



Soil lacquer peel do-it-yourself: simply capturing beauty

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Abstract. Visualization can greatly benefit understanding of concepts and processes, which in soil science and geology can be done using real-life snapshots of soils and sediments in lacquer peels and glue peels. While it may seem complicated, anyone can make such a soil peel for use in classrooms, public places, homes, and offices for teaching, outreach, decoration, and awareness. Technological development has considerably simplified the making of soil peels, but this methodological innovation has not been described in the literature. Here, we report on a thoroughly tested and simple method for taking peels of sandy soils using readily available tools and materials. Our method follows the main previously published steps of preparing a soil face, impregnating the soil face with a fixation agent in the field, extracting the resulting peel, and mounting it on a wooden panel. Yet instead of using lacquers and thinning agents, we use strong though flexible contact adhesive (glue), which has the major advantage that it no longer requires use and mixing of toxic chemicals in the field or reinforcement of the peel to prevent breaking. Moreover, the preservation potential is much higher than with the old method. This new twist to old methods makes creation of soil peels safer, simpler, and more successful, and thereby a true DIY (do-it-yourself) activity. The resulting increased accessibility of making soil and sediment peels can benefit research, teaching, and science communication and can thereby bring the value and beauty of the ground below our feet to students, schools, policy makers, and the general public.

1 Introduction

Attention for soils is increasing around the world, in part due to strong initiatives on soil health (Stott and Moebius-Clune, 2017; Schindelbeck et al., 2008) and soil carbon (4%, Minasny et al., 2017), explicit articulation of how soils can help achieve the United Nations Sustainable Development Goals (Keesstra et al., 2016; Bouma and Montanarella, 2016), and the recent United Nations and IUSS declarations of the International Year of Soils (FAO, 2015) and International Decade of Soils (IUSS, 2015), respectively. The relevance of soils lies in the valuable beauty of soils: their multidisciplinary functions and benefits (Brevik et al., 2015; Dominati et al., 2010) and thereby their basis for life, in a world where soils are under threat (Montanarella et al., 2016). Capturing this beauty in monoliths or soil lacquer peels can bring soils to life for education and outreach (Van Baren and Sombroek,

1981; Lawrie and Enman, 2010) or as a form of art (Feller et al., 2015; Breaker, 2013). While it is often thought to be quite challenging to capture soil profiles, a simple twist to an old method now makes the creation of soil peels a surprisingly simple do-it-yourself (DIY) activity for scientists, educators, and the general public.

Soils and sediments can be fixated in two distinct ways: using peels and monoliths. Both methods rely on impregnation of a soil face with a fixation agent (such as lacquer, resin, or glue), and their final product is typically mounted on a wall for study of undisturbed soil layers and characteristics, or simply for decoration. Peels and monoliths are used to record and illustrate a range of different features in soils, such as differences between soil types, soil processes (e.g. weathering, gley, eluviation, and illuviation of clay, iron, and organic acids; Fig. 1a), human impacts (Fig. 1b), as well as biological activity such as plant rooting patterns, burrowing

of soil fauna, and bioturbation. Sedimentological and geological processes can also be captured, such as cryoturbation, fluvial and aeolian layering (Fig. 1c), frost wedges (Fig. 1d), and faults (Fig. 1e). And finally, peels can show the splendid colours present in soils and sediments (Fig. 1a–f). These natural snapshots of the subsurface are an effective way to inspire people about soils (Megonigal et al., 2010) and geology, and are used around the world by museums, universities, schools, and institutes (Table 1) for teaching and outreach on the value of soils, the processes occurring in soils, effects of management, and other factors. Interestingly, these soil profiles are also used for testing knowledge of soils in job interviews (Jacqueline Hannam, personal communication, 2018). Peels and monoliths allow comparison of soils inside a classroom or museum environment without the need for students or visitors to travel, allowing exposure to a variety of soils in a short time and increasing accessibility of soil science to those with disabilities that prevent them from observing soil in situ. Consequently, soil science education at Wageningen University, the Netherlands, strongly relies on a collection of ~ 150 lacquer peels for teaching purposes – despite the fact that this university is intentionally strategically located in an area where soil variability is high (van der Haar et al., 1993) due to the range of distinct parent materials (glacial, periglacial, fluvial, aeolian, organic) and topography, and thus soil types within a 10 km radius of the university.

The main difference between making peels and monoliths is the location where the soil is impregnated with a fixing agent: a peel is impregnated in situ and extracted after drying, while a monolith is an undisturbed soil block that is extracted, transported, and then (repeatedly) impregnated in a laboratory (Van Baren and Sombroek, 1981). Monoliths can be created in any soil type, from sands to peats and heavy clays, but is rather time-consuming and requires specialized expertise in both the field and in the laboratory. Their creation and recent methodological developments are rather well described in scientific journals (e.g. Bouma, 1969; Haddad et al., 2009; Allaire and Bochove, 2006; Wessel et al., 2017; Wright, 1971; Donaldson and Beck, 1973; Barahona and Iriarte, 1999; Fitzpatrick et al., 2015), presentations (Fosberg, 2019), and reports (e.g. Van Baren and Bomer, 1979; Kiniry and Neitsch, 2019; Day, 1968; Schuurman, 1955), as well as illustrated in online videos and tutorials (e.g. University of Nebraska – Lincoln, 2016; Mueller, 2018). In contrast to soil monoliths, soil peels cannot be made from clay or peat soils since these are often too wet for impregnation in the field. Peels are therefore limited to relatively coarse sediments that retain less water (lower water holding capacity) and allow more rapid impregnation of fixation agents (because of their higher hydraulic conductivity), which is required in field situations. They thereby provide a rapid and accessible alternative to soil monoliths. The lack-film method for creating peels was first developed in the 1930s (Hähnel, 1962; Voigt, 1936; Jahn, 2006). Yet while the use of soil lacquer peels for scientific purposes has been recognized, e.g. to study sedi-

mentological structures (Bijkerk et al., 2014; Van den Berg et al., 2007), for palaeo-geochemical analysis (Arnoldussen and van Os, 2015), or archaeological applications (Voigt and Gittins, 1977), the guidance available in the scientific literature is scattered, (out)dated, and/or incomplete. An English book that stands out is the comprehensive work by Bouma (1969) that details the history of soil and sediment peels as well as a range of fixation agents used to make these peels. Other published work includes a range of Dutch- and German-language papers, popular-scientific articles and reports (Vos et al., 2016; Huisman, 1980; TNO, 2010; Van Veen, 1985; Hähnel, 1961; Voigt, 1936), as well as a few older English-language articles (Voigt and Gittins, 1977; Van Baren and Bomer, 1979; Brown, 1963; Hähnel, 1962). These publications describe a range of materials used to make peels, most notably (nitrocellulose) lacquers, but also glue and resin.

The main steps of the published methods for making peels are straightforward: a soil face was prepared under an angle and then (repeatedly) impregnated with a fixation agent, with the peel extracted after drying and then mounted on a wooden board. The challenge of the published methods lies in the fixation agents used 50 years ago that required use of toxic solvents (e.g. acetone, toluene, xylene, thinner; Bouma, 1969) in the field to achieve the right viscosity, increasing the risk of harming people and the environment. The resulting peel was rather fragile, and hence reinforcement with cheesecloth or bandage was required to prevent rupture of the dried lacquer peel (Bouma, 1969). This fragility results in a lower preservation potential, which we have noted was especially challenging when the soil peels were frequently handled when used for teaching.

Here we describe and illustrate a simpler, safer, more durable, and thereby more accessible approach to making soil lacquer peels, which relies on the use of glue available at hardware stores. While still synthetic, this glue is less harmful than the previous fixation agents, and its use straight out of the can reduces the spilling risk associated with the mixing of chemicals in the field. Finally, this method can be easily deployed by those who have received no training. This new twist to an old method was developed by Gert Peek, a soil science educator at Wageningen University who started teaching at what was then the Laboratory for Soil Science and Geology at the *Landbouwhogeschool* Wageningen. As such, this method was used to collect both teaching material and data for MSc theses (e.g. van der Beek and Ellenkamp, 2003) and to enthuse hundreds of students to get a podzol above their bed, through the organization of “soil profile weekends”. As we believe it is essential that scientific methods are preserved for future generations, we now report on the simple steps to capture the beauty of sandy soils for use in universities, schools, government buildings, museums, or simply at home.

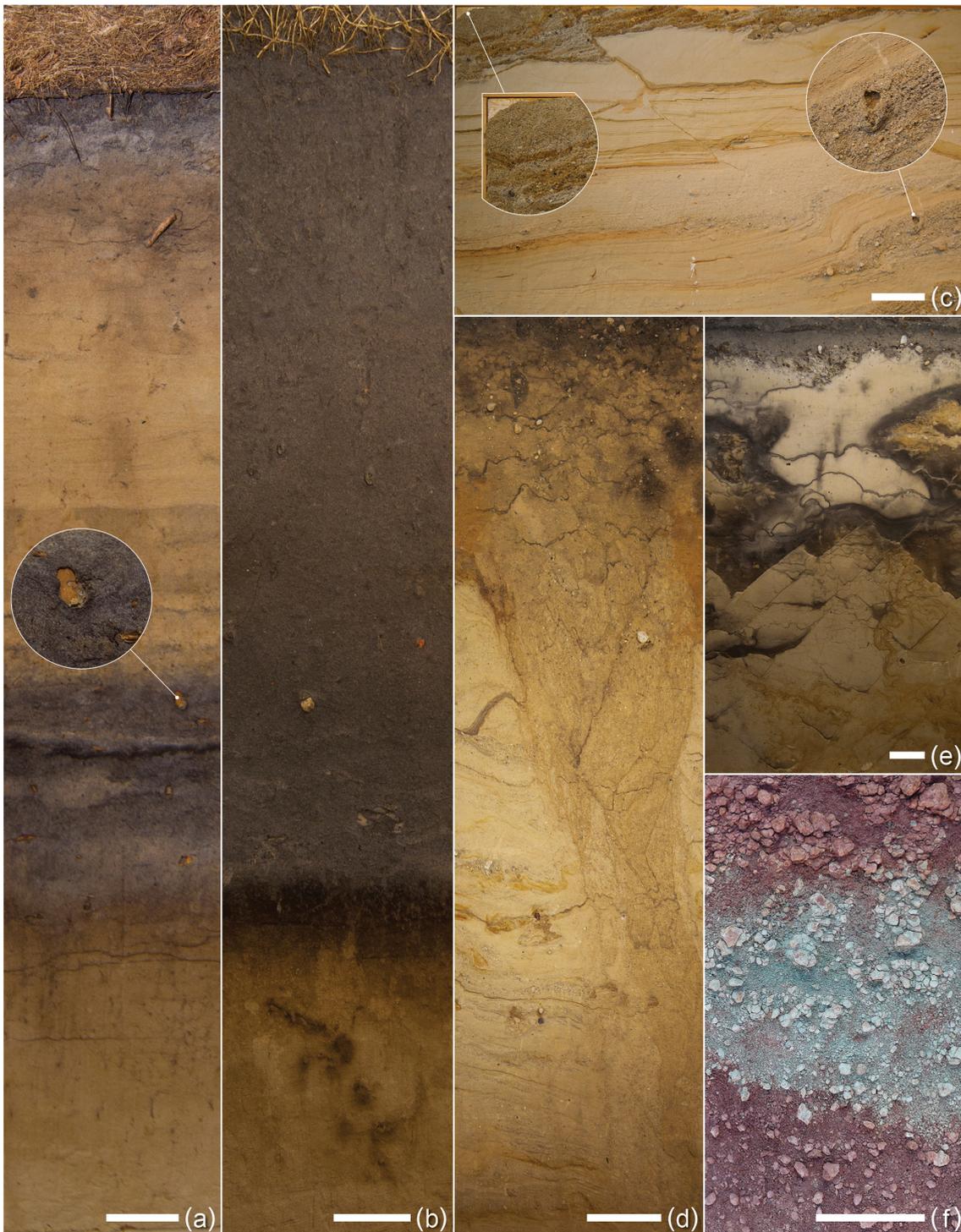


Figure 1. Lacquer peels showing (a) paleo podzol (from below inset) covered by drift sands in which a younger podzol is formed, (b) plagic anthrosol, (c) sedimentary layering, (d) frost wedge, (e) faulting, and (f) colourful sediments. Insets show close-ups of damaged parts of the peel; white horizontal bars represent 10 cm width; panels (a) through (e) are soil and sediment peels made in the Netherlands (Wageningen University collection, the Netherlands); panel (f) is a sediment peel of the Owl Rock member of the Chinle Formation, Chuska Mountains, New Mexico, USA (Diné College collection, Tsaile, Arizona). The white scale bars represent 10 cm.

Table 1. Example of 84 museums, universities, schools, and institutes with preserved soil profile collections (soil monoliths and/or lacquer peels) in 40 countries around the world.

Country	Institute	Source
Argentina	Universidad Nacional de Río Cuarto, Instituto Nacional de Tecnología Agropecuaria	Marcos Angelini and Alejandro Becerra (personal communication, 2018)
Australia	The University of Sydney (Australian Technology Park)	Ichsani Wheeler (personal communication, 2018)
Austria	University of Vienna	Feigl (2016)
Belgium	KU Leuven	ETWIE (2018), Karen Vancampenhout (personal communication, 2018)
Brazil	Universidade Federal de Lavras*, Universidade Federal de Roraima*, Universidade Federal de Santa Maria*, Embrapa Solos*.	UFRR (2018), UFLA (2016), UFSM (2018), Stephan Mantel (personal communication, 2019)
Canada	University of Alberta, University of British Columbia, Great Lakes Forestry Center (Ontario).	Krzic et al. (2013), Natural Resources Canada (2018), Liam Heffernan (personal communication, 2018)
Colombia	Museo de Suelos Ciro Molina Garcés*, Museo de Suelos Instituto Geográfico Agustín Codazzi*.	UNAL (2018), IGAC (2018)
Costa Rica	The Tropical Agricultural Research and Higher Education Center – CATIE*	Stephan Mantel (personal communication, 2019)
China	China Soil Museum*; The Modern Soil Monolith Exhibition Center*	GIWSR (2018), ISSCAS (2018)
Cuba	Instituto Nacional de Investigaciones de la Caña de Azúcar*	Stephan Mantel (personal communication, 2019)
Ecuador	Ministerio de Agricultura y Ganadería. Programa Nacional de Regionalización Agraria (PRONAREG), Museo de Ciencias Naturales*	Stephan Mantel (personal communication, 2019)
Estonia	Soil Museum Estonian University of Life Sciences	Eesti Maaülikol (2018)
Ethiopia	National Soil Service Project (Dept. of Watershed Development and Land Use)	Stephan Mantel (personal communication, 2019)
Germany	Halle University, University of Hohenheim, Technische Universität München	Jahn (2006), Steffen Schweizer (personal communication, 2018)
Ghana	Soil Research Institute*	Stephan Mantel (personal communication, 2019)
India	Kerala Forest Research Institute*, Tamil Nadu Agricultural University*; University of Agricultural Sciences Bangalore*	Kerala Forest Research Institute (2018), Stephan Mantel (personal communication, 2019)
Italy	JRC Ispra	Alberto Orgiazzi (personal communication, 2018)
Indonesia	Museum Tanah (Bogor Soil Museum)*	AMI (2018)
Japan	Natural Museum of History and Science; Natural Resource Inventory Museum; Tsuchino-Yakata, Hokkaido	Keiko Mori (personal communication, 2018)
Kenya	Kenya Soil Survey*	Stephan Mantel (personal communication, 2019)
Mali	Laboratoire Sol-Eau-Plantes*	Stephan Mantel (personal communication, 2019)
Mexico	Instituto de Recursos Naturales (CONABIO)*	Stephan Mantel (personal communication, 2019)

Table 1. Continued.

Country	Institute	Source
Netherlands	World Soil Museum, Wageningen University, VU University, Rijksuniversiteit Groningen, HAS Hogeschool, VHL University of Applied Sciences, Museonder, Geologisch Streekmuseum “de IJsselvallei”, Royal Eijkelpark, TNO Geological Survey of the Netherlands, Utrecht University	ISRIC (2018b), De Hoge Veluwe (2018), Geologisch Streekmuseum “de IJsselvallei” (2018), Martinius and Van den Berg (2011), Nauta (2009), Bernd Andeweg, Bram te Brake, Bram Hoogendoorn, Kim Cohen, Kirsten van der Ploeg, Richard Kraaijvanger, Sytze van Heteren, Wouter Thijs (personal communication, 2018).
Nicaragua	Universidad Nacional Agraria*	Stephan Mantel (personal communication, 2019)
Nigeria	University of Ibadan*	Stephan Mantel (personal communication, 2019)
Pakistan	Soil Survey of Pakistan	Stephan Mantel (personal communication, 2019)
Peru	Museo de Suelos*; Instituto Nacional de Recursos Naturales – INRENA*; Universidad Nacional de la Amazonía Peruana*	Fundacion ILAM (2018), Stephan Mantel (personal communication, 2019)
Poland	Muzeum Gleb (Krakow University of Agriculture)	Muzeum Gleb (2018)
Philippines	Bureau of Soils and Water Management*	Stephan Mantel (personal communication, 2019)
Russia	Vasily Dokuchaev Museum of Soil Science, St Petersburg; Williams Museum of Soil and Agriculture, Moscow	Russian Museums (2018), Jetse Stoorvogel (personal communication, 2018)
Spain	Universidad de Murcia; Universidad de Granada; Institut Cartogràfic i Geològic de Catalunya	UM (2018), UGR (2018), Lladós et al. (2017)
Taiwan	National Taiwan University*; Taiwan National Research Institute*	Chen (2019), Churchman and Landa (2014)
Thailand	Soil Museum Bangkok*	Thai Museums Database (2018)
United Arab Emirates	Emirates Soil Museum	Emirates Soil Museum (2018)
United Kingdom	Cranfield University	Jacqueline Hannam (personal communication, 2018)
United States of America	California Polytechnic State University, Kansas State University, Oklahoma State University, University of Idaho, Texas A&M, Virginia Tech, West Virginia University, University of Georgia, Smithsonian’s National Museum of Natural History (2008–2009), Cayuga Nature Center (NY), Diné College (Tsaile, AZ), American Museum of Natural History (NY)	University of Idaho (2018), Megonigal et al. (2010), PRI (2018), American Museum of Natural History (2018), Fitzpatrick et al. (2015), Colby Moorberg, Christine Morgan, Jason Warren, Maurica Fitzgibbons, Meredith Steele, Micky Ransom (personal communication, 2018)
Uzbekistan	State Research Institute of Soil Science and Agrochemistry	YGK (2018), Mirzokhid Mirshadiev (personal communication, 2018)
Venezuela	Universidad del Zulia Maracaibo*; Universidad Central de Venezuela Maracay*	Stephan Mantel (personal communication, 2019)
Vietnam	Soils and Fertilizers Research Institute*	Stephan Mantel (personal communication, 2019)
Zimbabwe	Chemistry and Soil Research Institute Harare*	Stephan Mantel (personal communication, 2019)

* Institute that partnered with ISRIC-World Soil Information to create a soil monolith collection (Stephan Mantel, personal communication, 2019).

2 Taking the soil peel: six main steps

2.1 Collect the required materials

2.1.1 Materials needed

A range of materials is required to make a soil peel that can typically be found in any hardware store. Table 2 lists all materials required to prepare the soil face (a spade, pruning scissors or garden shears, nail clippers, soil knife, ruler), to secure the soil (glue), to extract the peel (wooden board, spade, soil knife, pruning scissors or garden shears, garbage bag), to finish the lacquer peel (glue, notched trowel, Stanley knife, nail clippers, scissors), and to mount it (hooks). In terms of personal gear, garden gloves and clothes that can get dirty are sufficient. Any size can be chosen for the final size of the soil peel, and thus the size of the wooden board. Soil profiles at Wageningen University are typically 30×120 cm. A wooden panel > 12 mm thick (to prevent warping) is used for mounting – we use multiplex or medium density fibre board (MDF), though any wood can be chosen, depending on the desired aesthetics.

2.1.2 Characteristics of the glue

The fixation agent used to impregnate the soil face is a liquid contact adhesive based on neoprene rubber. Originally designed for shoe repairs that require two sides to be pressed together, this neoprene rubber contact adhesive works very well for making peels because it is flexible yet strong when dry. This flexibility is key for successful extraction of the peel from the soil face: glue that fully hardens when dry (like wood glue or glues used to impregnate monoliths in the lab) will break upon extraction and/or mounting of the peel. Another benefit of this glue is that it does not shrink when drying, unlike the lacquer used for instance by Hähnel (1962). In the Netherlands, neoprene rubber contact adhesive is sold as BisonKit Universal (Bolton Adhesives, Rotterdam, the Netherlands; Bison International, 2018b), which is internationally sold by the same manufacturer under the brand names Uhu Kontakt Kleber and Griffon Contact. The yellowish brown colour of this glue does not affect the colour of the final peel. Neoprene rubber contact adhesive is also known as polychloroprene glue, contact cement, or contact adhesive, and is elsewhere sold by manufacturers such as 3M, DAP Weldwood, Pliobond, and K-Flex-USA – check the suitability of these products in the field before purchasing large volumes. Because some of these brands still contain toluene, it is also advisable to request (material) safety data sheets (known as (M)SDS in the USA) to check for any required personal protective equipment.

The volume of glue (V_G , L) required to make a peel, including excess edges and mounting the peel, is calculated as Eqs. (1) and (2):

$$V_G = 3.8 \times (b_W + 0.2) \times (b_L + 0.2) + V_M, \quad (1)$$

$$V_M = 0.1 \times b_W b_L, \quad (2)$$

where b_W (m) and b_L (m) are the width and length of the wooden board and thus the final size of the peel, respectively, and V_M (L) is the volume of glue needed to mount the peel to the wooden board. For a final peel size of 30×120 cm, 3 L is sufficient. At a cost of 5–20 EUR L^{-1} , the total costs of a typical profile amount to under EUR 75. As many stores allow return of unopened cans of glue, we typically purchase more glue than we need and return the excess.

2.2 General preparation

2.2.1 Find a good location

Finding a good location can just be a matter of being outside a lot, knowing the surroundings, and scraping off the outer few centimetres of an exposed road cut to reveal the original soil underneath. In the old days (up to the 1990s) when workload at universities was still low, frequent and lengthy soil mapping field courses allowed for many opportunities to find beautiful soils and capture them in peels. Alternatively, with less time spent outside, good locations can also be found using digital maps that are often available online. Whether outside or behind a computer, four main factors determine the suitability of a location for making a soil peel: (1) soil texture, (2) groundwater depth, (3) a natural or man-made exposure, and (4) accessibility (Fig. 2a).

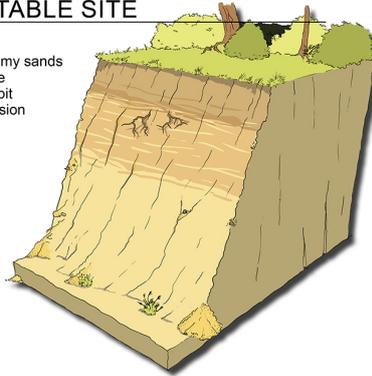
First, regarding *soil texture*, lacquer peels are best made in unconsolidated sandy deposits (such as commonly found in delta areas) with low clay, silt, and organic content and ideally low rock fragment or gravel content. Clay and silt have low permeability (Rawls et al., 1982), and so does organic matter when compacted (Ohu et al., 1985), and thereby result in very shallow impregnation of the glue, causing potentially fragile layers. Based on years of field experience in making soil peels we found that the textural classes “sand” and “loamy sand” (Soil Science Division Staff, 2017) are best suitable. This indicates that the clay + silt content should not exceed 30 %, with a maximum of 15 % clay. The minimum sand content should therefore be 70 %. At the same time, the organic matter content should not exceed ~ 8 % (humic conditions, sensu De Bakker and Schelling, 1966). Rock fragments and gravel are challenging to work with because they affect the smooth preparation of the soil face (Sect. 2.3) and additionally may fall off the final peel (Sect. 2.6), although results can still be quite successful. To find locations with suitable soil texture and organic matter content, the S-World model (Stoorvogel et al., 2017) and the SoilGrids tool (ISRIC, 2018a; Batjes, 2012) are both valuable and free resources. This can be verified with local soil maps and/or assessment of texture (NRCS, 2019; Thien, 1979) and organic matter content (Schulze et al., 1993; Wills et al., 2007) in the field.

Table 2. Materials required and their purpose.

Material	Purpose						
		1. General preparation	2. Field preparation	3. Glueing	4. Peel extraction	5. Mounting	6. Finishing
Ruler, measuring tape	To stake out the lacquer peel dimensions		×				
	To determine the finished peel dimensions					×	
Spade, shovel	To make a smooth soil face		×				
	To clean up excavated sand				×		
Soil knife (Nisaku Horihori weeding knife, Tomita Cutlery Co. Ltd., Koseki Tsubame-si Niigata Japan. Alternative: large serrated knife with a big handle)	To shape the ledge		×				
	To dig out the peel after the glue has dried				×		
Garden clipper/pruner					×		
Nail clippers (2×)	To cut small roots		×			×	
Polychloroprene glue	To secure the soil particles			×			
Garbage bag, pvc pipe sliced in half	To construct a collection unit to capture excess glue		×	×			
Sturdy garbage bags or bucket	To transport empty glue containers (potentially sticky), excess glue			×			
	To transport cut off lacquer peel				×	×	
Notched trowel	To evenly spread glue on wooden board					×	
Stanley knife	To cut off all parts of the lacquer peel that extend beyond the wooden board					×	
Workers gloves	Protect hands during digging, etc.		×	×	×		
Latex gloves	Protect hands while glueing board					×	
Wooden board	To support extraction and transport of lacquer peel				×		
	To mount lacquer peel on					×	
Blanket, cloth	To prevent lacquer peel from breaking				×		
Hooks	For mounting on wall						×

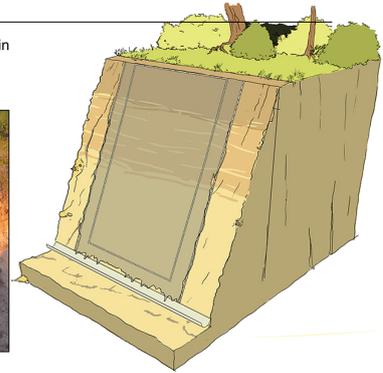
(a) IDENTIFY SUITABLE SITE

- ▶ Soil texture: sands & loamy sands
- ▶ Above groundwater table
- ▶ Exposed soil face/dig a pit
- ▶ Accessible & get permission
- ▶ Dry weather (2 weeks)



(e) LET DRY

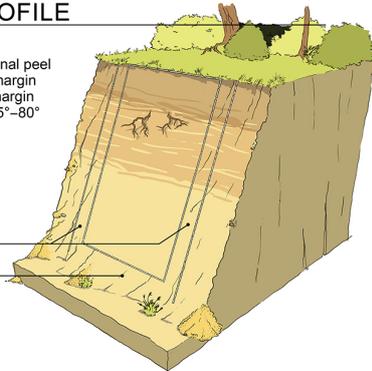
- ▶ Keep sheltered from rain
- ▶ Let dry for ±24 h



(b) PLOT OUT PROFILE

- ▶ Determine dimensions final peel
- ▶ Add ±10 cm horizontal margin
- ▶ Add 15–20 cm bottom margin
- ▶ Straighten soil face at 65°–80°

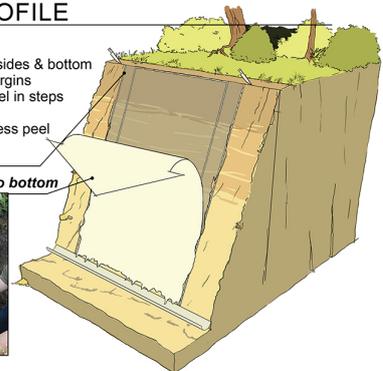
±10 cm margin
±15–20 cm margin



(f) EXTRACT PROFILE

- ▶ Clear sand away from sides & bottom
- ▶ From top, cut along margins
- ▶ Remove soil behind peel in steps
- ▶ Lift peel from soil face
- ▶ To prevent damage: press peel against board

Remove peel from top to bottom

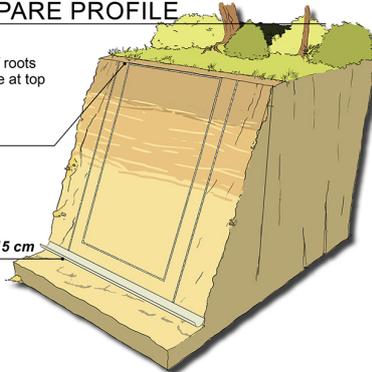


(c) CLEAN & PREPARE PROFILE

- ▶ Take out rocks & trim off roots
- ▶ Create ±5 cm wide ledge at top
- ▶ Install gutter

±5 cm ledge

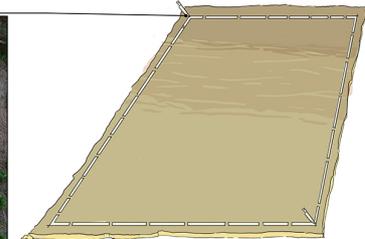
Gutter: PVC pipe, Ø 10–15 cm



(g) CUT TO SIZE

- ▶ Glue extracted peel to wooden board.
- ▶ Trim to size.

Trim peel to size



(d) APPLY GLUE

- ▶ Start at top ledge
- ▶ Apply glue evenly over surface
- ▶ Move horizontally and downward
- ▶ Excess glue caught by gutter

Apply glue in S-pattern



Excess glue caught by gutter

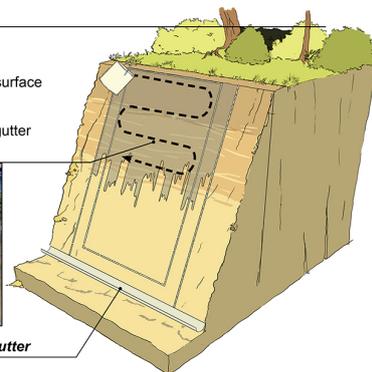


Figure 2. Main steps of making a soil peel.

Second, *groundwater depth* is important because results are best if soils are dry, since the glue used does not adhere properly when soils are wet. Groundwater level variation can be part of hydrological monitoring setups, but can also be recorded on soil maps as the average highest and lowest groundwater levels (e.g. BIS Nederland, 2018). Given that warm and dry weather in late spring or summer is often most beneficial for making soil peels, the most relevant groundwater information there is the average lowest groundwater level (which occurs in summer). The global map of groundwater table depths created by Fan et al. (2013), albeit coarse, can give a first indication of whether a region may be suitable for making soil peels. Alternatively, high (seasonal/perched) groundwater depths can moreover be inferred from soil type (e.g. Fluvisols, Luvisols) and geomorphology (e.g. lower river terraces, floodplains, wetlands, glacial till landscapes prone to hardpan formation), the information of which can be found on soil maps and geomorphological maps. Subsequent combination of soil texture, organic matter, and groundwater information can then provide insight into where peels can be made (e.g. Fig. 3). Combined with information about capillary rise (~ 2.5 cm in gravel to > 1 m in silt; Singhal and Gupta, 1999), locations of suitable dryness can be found, which is in soils and sediments above the capillary fringe.

Third, an *exposure* is essential when making lacquer peels of vertical cross sections of soil or sediment. This exposure can be created by digging a soil pit, which can be done by hand. Approximately 1 m^2 is needed to have sufficient work space, with a 1.0–1.5 m depth of the pit to obtain a 0.8–1.3 m long peel. However, as digging a pit can be time-consuming, the most ideal places to make peels are natural drops in elevation such as eroded river banks, or man-made cases such as road cuts, quarries, construction works (river restoration, cable installation), or archaeological digs. Contact local authorities or companies to ask for temporary opportunities, or consult elevation maps for more permanent locations. Elevation maps are often available online. Detailed digital elevation models (DEMs) may also be used; for example, the AHN (*Actueel Hoogtebestand Nederland*) in the Netherlands is a freely available elevation map with a resolution of 0.5 by 0.5 m (Van Heerd and Van't Zand, 1999). International examples include the EU-DEM with a resolution of 25 by 25 m (EEA, 2018). Exposures such as quarries may additionally be found from aerial photography (e.g. Google Earth).

2.2.2 Arrange permission

Locate the landowner and ask their permission. As many non-soil scientists do not know what a lacquer peel is, a simple explanation free of scientific jargon is to refer to it as a “soil painting” or “soil art”. Be honest about the use of glue, but also explain that you will clean everything up. Check whether the landowner would like to receive notice about the exact moment the fieldwork is planned – though as the

process of making a soil peel is weather-dependent, this can often not be indicated much in advance, and acknowledge them in activities resulting from work on their land. Making soil peels can be an opportunity to involve land owners as an outreach activity, by having them on site, or sharing information (photo/video) about the process. In the dry summer of 2018, we created three soil peels on Wageningen University farmland with the pit excavated by Unifarm (farm services) – in return we made a fourth soil peel for Unifarm outreach activities.

2.2.3 Get the timing right

In some climates, planning ahead for making lacquer peels can be challenging as this activity is rather weather dependent. Results are best when soils are dry, creating more intense colours and higher contrast of colours in the peel. In the Netherlands, our experience with the “soil profile weekends” taught that 2 weeks of dry weather in late spring or summer are sufficient to achieve good results. We have never had issues with soils that were too dry, and with the materials we use there is no need to spray the soil with water as suggested by Bouma (1969). While it is possible to make a peel when the soil is moist, the result is not as beautiful because of reduced appearance of for instance podzol fibres, or simply because the glue will not adhere to the sand. Note that while soil moisture contents may strongly vary in time, there may also be considerable differences within a soil profile. When sand may be already dry, horizons with more organic matter or clay can still be quite moist because of their strong effect on soil water retention (Rawls et al., 2003; Wösten et al., 1999). These within-profile differences may be exacerbated by impermeable layers: we once encountered major issues when extracting a peel from a podzol that had a perched water table due to an impermeable Bh horizon. While application of the glue (Sect. 2.4) was successful, the extracted peel showed that the glue had not adhered to the saturated E horizon above the Bh, while the C horizon below the impermeable layer was dry and adhered just fine. This peel was later restored in the lab (Sect. 2.6) using dried sand collected from the E horizon.

Dry weather is recommended both in the couple of weeks before making a peel as well as during the 2 days in the field (Sect. 2.3–2.6), when air temperature is also important. Follow the manufacturer’s recommendations regarding the temperature at which the glue can be used (e.g. 15–25 °C, Bison International, 2018a). Particularly the first hours after impregnation are critical because any rain occurring soon after impregnation (within 6–10 h) may create bubbles in the glue, resulting in poor impregnation and therefore “bald” spots with reduced sand cover upon extraction. High relative humidity can potentially have similar effects (e.g. $> 65\%$, Bison International, 2018a), although we have never had such issues in the field.

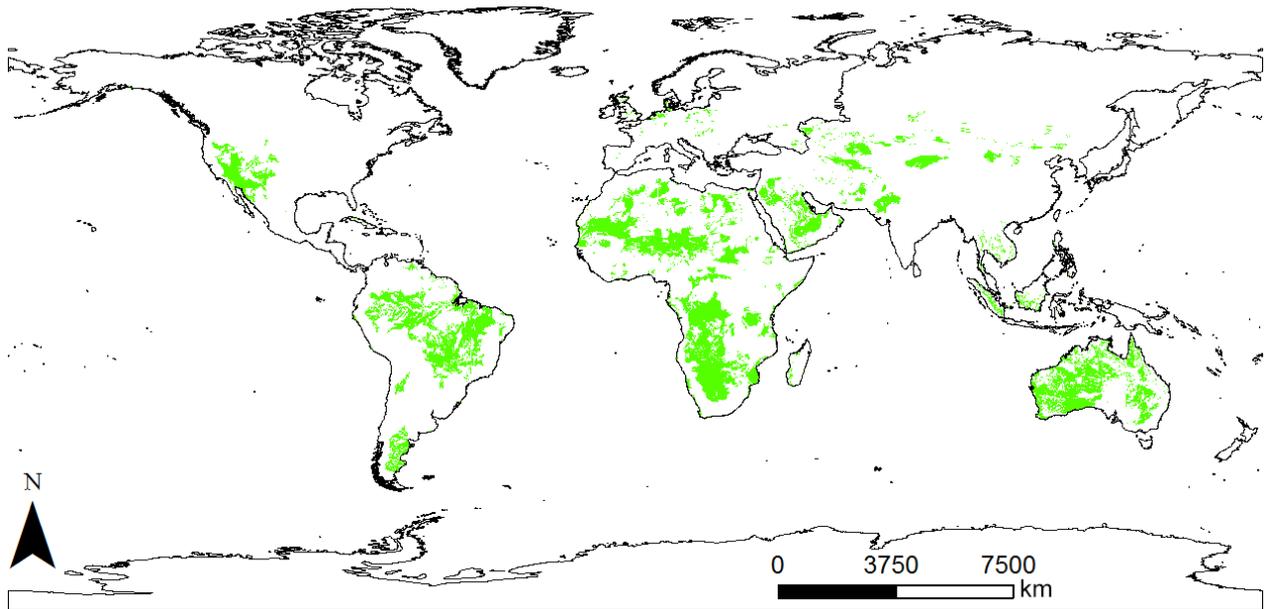


Figure 3. Overview of locations suitable for making soil peels in the world (sand content > 70 %, clay content < 15 %, organic matter < 8 %, and temporal mean groundwater depth < 1.5 m). This global map was made using soil information obtained from ISRIC (Batjes, 2012; ISRIC, 2018a) and groundwater depth information provided by Fan et al. (2013).

2.3 Field preparation: prepare soil face and cut all roots

2.3.1 Prepare soil face

Use a spade to make a straight soil face at a 65° (loamy sand) to 80° (sand) angle (Fig. 2b). The dimensions of the soil face to be impregnated should be somewhat larger than the intended size of the lacquer peel. Make the soil face 10 cm wider than the final peel on either side (Fig. 2b), because it is never fully predictable how the glue will flow and thus what the final surface is that will be covered. Also, extend it 15–20 cm below the bottom end of the intended peel to allow unimpeded flow. An additional benefit of making the soil face larger than the final size of the peel is that it allows selection of the best or most beautiful part of the profile for mounting. After all, the final appearance of the front of the lacquer peel remains hidden until after excavation, as the lacquer peel is a mirror image of the soil face. It is therefore always a surprise what the final peel will look like, which is why having additional space to choose the most beautiful part for installation on the board is useful. The prepared soil face should be as smooth and straight as possible – any bumps and hollows can hamper smooth distribution of the glue in the next step. Perfection is not possible though, especially when sediments are brittle or gravelly. It would not be the first time that removing “one last thing” can cause collapse of part of the soil face and thereby necessitate much larger restoration work before the glue can be applied.

2.3.2 Trim roots and remove rock fragments

Cut away all roots protruding from the soil face using garden or nail clippers (for large and small roots, respectively) and remove any rocks or large rock fragments (Fig. 2c). Roots or rocks that stick out will retain glue and can thereby create glue-less pockets that will appear as holes in the finished lacquer peel. Cut the roots as close to the soil face as possible while avoiding any dislocation of sand grains. This can be a rather tedious process as the number of roots can be surprisingly high. Yet careful removal of roots and rock fragments will allow smoother impregnation of the soil face (Step 3), easier mounting of the peel on the wooden board (Step 5), and thus better final results.

2.3.3 Make ledge

Create a 5 cm ledge above the soil face (Fig. 2c), providing a place to pour the glue and preventing any soil material from above from falling onto the profile. If the top of the soil face is the same as the mineral soil surface, this ledge can be created by removing any litter and vegetation. If the top of the soil face starts mid-way a slope, this ledge can be made by simply cutting 5 cm into the soil.

2.3.4 Install gutter

Position a gutter underneath the soil face that can collect any excess glue (Fig. 2c). A piece of PVC pipe (diameter 10–15 cm) sliced in two and then capped on both ends can function as a good gutter, although a plastic bag may also do if

positioned well. If the firmness of the soil profile allows, cut a 5 cm overhang below its bottom and locate the gutter underneath this overhang.

The total time required for field preparation strongly varies with the degree of care taken when preparing the soil face – a general time estimate for this step is ~ 2 h for soils with a good rooting pattern. In sediments with no roots this step can be done in 5–10 min.

2.4 Impregnation: securing the sand grains with glue

2.4.1 Apply the glue

To allow for rapid application of the glue, open all the cans of glue and place them within reach of the soil face – or close to a helping hand who can give the cans to the person applying the glue. In contrast to the previously discussed older methods that required on-site mixing of glues or lacquers with thinning chemicals, glues used here are ready-for-use and can thus be used straight out of the can. Application of the glue on the soil face is easiest when using wide-mouth cans (~ 15 cm diameter); we recommend using an empty vegetable can for pouring if the glue container has a narrower opening. Gently pour the glue by starting at the top ledge and moving the can across the width of the profile in a zig-zag pattern (Fig. 2d). While the glue moves downwards, also move down the location where the glue is applied. Most likely, a finger-like pattern will appear in the glue (Fig. 2d, Video S1 in the Supplement), especially when the soil face is rather vertical. This preferential flow is caused by the fact that liquids have a strong tendency to follow existing zones of (even slightly) higher liquid content (Liu et al., 1994), because of the large differences in hydraulic conductivity and thus flow velocity in dry and wet materials. Fill in the gaps between the preferential flow paths by pouring glue at their top and continue this process until the glue has reached the bottom of the soil face. When the bottom of the profile is reached, the impregnation stage is finished. We recommend application of only a single layer of glue: we qualitatively tested the effect of adding additional layers of glue, which did not improve the final product. In one case, application of a second layer of glue even resulted in movement of the initial layer, creating a glue-less patch and thus a hole in the final peel.

2.4.2 Clean up

With the glue application done, the impregnation step of making the lacquer peel is finished. The neoprene rubber contact adhesive is so strong and yet flexible within the first days of application that it can easily hold the weight of a soil profile without tearing. As such, reinforcement of the peel with cheesecloth as directed by Bouma (1969) is not required. Collect any excess glue that is still liquid from the top ledge and the bottom gutter. Remove all trash and leave the site such that any visitors (people or animals) cannot harm

themselves. Cover the impregnated soil face with a large (fisherman's) umbrella if there is a chance of light rain, and wait 20–24 h to let the glue dry (Fig. 2e). The exact drying time will depend on meteorological conditions (air temperature, relative humidity, and wind) and exposure of the profile. It may be that the profile is dry and ready for extraction after less than 20–24 h. Testing of potentially reduced drying times in different conditions is advisable in cases where time is tight and weather conditions are advantageous.

2.5 Extracting the peel

2.5.1 Clear sides

Extraction of the peel from the soil face involves the repositioning of a lot of loose sand from behind the peel to the sides. To facilitate this sand removal, make sure that the soil face on either side of the impregnated section is flush with the lacquer peel for a width of ~ 15 cm on either side. It is also advisable to remove sand around the bottom of the profile.

2.5.2 Cut out peel from above

Everything is now in place to start digging out the peel from above using the serrated edge of a (soil) knife. Starting at the top ledge, use the (soil) knife like a saw to make a cut 5–10 cm behind the glued soil face across the entire length of the peel (Fig. 2f, Video S1). The knife cuts fine roots; use garden clippers to cut off larger roots ~ 5–10 cm away from the glue. The further out from the glue you make these cuts, the longer the roots will be that stick out of the finished peel, which can always be trimmed in Step 5 (Sect. 2.6).

Extraction of the soil peel is best done with two people, and can be done from the top (as outlined here) or from below (as outlined by Bouma, 1969). To extract the peel from the top, one person cuts away the soil and moves loose sand away from behind the profile and works their way down the profile. Once the top of the lacquer peel has been freed, a second person then presses a wooden board against the soil face that supports the top of the profile against the board (Fig. 2f, Video S1). This is to support the peel and prevent any tearing along fragile layers such as podzol fibres or thin loam bands. If the peel is heavy, for instance in the case of very structured soil, it can be partly folded over the top of the wooden board. Covering the edge of the wooden board with a thick towel can then reduce the risk of tearing that can occur in fragile layers.

Digging out the lacquer peel can be easy and straightforward if the peel is small and does not contain roots or concretions. Very small profiles (e.g. 40 by 40 cm) can even be done by a single person. Extracting a more typically sized peel (e.g. 30 cm wide by 120 cm long) is not necessarily difficult, but it can be arduous if layers are densely rooted or structured. Still, 15 to 30 min is usually sufficient to remove peels from a soil face.

2.6 Mounting the peel

2.6.1 Choose your mounting location

The extracted soil peel can be mounted on a wooden board either directly in the field or after transporting the peel to a laboratory, shed, carport, or garage. Mounting the peel in the field allows for safer transport, yet it does typically mean that the size of the wooden board and thus the final size of the lacquer peel is predetermined – unless there is a possibility of bringing power tools to the field to trim a board to size. Using a fixed board size is not a problem when making soil peels for teaching or outreach collection, but when using peels for soil art it can be worthwhile to determine the final peel size after extraction. After all, since the peel is a mirror image of the soil face (as discussed in Step 2), its final appearance remains a surprise until it is extracted from its location.

2.6.2 Test positioning

When ready to mount the peel, test its position on the wooden board to decide which features to keep. Measuring how much the peel will extend beyond the sides of the wooden board helps exact positioning once the board is glued. If the peel is too heavy to lift, reduce its weight by removing large aggregates by hand and/or by very carefully removing any large clumps of soil with a soft brush. A brush may also be used to remove loose sand (always stroke sand away in the direction of any soil layering), but only if the glue is fully dry.

2.6.3 Glue the wooden board

Cover the wooden board with some of the remaining glue (Fig. 2g), making sure to particularly cover its sides and corners as these are the most vulnerable parts of the finished peel. Use of a notched trowel facilitates an even spread of the glue, while corners and sides can be reached by hand using household gloves. Work swiftly as the glue dries quickly, particularly when the weather is warm ($> 25^{\circ}\text{C}$) and windy.

2.6.4 Attach peel to board

Lift the lacquer peel up with two people and place it on the wooden board directly in the desired location: as the glue will create an instant grip, changing the alignment of the lacquer peel will be very challenging if not impossible.

2.6.5 Press peel in place

Carefully but firmly press the lacquer peel to the wooden board with your fingers. Again pay particular attention to the sides and corners of the wooden board to secure these well.

2.6.6 Remove loose sand

Turn the peel on its side and release any loose sand still resting on the peel by manually knocking the back of the wooden

panel. Repeat until no sand falls off anymore. Keep some excess material from each layer (soil, any rock fragments, large roots) to restore any damaged patches later if needed.

2.6.7 Trim peel to size

Now that the peel has been secured to the wooden panel, trim it using a sharp (Stanley) knife (Fig. 2g). With one side of the knife touching the side of the wood, cut off all parts of the soil peel that extend beyond the wooden board. Retain strips to make mini-profiles or to test the effects of impregnation with a fixing agent (Sect. 2.7).

2.6.8 Restore any damaged patches and trim roots (if desired)

In some cases peels may have small holes or damaged patches if glue distribution was not uniform or where rock fragments or larger roots have fallen off. These patches can be easily restored by applying some glue and covering them with the appropriate material for that layer, such as soil particles, a rock fragment, or a large root. This is also the moment where roots can be trimmed if desired using shears or nail clippers. There is no predetermined root length: the final root length is very much part of the artistic freedom and the message that is communicated with the soil peel, if any.

2.7 Finishing, installation, and maintenance

2.7.1 Ventilate

The soil peel now requires some rest in a well-ventilated place to let the glue fully solidify – we ventilate our profiles for a minimum of 4 days. As glue fumes can be rather intense, a garage, shed, or covered dry outdoor location is best for this. Make sure to place the lacquer peel in a horizontal position – placing it vertically shortly after mounting may result in vertical movement of the drying glue and thus distortion of the soil profile.

2.7.2 Finish

Many authors suggest impregnating the undisturbed front of lacquer peels (e.g. Huisman, 1980; TNO, 2010) to intensify the colours of the soil particles and secure any loose particles. Our team did that from 1978 to 2010 using a large can of the cheapest hairspray sold at the local pharmacist, applying it 1 week after the soil peels were mounted. The hairspray did bring out the colours more, but once surprisingly produced such dark colours that any colour variation in the peel was obscured. It may be that the formula of the hairspray had changed, but the exact reason for this dramatic colour change was unknown. Since then, we have not sprayed peels anymore and are very satisfied with the original colours. As such, there was no need to find an alternative impregnation material. In the case that colours are weak, spraying with

hairspray can be a way to intensify colours, but we strongly recommend testing of results along the entire length of the lacquer peel using the trimmed-off edges of the peel. In that case, turn the profile on its side to knock off any loose particles before spraying and ventilate again for a few days before installation.

2.7.3 Install

After a week of rest when the glue will be firm and odourless, the finished lacquer peel can be installed in its final location. Hooks screwed into the top of the board allow it to be hung vertically on a wall in a classroom, office, living room, museum, or wherever this piece of science art is desired. If desired, slats can be used to construct a wooden frame around the finished lacquer peel.

2.7.4 Maintenance

We have heard reports of people annually impregnating their soil peel with spray to “maintain its colours”. We have never seen a need for this and do not perform any maintenance of the finished peels. After changing from lacquer to glue, preservation of our peels has improved such that even intensive use in hands-on teaching does not degrade the peels anymore. If required, dust can be carefully removed from between any roots using a vacuum cleaner set at its lowest speed.

3 Discussion and conclusion

High participation in the maker-ed and DIY movements (Holtzman et al., 2007; Atkinson, 2006) indicates renewed interest in making things at home, while the potential of visualization is being recognized in science communication and education (Evagorou et al., 2015; Venhuizen et al., 2019). At the same time, there is increased interest in the value of soils for life (Keesstra et al., 2016; FAO, 2015). The creation of soil and sediment peels combines all these aspects, and can be done by non-specialists. Materials including glues are readily available at hardware stores, and even novices can create beautiful peels. Here we discussed the benefits of using peels and the challenges posed by the old methods (e.g. Voigt and Gittins, 1977; Van Baren and Bomer, 1979; Bouma, 1969) used to create these peels. We described the main steps of making a soil peel: impregnation of a smooth soil face with glue in the field before extracting the peel and then mounting it on a wooden panel. Because of a technological advance in the impregnation material (going from lacquers to glue), the method reported here is safer, simpler, more successful, more durable, and more accessible because (1) the glue can be used without the use and mixing of toxic chemicals in the field, (2) the firmness of the resulting peel is such that additional support materials (such as cheesecloth) are not required, and (3) consequently the soil peel will

last for a long time, even when intensively used in hands-on teaching. While this method can be applied to a range of moisture contents and sand textures, further research on the best environmental conditions is required for those interested in achieving perfection in terms of appearance. Similar exploration is advised for alternative glues. Such additional research would be valuable for some (e.g. soil museums), but based on our experience, we believe that those simply interested in capturing a beautiful snapshot of soils can do so with the more qualitative guidance described in this paper. We hope that this thoroughly tested successful and simple method will inspire and enthuse researchers, educators, and the general public to make soil lacquer peels and thereby bring the value and beauty of soils to a wider audience.

Data availability. Data used in this article can be found in Sect. 2, Table 2 and Video S1.

Video supplement. Video S1 can be downloaded free of charge from the TIB-AV portal (<https://doi.org/10.5446/40805>, Stoof et al., 2019).

Supplement. Instruction video showing how to make a soil peel in the field. The supplement related to this article is available online at: <https://doi.org/10.5194/soil-5-159-2019-supplement>.

Author contributions. CRS conceptualized the main ideas, with input from JHJC and GP. GP developed the methodology, with input from CRS and JHJC. Visualizations were made by LAGMvdW, who coordinated the video with help from JHJC and CRS. CRS wrote the manuscript with contributions from all co-authors.

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Disclaimer. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by Wageningen University and Research.

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