	−8868	JCA-90 ABA	89.5	BP	ABA	1026±72
−4443	JC-A-2 24-25	24.5	BP	ABA	395±76	−5610	JCA-91-C-A	90.5	C	A	995±51
−5750	JCA-25-C-A	24.5	C	A	139±68	−8869	JCA-91-C-ABA-L	90.5	CL	ABA	908±71
						−8870	JCA-91-C-ABA-R	90.5	CR	ABA	961±72

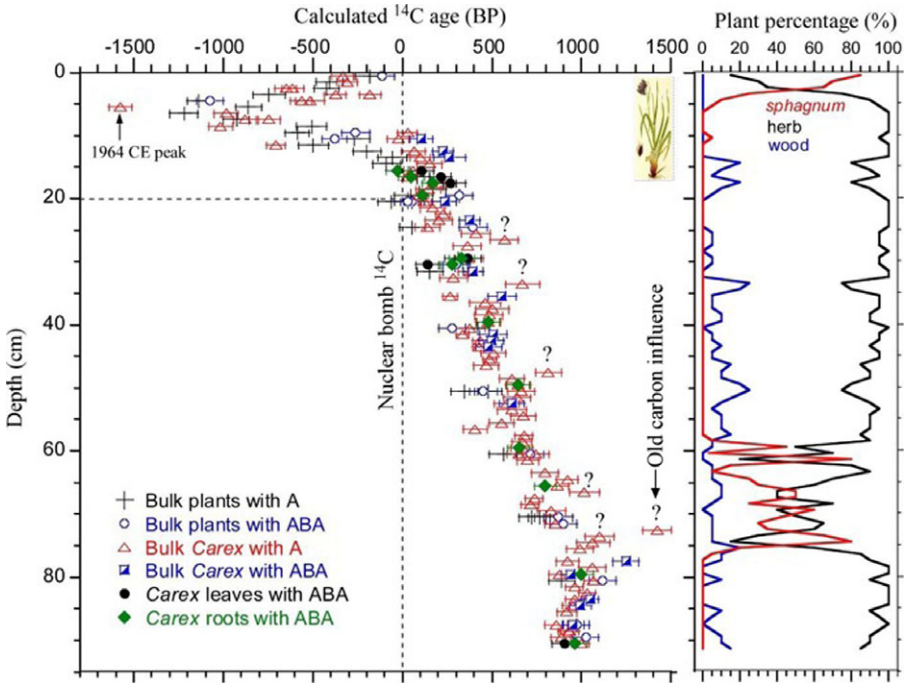

Figure 2 Variations of measured ^{14}C ages of the studied plant samples and previously published plant percentage (Sun et al. 2019) in JCA. Notes: A = acid-treated samples; ABA = acid-base- acid treated samples. The question mark denotes significant OCI. A typical *Carex* picture is shown in the figure.

during plant growth (MacDonald et al. 1987; Saarinen 1996); discharged older organic matters through thawing permafrost (Damon et al. 1996).

4.2. OCI in Different Parts of Vascular Peat Plants

Peat is composed of a heterogeneous mixture of organically decomposed plant remains. Different plant species have different biochemical and bio-degradational pathways and may use both atmospheric CO_2 and dissolved CO_2 in the peat water during photosynthesis (Koncalov et al. 1988; McClymont et al. 2010). The main sources of carbon fixation in peatlands can be categorized into three types: (1) CO_2 from the atmosphere that is mixed well with high altitudes (>5 m above the peat surface); We define this CO_2 as C1 (the same as for tree photosynthesis). (2) CO_2 in the air near the peat surface (with <3 m from the surface); This part CO_2 is partially mixed with degassing CO_2 produced by the decomposition of OM in old peat remains, so that its $^{14}C/^{12}C$ ratio should be lower than that of C1. We define this part of CO_2 as C2. (3) CO_2 dissolved in peat water; We define this part of CO_2 as C3. The dissolved CO_2 in peat water can be influenced by exchange with the atmospheric CO_2, mixing with CO_2 in surface runoff; and mixing with CO_2 (and CH_4) produced by the decomposition of old peat remains. In principle, the $^{14}C/^{12}C$ ratio of C1 should be higher than those of C2 and C3. The above-ground growing mosses mainly utilize C1, perhaps some C2 during their growth. Vascular plants in peatlands may use C1, C2 and C3 during photosynthesis. Thus, the carbon isotopic fractionation during photosynthesis and differential carbon fixation may be the most possible cause for differential ^{14}C ages in different plant remains.

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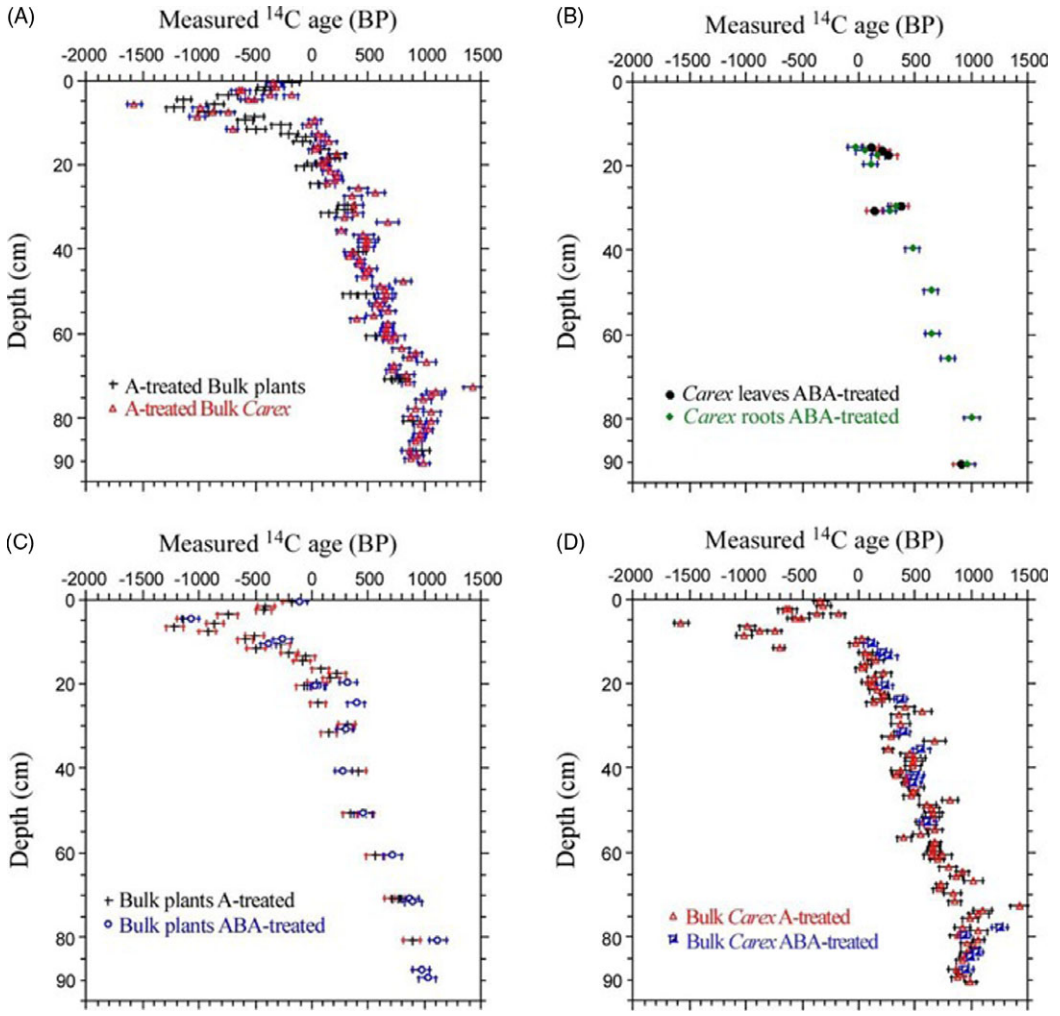

Figure 3 (A) Comparisons of the ^{14}C ages between A-treated bulk plants and A-treated bulk *Carex*. (B) Comparisons of the ^{14}C ages between ABA-treated *Carex* leaves and *Carex* roots. (C) Comparisons of the ^{14}C ages between A-treated and ABA-treated bulk plants. (D) Comparisons of the ^{14}C ages between A-treated and ABA-treated bulk *Carex* samples.

Table 1 lists the ^{14}C ages of different plant types with different treatments at the same depth in 49 horizons. Several horizons (e.g., 2.5-, 3.5-, 5.5-, 7.5-, 50.5- 70.5- and 88.5 cm depths) had the same plant type and treatment samples. Those duplicated samples including results from the two labs, show generally similar ages within uncertainty and indicate that the age reversals and discrepancies among different plant types and treatments were not attributed to dating error in the labs.

Figure 3 (A) shows the comparison of ^{14}C ages between A-treated bulk plants and A- treated bulk *Carex*. The comparison indicates that except for the uppermost 12 cm depth, the majority of bulk plants had younger ^{14}C ages. This observation can be explained by the partial utilization of dissolved CO_2 in the peat water in the case of *Carex* (McClymont et al. 2010). As

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described before, if *Carex* uses partially dissolved CO_2 in the peat water (C3), the OCI can be stronger compared to the peat plants which do not use dissolved CO_2 in the peat water. But, how to explain some of the ^{14}C ages of bulk *Carex* are younger than those of bulk plants at the same depths in the uppermost 12 cm depth (Figure 3A and Table 1)?

Carex belongs to the vascular plant (Family: Cyperaceae) domain and is a dominant plant species in the fen type of peatland. Unlike bog peatlands which receive nutrients, minerals and water mainly from the atmosphere with a small influence of surface runoff, fen type of peatlands have a strong influence of surface runoff. Jinchuan Mire is a fen type peatland (Sun et al. 2019; Ma et al. 2020). A small river passes through this peatland. Thus, the physiochemical (water level and temperature), chemical (such as pH and nutrient concentrations) and biological properties of Jinchuan Mire can be affected by surface runoff. The pH values of a peatland are further influenced by vegetation type, decomposition of OM, dissolution of inorganic materials and alteration of the water table (Bleuten and Lapshina 2001; Yang et al. 2017).

The H_2O content, pH, DBD (dry bulk density), TOC (%), LOI (loss of ignition), absorbance and plant microfossil analysis of the JCA core were previously reported by Sun et al. (2019). The pH values for the JCA peat profile indicate intermediate oligotrophic fen characteristics. A similar observation on Jinchuan Mire was also documented by Sun et al. (2019) and Ma et al. (2020). The surface water is nutrient-poor. Modern peat cores in Hani Mire (HNS1 and HNS2) and Jinchuan Mire (JC1) showed that the pH profiles of those cores increased from 4.5 in the upper 30 cm depth to about 6 quickly to 40 cm depth (Yang et al. 2017; Sun et al. 2019). On the other hand, the total organic carbon contents (TOC%) in both Hani Mire (the bog-type) (Yang et al. 2017) and Jinchuan Mire (the fen-type) (Sun et al. 2019) decreased quickly from the upper 30 cm to 40 cm depth, reflecting organic matter decomposition below 30 cm depth. This means that peat plants growing in the surface layer have less influence with dissolved CO_2 in the peat water below 30 cm depth. However, the fluctuation of peat water level is seasonal. In Jinchuan peatland, the summer monsoon brings heavy rainfall to elevate the water level. Peat plants, which use dissolved CO_2 in the peat water, are significantly influenced by surface runoff. Previous studies documented that the pore water CH_4 in peatlands (both bogs and fens) was enriched in ^{14}C relative to the peats at the same depth horizon (Aravena et al. 1993; Charman et al. 1994; Chanton et al. 1995). Hence, *Carex* can uptake dissolved CO_2 from peat water when surface runoff had a higher $^{14}C/^{12}C$ ratio in the upper 20 cm depth. This situation would be more likely in samples with post-bomb effects.

The age differences between A-treated bulk plants and A-treated bulk *Carex* are mainly attributed to the uptake of dissolved CO_2 from peat water by *Carex*. In addition, *Carex* is a perennial plant (Mohlenbrock and Nelson 1999), which means *Carex* can survive more than a year in a peatland, so a *Carex* sample may contain the atmospheric $^{14}CO_2$ longer than a year (Wallén 1984; Goslar et al. 2005). The above scenario can be further illustrated by Figure 3(B).

Figure 3(B) shows the ^{14}C ages of ABA-treated *Carex* leaves and roots (with the same treatment). Six pairs of ^{14}C dates belonging to *Carex* leaf and root from the same depth are compared. Out of the six pairs, three pairs display comparatively younger ^{14}C ages in the *Carex* roots in the upper 20 cm depth (15.5-, 16.5-, and 17.5 cm, respectively), reflecting the uptake of dissolved CO_2 from peat water (mixed with surface runoff with enriched ^{14}C) by *Carex* root. Hence, the intermingling of surface runoff with the peat water at the shallower level may cause the younger shift of ^{14}C ages. In upper peat layers, the diffusion of "young carbon influence" is

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more predominant owing to the mixing of peat water with atmospheric precipitation (Chanton et al. 1987; Chanton et al. 1995). Moreover, the greater hydraulic conductivity of the *Carex* leads to more "young carbon influence" in fen peatland (dominated by *Sedge*). Therefore, *Carex* roots in the upper peat layers are able to use young carbon (or higher $^{14}C/^{12}C$) especially when the post-bomb peat decomposes. In contrast, the *Carex* roots have older ^{14}C age than the *Carex* leaf at 30.5 cm depth as the old CO_2 produced by peat decomposition increased in this depth. This signifies the stronger influence of old dissolved CO_2 in peat water for *Carex* roots (C3 fraction of Carbon fixation; previously discussed in section 4.2) with minimal surface runoff influence at this depth. Moreover, ^{14}C dates of the studied samples (bulk plants, *Carex* leaf and *Carex* root) indicate the existence of OCI even after both A and ABA treatment. This phenomenon further signifies that *Carex* leaves and above-ground growing mosses may use degassing CO_2 (defined as C2 in section 4.2) near the peat surface. Although we have no direct evidence for this hypothesis, it is reasonable to assume that the degassing CO_2 (C2) which has a lower $^{14}C/^{12}C$ ratio can be uptaken for peat plants during photosynthesis.

4.3. Effect of Pretreatment on OCI in Peat Plants

The former sections have demonstrated that OCI may exist for peat plants through carbon fixation by the uptake of degassing CO_2 (C2) near the peat surface and dissolved CO_2 (C3) in peat water during photosynthesis. Because the $^{14}C/^{12}C$ of both C2 and C3 were lowered by old carbon decomposition in peatlands, the OCI in the peat ^{14}C age is a problem compared to the ^{14}C dating of terrestrial plants. Currently, ABA treatment is a common procedure to be exercised for the removal of contaminated components in peat samples. However, the present study confirms that mostly the ABA-treated samples have older ^{14}C age than the A-treated samples for the same depth.

Peat formation is the result of the incomplete decomposition of dead plant remains, their accumulation, biochemical alteration (humification) and compaction. Peat is considered to have three organic fractions of the humification process: (1) humic acids (HA): the alkali-soluble but acid-insoluble fraction; (2) fulvic acids (FA): the acid and alkali-soluble fraction; and (3) humin (HM): the acid and alkali-insoluble fraction (Cook et al. 1998). Humic acids and humin fractions are regarded as the most representative of the original plant precursor (Ascough 2014). Fulvic acids are regarded as the secondary mobile product formed owing to the decomposition of the OM and hence unreliable for dating and must be removed prior to the ^{14}C dating (Shore et al. 1995). Conversely, humic acids and humins are thought to provide ^{14}C ages that more accurately reflect the time at which the peat sample formed (Cook et al. 1998; Ascough 2014). The ABA treatment is usually regarded as the most followed pretreatment method for ^{14}C AMS dating to remove carbonates, fulvic acids and humic acids as contaminants. As the pH of a peatland is usually acidic (4.5–5 in the present case), carbonates seldom endure in peat mires.

For the present study, both A-treated and ABA-treated (following Brock et al. 2010) samples of JCA are compared (Table 1 and Figures 3(C) and 3(D)). Figure 3(C) displays the comparison of the ^{14}C ages between A-treated and ABA-treated bulk plants. Among the 11 pairs, 9 pairs exhibit that the ABA-treated bulk plants are older than A-treated, 2 pairs have similar results, and only one pair at 40.5 cm depth shows younger ABA-treated bulk plants (Table 1 and Figure 3(C)). Figure 3(D) exhibits the ^{14}C ages of bulk *Carex* samples treated with A- and ABA treatments. The comparison of 16 pairs of A-treated and ABA-treated samples indicates that all ABA-treated samples have older ^{14}C ages (Table 1, Figure 3(D)). The

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substantial disparity of the ^{14}C ages between A-treated and ABA-treated samples at the same depth horizon has been perceived with older ^{14}C ages for the majority of ABA-treated samples. The removal of some essential portions of humic acids owing to base treatment is attributed to the ^{14}C age difference. In addition, the age discrepancy between A- and ABA-treated samples became much smaller or even disappeared in the deepest part of the core (Figures 2 and 3). Based on the observations from Figure 3, some hypotheses can be made: (1) $^{14}C/^{12}C$ ratio in the humic acids of the peat plant remains should be higher than (less OCI and younger ^{14}C age) that of humin fractions in most cases. Therefore, the elimination of humic acids during the base (B)-treatment induces older ^{14}C ages in ABA-treated samples. If humic acids and humin fractions have the same $^{14}C/^{12}C$ ratio, the treatment would not make an age difference. (2) We believe, the base treatment removes some of the humic acids that form through photosynthesis and hence the loss of essential organic matter during base treatment induces the age deviation from the true age. The elevated hydraulic conductivity of *Carex* (sedge; vascular plant) may instigate greater production of labile organic carbon in fen type of peatland (Chason and Segel 1986). (3) The humic acids in the peat plant remains are easier to be decomposed than the humin fractions. The less amount of humic acids in deeper parts of the peat depth horizons can be explained by minimal biological degradation. Consequently, the reduced ^{14}C age deviation between the A- treated and ABA-treated samples in deeper peat depth horizons (Table 1 and Figure 3) can be explained by the net decrease of humic acids which can be removed by B-treatment. (4) The *Carex* roots uptake more dissolved CO_2 in peat water (C3) compared with *Carex* leaves. Accordingly, ABA-treated *Carex* leaves can be older or younger than ABA-treated *Carex* roots depending on the influence of surface runoff on dissolved CO_2 in peat water at different depths (Figure 3(B)) as discussed in the previous section.

Therefore, based on our observations, different peat plants will contain different $^{14}C/^{12}C$ ratios during their growth depending on the uptake of CO_2 (C1, C2 and C3) through photosynthesis to make age discrepancies on different species. Humic acids and humin fractions in the peat plant remains contain different $^{14}C/^{12}C$ ratios (ages). Different treatments (A- and ABA-) can change the $^{14}C/^{12}C$ ratio of organic carbon for ^{14}C dating by changing the humic acid/humin fraction ratio. In the next section, we shall discuss the mechanism.

4.4. Uptake of different CO_2 by Peat Plants and Removal of Different Carbon Fractions by Pretreatment Method

In general, plant uses atmospheric CO_2 through leaves and takes water through their roots for photosynthesis. For terrestrial plants, the isotopic exchange ($\Delta^{14}C$) of CO_2 used for photosynthesis is in equilibrium with the atmospheric $\Delta^{14}C$. However, peat plants in a peat basin may contain different sources of CO_2 for photosynthesis, and the latter has different $^{14}C/^{12}C$ due to old peat decomposition. As described before, C1 comes from the contemporary atmospheric CO_2 which represents the true ^{14}C age. C2 denotes CO_2 at or near (within <3 m) peat surface. The difference of C2 from C1 is that C2 may contain evasion CO_2 (degassing CO_2 from peat decomposition). Garnett et al. (2011) measured the ^{14}C age of CO_2 gas in a raised peat bog. Their results showed that the age of peatland CO_2 increased with depth from modern to ~ 170 BP at 0.25 m depth to ~ 4000 BP at 4 m depth. Furthermore, the Garnett group found that CH_4 and CO_2 emitted from the surface of peatlands had ^{14}C ages of hundred to thousand years (Garnett et al. 2012, 2013). Those studies indicate that C2 can be influenced by CH_4 and CO_2 emissions from decomposed peat plants. However, Garnett and Hardie (2009) detected that the CO_2 collected from plant-free static chambers at the surface of the peatland had slightly higher $^{14}C/^{12}C$ compared to the contemporary atmosphere. They attributed the higher

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$^{14}C/^{12}C$ of the CO_2 emissions predominantly derived from carbon fixed during the post- bomb era. Thus, C2 is commonly older than C1 except when the CO_2 emissions mainly come from the decomposition of the peat plants which were influenced by nuclear bomb ^{14}C. The above phenomena were also found by Stuart et al. (2023). In the case of Jinchuan Mire, if the ^{14}C activity of C2 is the same as that of C1, and all peat plants use the contemporary atmospheric CO_2, there would be no ^{14}C age difference among plant species and A-treatment vs. ABA-treatment.

It is well-known that C3 (here we define dissolved CO_2 in peat water) is derived from the decomposition of organic matter from all the available organic sources within the peatland. In some studies, named dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) or dissolved organic matter (DOM) are older than C1 owing to the interference from old peat decomposition. Clymo and Bryant (2008) measured ^{14}C ages of dissolved CO_2 and CH_4 gases, dissolved organic carbon (DOC) and bulk peat, at 50-cm intervals in a 7-m-deep rainwater-dependent raised (domed) bog (Ellergower Moss) in southwest Scotland. All profiles of the ^{14}C ages increased with depth as their concentrations increased, but the gases were younger than DOC ages which were younger than the bulk peat ages in the same horizons. The poor hydraulic conductivity of the peat bog may result in weak gas and water mixing with depth. Nevertheless, the dissolved CO_2 and CH_4 gases, and dissolved organic carbon in that bog peat was older than the contemporary atmospheric CO_2, indicating OCI (radiocarbon reservoir effects). Gandois et al. (2019) also found that the $F^{14}C$ of dissolved organic matter (DOM) decreased with depth in peat bogs. However, if peat plants (such as the above-ground grow mosses) do not uptake C3, there would be no OCI in the ^{14}C age after ABA treatment. In the same study, Clymo and Bryant (2008) found no age difference between humic acid and humin fraction from the same horizon below 4-m depth, but humic acid was younger than the humin fraction at 2-m depth. This means that peat plants normally grow in the upper 30 cm. Even vascular plants probably do not uptake dissolved CO_2 below 1 m water depth. Thus, the OCI in a growing peat plant caused by C3 mainly occur in shallow water depth (MacDonald et al. 1987; Shore et al. 1995; Saarinen 1996; Nilsson et al. 2001).

The uptake of dissolved CO_2 by some aquatic plants is well-known (Nielsen 1946). For example, the "biological carbon pump" in the ocean is considered the uptake of CO_2 and/or HCO_3- in water (Falkowski 1997; Cassar et al. 2004; Tortell et al. 2008). Although the role of terrestrial aquatic photosynthesis in CO_2 uptake is more complicated and less studied, Chen et al. (2021) provided direct evidence of alive aquatic plants (both submerged and emerged plants) used dissolved CO_2 in karst water, resulting in low $D^{14}C$. Even though we do not know how vascular plants in peatland uptake dissolved CO_2 in peat water, the age difference between ABA-treated *Carex* leaves and *Carex* roots suggests that the roots uptake dissolved CO_2 in peat water (Figure 3(B)). The above discussion demonstrates that peat plants uptake CO_2 for photosynthesis from different sources with different ^{14}C activities.

The organic matter (OM) is comprised of (1) unaltered OM including fresh plant matter and non-transformed components of older plant OM matter and (2) transformed OM of older plant debris (termed as humus) that bear no morphological resemblances to the original structures (Hayes and Swift 1978). Humus can be again categorized into three fractions based on the response to different pH: (1) fulvic acid (FA); (2) humic acid (HA); and (3) humin (HM) (Cook et al. 1998). The recalcitrance of humin (Hayes and Swift 1978, 1990) can be explained by its higher molecular weight and lower level of functional groups (particularly carboxyl and hydroxyl) that induce decreased polarity and lower charge density and consequently yield

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decreased solubility in alkaline or base solutions. In contrast, fulvic acid is biologically very active (readily soluble to both acid and base) and considered as a product of the biological breakdown of decomposed plant matter in response to microbial activity. The amount of OM in a depth horizon in peatland, therefore, reflects the balance between the supply of OM and the degree of resistance to biological degradation. Hence, both humin and humic acids are thought to provide ^{14}C ages that more accurately reflect the time at which the peat sample formed (Ascough 2014). According to the above discussion, peat plants may have different ^{14}C activities in different species and part by uptake CO_2 from different sources through photosynthesis during their growth. Thus, age differences may exist when the peat plants are alive. Through the humification process, the age difference may further vary, but humic acid and humin fraction should be considered as the original components from the original plants. Fulvic acid, on the other hand, may be contaminated by an exogenous carbon source which should be removed in the lab pretreatment. However, ABA treatment to remove both FA and HA will cause age differences. As the $^{14}C/^{12}C$ of the peat plants is a combination of $^{14}C/^{12}C$ in C1, C2 and C3, we can use a simple mass balance equation to describe it:

$$(^{14}C/^{12}C)_p = f_1 * (^{14}C/^{12}C)_{C1} + f_2 * (^{14}C/^{14}C)_{C2} + f_3 * (^{14}C/^{12}C)_{C3} \quad (1)$$

$$f_1 + f_2 + f_3 = 1 \quad (2)$$

where p denotes the total organic carbon in plants. C1, C2 and C3 have been defined before, and f_1, f_2, and f_3 are their respective fractions. For accurate ^{14}C dating of peat plants, one should understand fractions of C2 and C3. In general, C1 and C2 for a specific peatland, especially for a rainwater-dependent raised peat bog, should be identical or similar to each other. C3 should be the main factor to cause OCI. In the case of JCA ^{14}C dating, *Carex* may have a significant portion of C3 which may be used more for carbon fixation of humin in the root. The ABA treatment to remove humic acids will elevate the difference between C3 and C1/C2.

4.5. Bacon Model of ^{14}C Chronology and OCI Variation with Depth

Based on the discussion in the previous sections, ABA treatment leads generally to an older age shift due to the removal of humic acids. Furthermore, *Carex* will uptake dissolved CO_2 from peat water, which may contain more OCI compared with bulk plants. Thus, we select the ^{14}C dates of A-treated bulk plants and a few *Carex* samples for age-depth modelling for the JCA core by the Bacon model (Blaauw and Christen 2011). Supplement Figure S1 shows the model results based on 33 ^{14}C dates of A-treated bulk plants (17) and *Carex* (16). To understand the labile organic matter influence, Bacon age-depth modelling has been executed on ABA-treated samples. Our selection follows the criteria: if the ^{14}C age is significantly older than the age of the deeper layer (out of age uncertainties), this age can be considered as contaminated by "older carbon influence", and should be excluded from the model. The selected dates for both A- treated and ABA-treated Bacon models were marked in Supplement Table S1. Supplement Figure S2 shows the Bacon model results for 23 ABA-treated dates. The selections eliminate maximum OCI in the chronology. The comparison of the modelled age-depth results between A-treated and ABA-treated will allow us to see the influence of pretreatment and understand its variation with peat water depth.

Figure 4 shows the comparisons of the age-depth models based on A-treated dates (black curve) and ABA-treated dates (blue curve) and their age difference (red curve) with depth for

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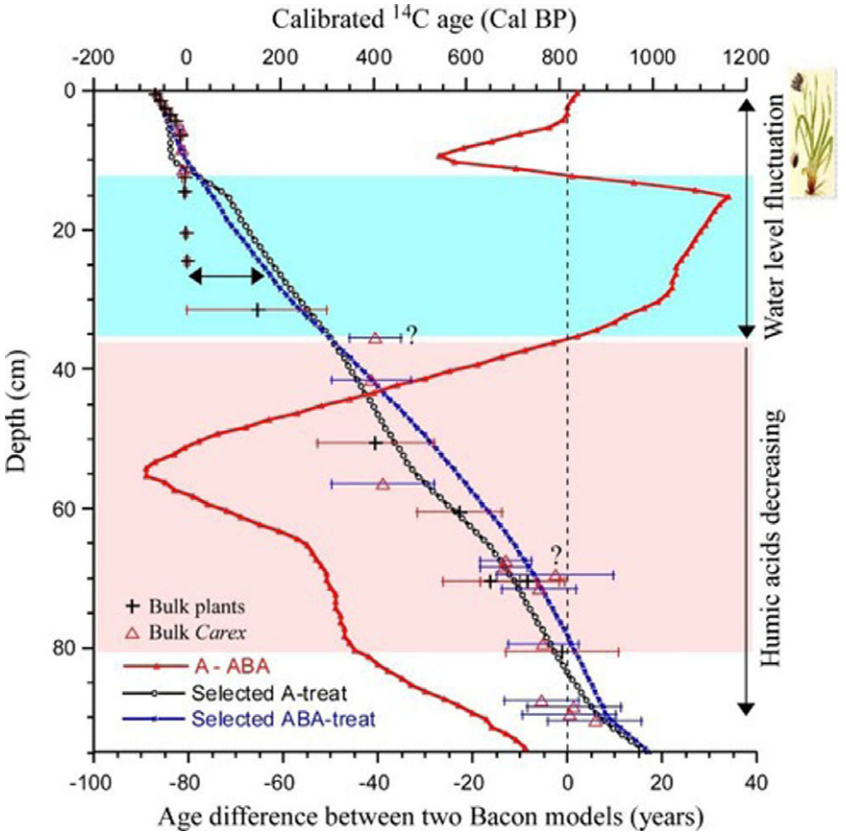

Figure 4 Comparisons of the Bacon age model results (mean ages) between selected A-treated (black curve) and selected ABA-treated (blue curve) ^{14}C ages, and their age differences (A – ABA) with depth (red curve). A = acid-treated; ABA = acid-base-acid-treated. The cross and triangle symbols denote the calibrated ^{14}C ages of A-treated bulk plants and A-treated bulk *Carex*, respectively. The question symbol refers that the two *Carex* dates can be excluded for better chronology. A picture in the upright corner shows a whole *Carex* example.

the JCA core. With 33 dates of A-treated samples, the age-depth relationship of the Bacon model generally reflects the calibrated ^{14}C ages very well, except between 15 cm and 30 cm depths (indicated by the double arrow symbol in Figure 4) where the modelled results are substantially older than the true age. One reason that may explain this error is that when the Bacon model involves post-bomb ^{14}C dates, some strange results may occur (e.g., the case in Li et al. 2019). The Bacon model turns to a smooth sedimentation rate. For instance, the fast accumulation rate between 15 cm and 25 cm depth in JCA was documented by human impact and the ^{210}Pb/^{137}Cs dating (Li et al. 2019). During 1950~60s, local people cleaned out vegetation around the peatland to turn it into farmland. Nevertheless, the age-depth model based on the 33 selected dates provides the most reasonable chronology of JCA, which is improved compared to the previously published chronology by Li et al. (2019).

Although the age-depth model based on 23 selected ^{14}C dates of ABA-treated samples is similar to the model based on selected ^{14}C dates of A-treated samples, the maximum age difference is about 90 years at 55 cm depth. It is interesting to see that when we combine dates of bulk

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plants, bulk *Carex*, *Carex* leaves and *Carex* roots, the modelled age from the selected ABA-treated samples are not always older than the modelled age based on the selected A- treated samples (Figure 4). Between 15 cm and 35 cm depths, the ABA-treated age was younger than the A-treated age (A − ABA > 0). If we use only bulk *Carex* to compare the modelled results between A-treated and ABA-treated dates, the modelled ABA-treated ages were older than the modelled A-treated ages throughout the core. Moreover, the age difference between the two modelled chronologies varies with depth, reflecting the variation of C3/C2 contribution in the ^{14}C age with depth.

As discussed before, *Carex* (sedge; vascular plant) roots probably preferentially use C3 whereas *Carex* leaves perhaps preferentially use C2 during its growth in the peatland. In the upper 30 cm of the peatland, fluctuation of water level is strongly influenced by surface runoff, so the ^{14}C activity of C3 in the upper water level might be higher than that of C2, especially when the post-bomb peat was decomposed. In addition, labile organic carbon may be dominant in the form of humic acids. The removal of labile organic carbons by base treatment (in ABA- treated samples) should be one of the causes of changes in age difference with depth in Figure 4. The younger shifts of the ^{14}C ages between A-treated and ABA-treated samples and bulk plant vs. bulk *Carex* illustrate the above situation. For a pre-bomb time, the OCI caused by C3 increased with depth from 35 cm to about 55 cm, then decreased downward probably owing to loss of labile organic carbon as biological degradation decreases. Tfaily et al. (2018) measured dissolved organic matter (DOM) in peatlands and found that (1) surface DOM was dominated by inputs from surface vegetation and (2) the intermediate depth zone (~ 50 cm) was identified as a zone where maximum decomposition and turnover is taking place. Such findings agree with the pH and TOC profiles in Hani and Jinchuan Mires (Yang et al. 2017; Sun et al. 2019).

Carex will use C3 in peatlands so that its ^{14}C age contains OCI. The OCI cannot be eliminated by ABA treatment. The removal of humic acids during base treatment of ABA- treated samples would make further age differences in comparison to the A-treated samples. As humic acids are part of the essential OM with an original plant photosynthesis imprint that represents the true age of a depth horizon in peatland, the ABA treatment for bulk peat samples is not recommended. Previous studies (Blaauw et al. 2004; van der Plicht et al. 2013) suggested that above-ground growing plants such as *Sphagnum* should be employed for ^{14}C AMS dating to avoid the labile organic carbon influence. However, those species are very easily decomposed and difficult to be collected throughout the depths of the peat core. As the "labile organic carbon influence" from the dissolved CO_2 and CH_4 varies with time, increasing dating resolution seems a necessary way to sort out anomaly ages.

5. CONCLUSIONS

The high-resolution AMS ^{14}C dating of the bulk plant, bulk *Carex*, *Carex* leaf and root samples in the JCA core reveals complicated issues in precise ^{14}C dating on peat sequences. The uptake of old CO_2 by vascular plants in peatlands during photosynthesis is one of the major factors causing ^{14}C depletion in plant remains. *Carex* (sedge; vascular plant) can uptake dissolved CO_2 (C3) from peat water through its root, uptake degassing CO_2 (C2) near the surface of the peatland. Both C3 and C2 can be influenced by the decomposition of old peat so the radiocarbon reservoir effect or old carbon influence (OCI) exists in peat ^{14}C dating. The OCI cannot be eliminated by ABA treatment. Our study demonstrates that the $F^{14}C$ (or ^{14}C age, $D^{14}C$) of the peat plants including (bulk plants and *Carex*) in Jinchuan Mire is not only

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lower than that of the atmospheric CO_2 but also depends on pre-treatment. The removal of humic acids by ABA treatment will alter the true ^{14}C ages of the studied samples as humic acids are part of the essential OM with original plant photosynthesis imprint that represents the true age of a depth horizon in peatland. The OCI varies with time and peat depth depending on the "labile organic carbon" profile of a peat sequence. In the case of Jinchuan Mire, the upper 20 cm appears the influence of the surface runoff on C3. The OCI increases from 35 cm to 55 cm, then decreases downward as the decrease of "labile organic carbon" with depth. As air-growing *Sphagnum* species are very difficult to be picked up in peat cores, either bulk peat or herb species were used for ^{14}C dating. The leaf fraction of peat plants should be better. *Carex* is not recommended for ^{14}C dating. ABA treatment for bulk peat samples may not be necessary. Increasing dating resolution seems a necessary way to sort out anomaly ages. Reversed ages should be excluded from the Bacon model. Bacon model may be smoothed out potential rapid accumulation rates, especially involving post-bomb dates.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2023.112

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