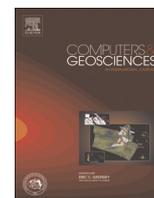




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Case study

From oblique photogrammetry to a 3D model – Structural modeling of Kilen, eastern North Greenland

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ARTICLE INFO

Article history:

Received 6 January 2015

Received in revised form

2 June 2015

Accepted 13 July 2015

Available online 15 July 2015

Keywords:

Oblique photogrammetry

Structural geology

3D modeling

Field mapping

ABSTRACT

We present a workflow for building 3D geological models from oblique photogrammetry of outcrops. The workflow is used to build a 3D model of Kilen, a structurally complex and remotely located pseudo-nunatak in eastern North Greenland. The area was visited during two brief field seasons during which 1300 oblique photographs were taken by a hand held digital camera from a helicopter. The photos were triangulated and georeferenced and visible geological features as bedding and faults were mapped as 3D polylines. The polylines were used to calculate strike and dip of bedding and faults, generating a large number of structural information. These were imported into a 3D modeling software along with the 3D polylines, an unpublished digitized field map, a Digital Elevation Model, an orthophoto and georeferenced field observations. The 3D modeling software allows us to produce 2D cross-sections and 3D surfaces so that structural hypotheses could be tested through restoration and extrapolation of the data. This workflow proved effective in improving the structural knowledge of a remote area in the Arctic, showing that it is possible to produce quality 3D data from oblique photogrammetry and that those data can be used for 3D modeling.

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1. Introduction

Data used for 3D modeling are traditionally either 2D data (maps, sections, etc.) with an interpolated z coordinate from a Digital Elevation Model (DEM) or native 3D data such as geophysical data. The interpolation introduces a number of errors with respect to georeferencing, resolution and quality of the 2D data and the DEM, while native 3D data are usually expensive and relatively complex to acquire and handle.

In this paper a workflow is described where 3D outcrop data from oblique photogrammetry is integrated in 3D modeling and applied to a remote pseudo-nunatak, Kilen, in eastern North Greenland (Fig. 1) to better understand the structural evolution. The geological knowledge of Kilen is limited due to the remote location, limited infrastructure, short field seasons and its relative large size. Several efforts have been made to understand the complex structural geology of Kilen in the past (Håkansson et al., 1993; Lyberis and Manby, 1999; Von Gosen and Piepjohn, 2003). To further advance the structural knowledge of Kilen a new

approach was needed that (1) could deliver a large quantity of high quality structural data during the relative short field seasons and (2) could process these data into a geological model honoring the quality of the 3D data. Oblique photogrammetry has previously been successfully integrated in the exploration of remote areas in Greenland (Dueholm and Pedersen, 1992; Sørensen, 2011) and proved to be able to deliver a solid base for structural analysis (Pedersen, 1981). Previously, these 3D data were projected into 2D sections (Martín et al., 2013; Pedersen and Dueholm, 1992; Vosgerau et al., 2010) but here, for the first time, they are kept as 3D data and used for 3D modeling.

2. Geological setting

The Late Paleozoic to Paleogene Wandel Sea Basin in eastern North Greenland shares a common geological and structural history with the surrounding Mesozoic sedimentary basins in Arctic Canada, Svalbard and the western Barents Sea (Håkansson and Stemmerik, 1989; Stemmerik and Worsley, 2005) but it is still relatively underexplored due to its remote location. The sediments are affected by post-Cretaceous deformation related to the opening of the North Atlantic and the Fram Strait (Håkansson and Pedersen, 1982; Lyberis and Manby, 1999; Von Gosen and Piepjohn

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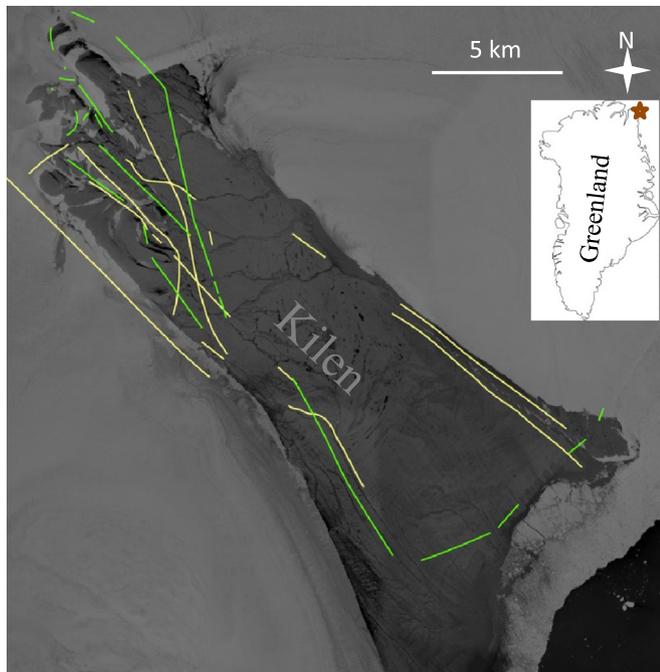


Fig. 1. Orthophoto of Kilen showing flight lines for oblique photogrammetry. Yellow (2012) and green (2013). The position of Kilen is marked by a red star on the insert map of Greenland (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2003). However, the nature of this deformation is debated. It has been described as the result of transpressive dextral strike slip movements by some authors (Håkansson and Pedersen, 2015, 2001, 1982; Von Gosen and Piepjohn 2003) while others suggest pure compression (Lyberis and Manby, 1999; Manby and Lyberis, 2000; Soper and Higgins, 1991; Soper et al., 1982).

The deformed Wandel Sea Basin sequence is best exposed in the south-eastern part of the basin on the remote pseudo-nunatak Kilen (Fig. 1). Here, the ice sheet Flade Isblink surrounds faulted and folded Mesozoic siliciclastic sediments and small patches of Upper Palaeozoic evaporites. Previous work has revealed a complex structural geology of folded, faulted and thermally affected strata deformed in several deformation events during the Mesozoic and Paleogene periods (Håkansson et al., 1994, 1993; Pedersen and Håkansson, 1999; Von Gosen and Piepjohn 2003). The present mapping has revealed that the dominating structures are upright and cylindrical folds with fold axes trending roughly E–W and moderately plunging ($10\text{--}15^\circ$) to the W. The plunge of the fold

axes varies where the folds interfere with NNW–SSE trending normal faults and there the folds become non-cylindrical and the complicity of the 3D architecture increases. Minor thrusting associated with the folding is also observed and has a general tectonic transport to the S.

3. Methods

3.1. Data acquisition and compilation

The data used to produce a 3D model of Kilen includes: (1) field observations, (2) digital mapping of geological features from oblique photogrammetry, (3) a DEM, (4) an orthophoto and (5) a digitized unpublished geological map (Pedersen, 1989) (Fig. 2). The software used are Socet Set 5.5 (BAE Systems) to set up the photos, extracting the 3D polylines and building a DEM, ArcMap (Esri) as database and for annotation of 3D polylines, and Move version 2014.2 (Midland Valley) to compile the various data, build and subsequently manipulate the 3D model.

3.1.1. Mapping from oblique photogrammetry

The method was developed at the Geological Survey of Denmark and Greenland (GEUS) to support mapping in areas of difficult access in Greenland (Dueholm, 1981; Dueholm et al., 1993) and therefore thought to be well fitted for the mapping of Kilen. Other more recent works implementing photogrammetry in geoscience include Sørensen (2011), James and Robson (2012), Martín et al. (2013), Saunders (2014), Vosgerau et al. (2014) and Svennevig (2014).

For this study, the oblique photogrammetry data were collected during two short field seasons in August of 2012 and 2013. The first season was used to establish the photogrammetric coverage needed to produce a general structural model of Kilen. During the second season, the structural model was validated in the field and additional photogrammetric data were acquired.

The camera used was a hand held digital Single-Lens Reflex (SLR) Canon EOS-1Ds Mark III equipped with a calibrated Canon EF 35 mm f/1.4L USM lens. The focal length of the lens was fixed to infinity with duct tape to ensure that all photos were taken with the same focal length and that the whole scene is sharp. The photos were taken in 21 megapixels (5616×3744) resolution in RAW format. Under the camera house an Xsens MTI-G Inertial Measurement Unit (IMU) was attached, recording relative orientational data. The absolute position was recorded by an integrated GPS unit in the IMU via an external antenna fixed to the

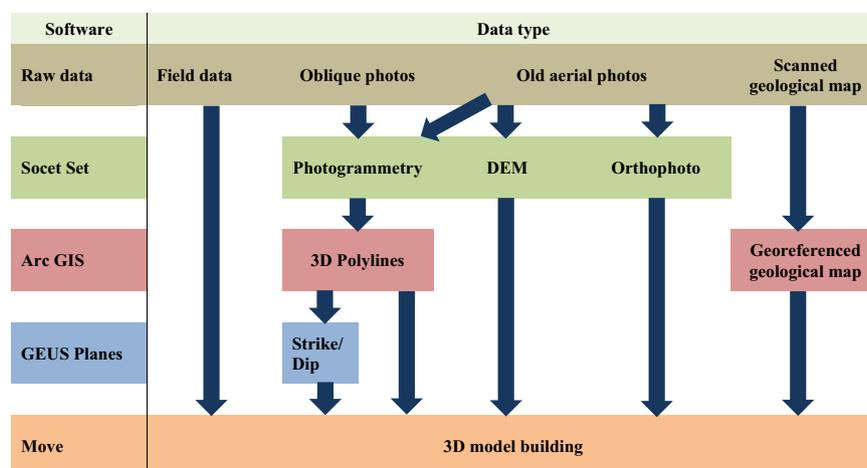


Fig. 2. Workflow for the gathering and processing of data to build the 3D model.

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