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A high-precision Jacob's staff with improved spatial accuracy and laser sighting capability

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ABSTRACT

A new Jacob's staff design incorporating a 3D positioning stage and a laser sighting stage is described. The first combines a compass and a circular spirit level on a movable bracket and the second introduces a laser able to slide vertically and rotate on a plane parallel to bedding. The new design allows greater precision in stratigraphic thickness measurement while restricting the cost and maintaining speed of measurement to levels similar to those of a traditional Jacob's staff. Greater precision is achieved as a result of: a) improved 3D positioning of the rod through the use of the integrated compass and spirit level holder; b) more accurate sighting of geological surfaces by tracing with height adjustable rotatable laser; c) reduced error when shifting the trace of the log laterally (i.e. away from the dip direction) within the trace of the laser plane, and d) improved measurement of bedding dip and direction necessary to orientate the Jacob's staff, using the rotatable laser. The new laser holder design can also be used to verify parallelism of a geological surface with structural dip by creating a visual planar datum in the field and thus allowing determination of surfaces which cut the bedding at an angle (e.g., clinoforms, levees, erosion surfaces, amalgamation surfaces, etc.). Stratigraphic thickness measurements and estimates of measurement uncertainty are valuable to many applications of sedimentology and stratigraphy at different scales (e.g., bed statistics, reconstruction of palaeotopographies, depositional processes at bed scale, architectural element analysis), especially when a quantitative approach is applied to the analysis of the data; the ability to collect larger data sets with improved precision will increase the quality of such studies.

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1. Introduction

Measuring stratigraphic thicknesses in an accurate manner is one of the key data acquisition workflows for sedimentologists and stratigraphers. Some examples of the type of research that benefits from high precision stratigraphic thicknesses measurements include: characterisation of depositional processes at bed scale (e.g., Eggenhuisen et al., 2011; Sumner et al., 2012; Fonnesu et al., 2015); reconstruction of short-time variability of creation and fill of accommodation space (e.g., Banham and Mountney, 2013); architectural analysis (e.g., palaeo-depths of channels related to measurements of channels fills and bars, Bridge and Tye, 2000; deep water lobe thicknesses, Prélat and Hodgson, 2013; Marini et al., 2015); outcrop-derived angles of progradation or aggradation of parasequences (e.g., Zhu et al., 2012); analysis of bed thickness statistics (e.g., Marini et al., 2016); population of numerical models using thickness data from outcrop (e.g., Amy et al., 2013).

The simplest tool used in the field to measure stratigraphic thicknesses is a tape measure, commonly the rigid folding type. This is quite effective in certain outcrop conditions, such as when measuring horizontal beds on a vertical outcrop face or dipping beds on a face parallel to their dip direction (e.g., along a road cut), because the apparent and real thicknesses of the beds in these configurations coincide. However, when the apparent and real thicknesses of beds diverge, measurement using a tape can be very difficult to carry out in a precise manner. For example, this is the case with low relief outcrops where bedding is anything but vertical, such as while logging along a ridge crest leading to a hilltop or along a wave-cut platform (Fig. 1). Another situation when a tape measure is not very effective is the case of a significant interval (e.g., metres to tens of meters) without clear surfaces indicating the structural dip (e.g., a very thick unit without internal bedding or with disrupted bedding or a covered interval). In these scenarios stratigraphic thickness measurements must be carried out by sighting, for which the most effective tool is a Jacob's staff (see Merriam and Youngquist (2012) for an historical perspective and for a discussion on the origin of the name). In its simplest version a Jacob's staff for logging purposes is a vertical rod of known height with a device to help sighting mounted on its top (e.g., a sight or a flat disc). The rod is then placed orthogonal to bedding (often with the aid of a compass and a clinometer) and the sighting device is used to measure true stratigraphic thicknesses (Fig. 1; see also Compton (1985), Chapter 11, and references therein). In the last twenty years, improved models of Jacob's staff have been developed (e.g., Elder, 1989; Brand, 1995; Evans,

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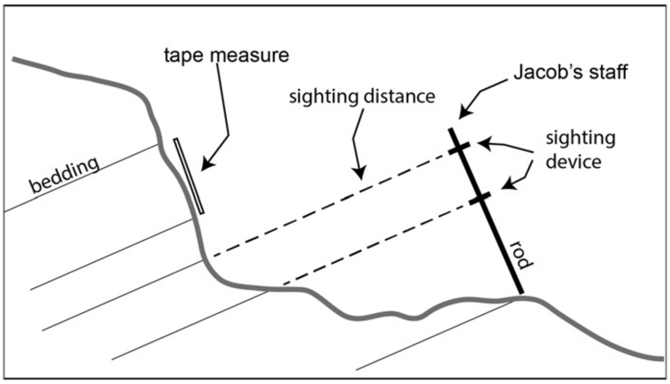

Fig. 1. A tape measure is an effective tool for measuring stratigraphic thicknesses when apparent and real thicknesses tend to coincide (e.g., shallow dipping beds on a vertical cliff). When apparent and real thicknesses of beds diverge (e.g., shallow dipping beds along a crest leading to a hilltop), measurement must be carried out by sighting. In this scenario a Jacob's staff (comprising a rod and sighting device) is the most effective tool for measuring stratigraphic thicknesses. Note that the sighting device can be fixed (as in most traditional designs) or be able to move along the rod (as shown here, in the new design).

2002), aiming to increase measurement precision and ease of use, while at the same time maintaining reasonable manufacturing costs. This paper describes a new Jacob's staff, with some key improvements over the currently used models.

2. New Jacob's staff

2.1. Design

The new Jacob's staff (Fig. 2A) consists of three main parts: a vertical rod measuring 210 cm, a 3D positioning stage (Fig. 2B-C) and a laser sighting stage (Fig. 2D). The vertical rod is composed of four pieces which can be connected and disconnected in the field for ease of carrying. Three of the pieces are 50 cm long, and the uppermost is 60 cm long (see Fig. 2E for a detail of the connecting mechanism between rod pieces) combining to allow measurements up to 2 m. The rod has a cm-scale graduation from 0 to 210 cm, with each 10s of centimetre mark highlighted to make reading vertical values easy. A first novelty of this new design is the 3D positioning stage (Fig. 2B-C). This consists of a base plate compass and a circular spirit level glued on to a plate, which is connected to an adjustable angle gauge by a 90 degree bracket. The bracket is mounted on a vertically sliding block that can be fixed in a defined position using a screw clamp. With the angle gauge set at zero, the plate on which compass and spirit level are hosted is orthogonal to the vertical rod, but can be rotated in the vertical plane using the angular scale to match the structural dip of bedding before being clamped in position. The second element of the novel Jacob's staff is a laser sighting stage (Fig. 2D), which allows a pen-shaped laser to rotate around and to move up and down along the rod. Note that the laser is only able to rotate on a plane orthogonal to the rod itself.

The materials were selected for their strength, weight, durability to wear and tear and for their lack of magnetism, to avoid the compass being affected (aluminium being chosen for most of the parts, including the rod). The rod parts and the angle gauge can be bought from most builders merchants, while the laser holder was manufactured. Regarding the compass, a relatively inexpensive base plate compass was deemed sufficient. For the laser, a very inexpensive green light 1 mW laser was chosen to allow its light to be visible even in bright sun and to a reasonable distance. The maximum sighting distance is dependent on lighting conditions, and can vary from around 10–20 m under direct sunlight on a bright sunny day to >100 m in dark cloudy conditions. Manufacturing and assembly was carried out by Antony Windross and Stephen Burgess at the instrument workshop of the School of Earth & Environment (University of Leeds).

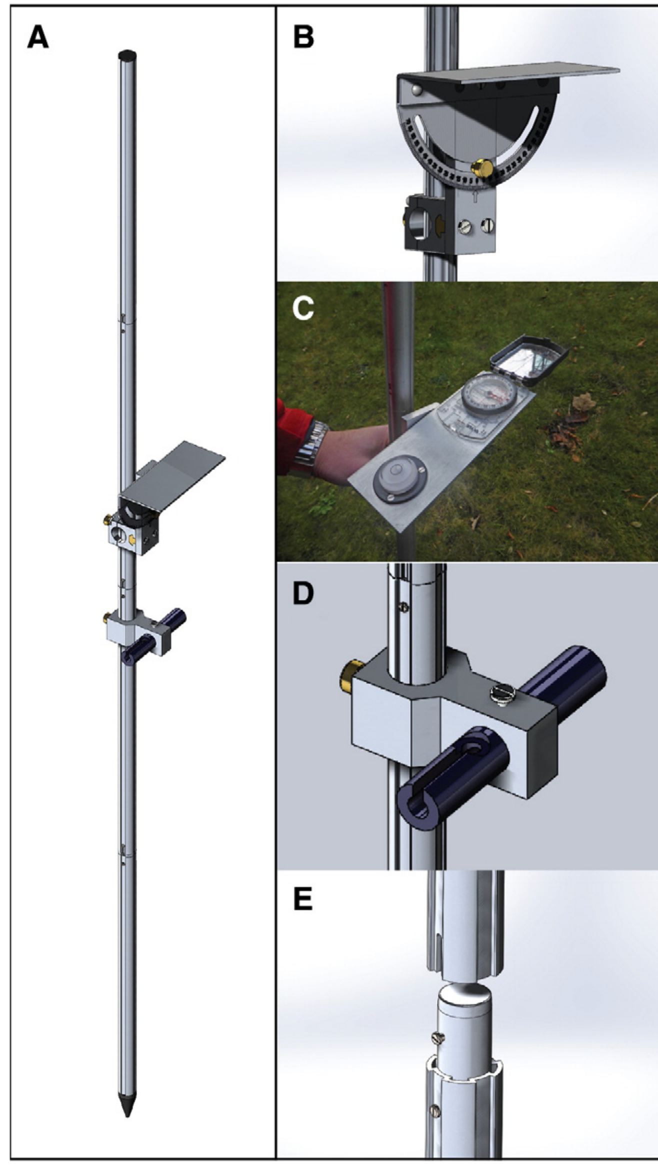

Fig. 2. A) The new Jacob's staff design. B-C) 3D positioning stage, including an angle gauge with the attached bracket holding a circular spirit level and a base plate compass (note that spirit level and compass are not shown in the technical drawings). D) Laser sighting stage (laser is not shown). E) Connecting mechanism between pieces of the rod. Technical drawings courtesy of Antony Windross.

2.2. Suggested mode of use

Before starting logging, as with any Jacob's staff, a precise measure of the strike and dip of the bedding should be obtained. The four parts composing the rod should be assembled and the two moving pieces (3D positioning stage and laser holder) inserted and fixed to the rod. The compass dial should be set to the structural dip direction and the angle gauge should be set to the angle of dip.

To begin the measurement, the user should place the base of the rod on the initial point of measurement (e.g., the base of a bed; a trowel inserted in the soil below the bed might be used to provide a solid base in case of loose sediments). The Jacob's staff should then be aligned to be orthogonal to structural dip checking that the North needle of the compass aligns with the North on the compass dial and that the air bubble of the circular spirit level is in its central position (Fig. 3). At this point the user should start moving the laser holder vertically along the rod intermittently activating the laser beam to check where the laser

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