



The link between peat hydrology and decomposition: Beyond von Post

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SUMMARY

Hydrology is central to the formation, growth and utilisation of peat soils. However, peat presents a difficult medium in which to measure hydrologic properties, due to its soft structure and high water content. The von Post scale is a widely used measure of the extent of decomposition of peat, which can be applied in the field or the laboratory without specialised equipment. von Post decomposition has been shown to correlate with hydraulic conductivity. However, it is a categorical and subjective measure of decomposition. Technological advances now enable peat chemistry to be described quantitatively and objectively. ¹³C nuclear magnetic resonance (NMR) is now routinely used to describe peat chemistry, and the capability of this technique has been extended by the development of the molecular mixing model (MMM). The MMM predicts the molecular composition of organic material from the spectral information provided by ¹³C NMR. We found significant relationships between the hydrologic properties hydraulic conductivity and water yield and peat chemistry as described by ¹³C NMR and the MMM. These relationships have potential application in all fields where the hydrologic properties of peat soils are of interest (i.e. peat mining, peatland restoration, catchment management) and also in modelling of peatland development and responses to climate change.

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1. Introduction

Peatlands are water-dependant ecosystems. Peat soils develop where plant growth exceeds plant decomposition, and this commonly occurs where the anoxic conditions associated with waterlogging hinder the breakdown of plant material. The critical role that hydrology plays in the development and persistence of peatlands has attracted considerable research attention. Agriculture, forestry and peat mining for energy and horticulture all require the drainage of peatlands, and these needs prompted early work on peat hydrology (Boelter, 1965; Korpijaakko and Radforth, 1972). Conservation, restoration and the water and carbon resources mediated by peatlands have ensured sustained interest in their hydrology (Egglesman, 1988; Komulainen et al., 1999; Price et al., 2005).

There are standard methods for measuring the hydraulic properties of mineral soils. However, their applicability to peat has been debated for some time (Beckwith and Baird, 2001; Hemmond and Goldman, 1985; Mathur and Levesque, 1985; Reynolds et al., 1992; Rycroft et al., 1975). The difficulty of making meaningful

measurements of the hydrologic properties of peat originates from the challenging environmental conditions (Ingram, 1983) and the soft physical structure of the peat. Typically more than 95% water when saturated (Charman, 2002), peat is easily altered by the process of measurement, whether it be in the field or in the laboratory. Utmost care must be taken not to compress or dry out the peat, to the extent that it is advisable to avoid standing on the peat surface while taking measurements (Hemmond and Fifield, 1982; Ingram, 1983). Holden and Burt (2003) found that the application of compressible soil theory improved the utility of the falling head method of field measurement of peat hydraulic conductivity. Price et al. (2008) designed a laboratory-based apparatus to measure the hydraulic conductivity of the peatland surface, specifically catering for the large vertically-oriented pores and water storage cells (hyaline cells) of *Sphagnum* mosses. Hydraulic conductivity remains the most important, yet most methodologically challenging hydrologic property of peat soil. Consequently, there have been several attempts to develop correlations between the hydraulic conductivity of peat and another, easier to measure, property (Baden and Eggelsman, 1963; Bloemen, 1983; Korpijaakko and Radforth, 1972).

Peat is, by definition, composed primarily of organic matter and water (Charman, 2002). It seems logical, then, that the nature of the organic material ought to influence the movement of water through peat. The physical structure of the organic material is determined by its botanical origin and the extent to which its original structure has been altered by decomposition. This has long

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been recognised and it was these two properties, botanical origin and decomposition, that Baden and Eggelsman (1963) identified as predictive of hydraulic conductivity in their much cited work (Armstrong and Castle, 1999; Charman, 2002; Rycroft et al., 1975). The measure of decomposition was the von Post scale. The von Post scale is a ten class classification system, designed for describing peat soils in the field, based on “nature of liquid expressed on squeezing”, “proportion of peat extruded between fingers” and “nature of plant residues” (Armstrong and Castle, 1999) which was proposed originally by von Post in 1924. The von Post scale is widely used, but remains a subjective and qualitative measure of decomposition. Dry density, bulk density and solid matter volume have all been suggested as proxies for decomposition, which show strong correlations with hydraulic conductivity and have the benefits of being objective, quantitative and easy to measure (Bloemen, 1983; Korpijaakko and Radforth, 1972). Two recent models of peatland development emphasise the link between hydraulic conductivity and extent of decomposition. Frolking et al. (2010) used bulk density as a proxy for extent of decomposition. Morris et al. (2011a) represent extent of decomposition as proportional remaining mass, and show that the link between peat decomposition and hydraulic conductivity is of fundamental importance to understanding the development of peatlands over long timescales. A direct measure of peat decomposition that is mechanistically linked to hydraulic conductivity could thus help to constrain predictions of peatland response to climate change and thus improve peatland management.

Solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy has gained acceptance as a method capable of characterising the chemical structure of a diverse range of organic materials found in various natural environments (Kögel-Knabner, 1997, 2000; Mathers et al., 2000; Preston, 1996). As organic material decomposes, its chemical structure changes, as decomposer organisms utilise first the most bioavailable molecules and subsequently those that are more biochemically recalcitrant. NMR data can be used to describe the extent of decomposition (EOD) of organic materials (Baldock et al., 1997) and also to predict the molecular composition of organic materials (Baldock et al., 2004). This method has the advantage over traditional wet-chemistry methods used to define carbon chemistry of minimally altering the sample and directly measuring the allocation of carbon to the different chemical structures present. The chemical structure and molecular composition of organic matter ought, theoretically, to affect and thus be correlated with, the hydrologic properties of peat soils. To measure the chemical structure of peat with ^{13}C NMR is considerably faster and more straightforward than to measure directly the hydrologic properties of the peat, and the need to avoid compressing or drying the sample during collection is eliminated.

The objectives of this study were to measure the hydrologic properties and chemical composition of peat soils and to determine whether there existed a relationship between them. In light of the existence of such a relationship, we sought to identify the most useful chemical parameters to measure, in order to predict hydrologic properties. To make this work broadly applicable, peat was sampled from intact, undisturbed *Sphagnum* bog peats and drained dried peats: natural and human-altered environments spanning a large range of hydrologic properties and extents of decomposition.

2. Methods

2.1. Site description

Peat was sampled from a sub-alpine *Sphagnum* peatland (Wellington Plains peatland, 37°29'43.42"S 146°49'44.03"E) in

the Australian Alps, south eastern Australia. A map of the location is in Supplementary Data. The characteristic vegetation of the bog peat is *Sphagnum cristatum*, *Empodisma minus*, *Baloskion australe*, *Epacris paludosa*, *Richea continentis*, *Baeckia gunniana*, *Astelia alpina* and *Carex gaudichaudiana*. The characteristic vegetation of the dried peat is *Empodisma minus*, *Baloskion australe*, *Poa costiniana*, *Epacris paludosa*, *Baeckia gunniana* and *Carex gaudichaudiana*. Thus, there is much overlap of species, with the notable exceptions of a lack of the hydrophilic *Sphagnum* on the dried peat and a lack of the less-waterlogging-tolerant *Poa* on the bog peat. A detailed description of the site, including geology, vegetation and photos of soil pits can be found in Grover et al. (2012). The carbon chemistry and decomposition processes of these peats are described in Grover and Baldock (2010, 2012). The properties of the peat from Wellington Plain are comparable with those of *Sphagnum* peatlands in the northern hemisphere (Grover, 2006). A paleobotanical study at this site found that the vegetational composition of the peatland has remained stable since its formation (Elwood, 2001). Following the hydrogeomorphical classification of Lawrence et al. (2009), the site is a hillside peatland, and this category accounts for 50% of the state's high country peatlands.

2.2. Sample collection

Samples were collected from soil pits in three profiles¹ of bog peat and six profiles of dried peat on the Wellington Plain peatland. The location of each profile was chosen after an extensive survey of the entire peatland to be representative of bog peat and dried peat. Intact peat cores were collected in brass rings (diameter 7.3 cm, height 5.7 cm) compatible with the apparatus used to measure hydraulic conductivity and water retention. Peat structure was minimally disturbed during sampling, as we carefully worked the ring into the peat by hand, with the aid of a serrated knife. Adjacent peat was cut away, and the sample was removed from the base of the soil pit. The core was trimmed, two end caps were fitted, and water from an adjacent stream was added, to buffer the peat structure during transport to the laboratory. Samples were stored at 4 °C until required for analysis. Sampling followed the scheme in Table 1. The dried peat was sampled at the surface, mid profile and at the base of the profile. The profiles of bog peat were sampled at the surface (defined as the closed surface of the moss capitula, after Ingram (1978)) and in the fibric, hemic and sapric layers, as defined in the Australian Soil Classification (McDonald et al., 1990). These layers are defined by their chemistry, morphology and extent of decomposition and not by their depth below the surface. Consequently, for example, the fibric peat samples from the three different profiles came from 15, 20 and 24 cm below the surface.

2.3. Water retention, bulk density and specific yield

The ability of the peat to retain water under suction was measured in order to better understand how water drains from peat as the watertable falls. Thus this study focused on the low end of the scale of suctions normally applied in the study of the water retention properties of soil. Water retention was measured on samples from all three profiles of bog peat, and from four of the six profiles of dried peat (due to time constraints), totalling 92 samples, after the method in Topp et al. (1993). Suctions of 0, 2, 3, 4, 5, 6, 8 and 10 kPa were applied to the peat cores with presoaked ceramic pressure plates (10 kPa) above hanging columns of water (of 0, 20, 30, 40, 50, 60, 80 and 100 cm length, respectively). The base of the cores was used as the reference point. Cores were

¹ The soil profile is defined as a vertical section of the soil from the ground surface downwards to where the soil meets the underlying rock.

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