Analogue Modeling of the Multi-Layer Over-Thrust System in South China

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1 Introduction

The structural evolution of a thrust system depends on stratigraphy, mechanical property of the rocks, duration and rate of deformation and uplift versus subsidence ratios. In particular, the mechanical property of the deformed rocks (e.g. presence of competency contrasts) and the detachment layer appear to be of great significance in influencing the final geometry of the structures and the kinematics of the thrust system. In South China, detachment is a common structural phenomenon that has absorbed a large portion of intra-continental deformation in sedimentary rocks with a various mechanical contrast (Yan et al., 2003, 2009). It normally took place in and along incompetent layers, and produced kinds of detachment structures. Multi-layer detachment structures of South China had been identified by geophysical and geological data (Yan et al., 2003, 2009). The present paper aims to analyze the role played by multiple detachment layers in the Mesozoic over-thrust system in South China by analogue modeling.

2 Geological Background

A thickness of more than ten kilometers of sedimentary rocks has been deposited in the South China Block. Due to high competency contrasts among strata, multi-layer detachment structure, multi-layer thrust fold structure, and multi-layer nappe structure of several stages are developed.
in the South China Block which is characterized by
detachment structures in upper crust and rheological
structure in middle crust (Wang et al., 2005). Especially,
thin-skinned structure belt in the south Qin-ling orogenic
belt, northwest Xuefengshang thick-skinned structure belt
and east Sichuan Basin is characterized by later-Mesozoic
multi-layer detachment structures, and strata at different
depths have different deformation styles (fig. 1 and 2) (Yan
et al., 2003).

3 Model Construction and Experimental Set
Up

In order to better understand the geometrical and
kinematic implications of this setting in the evolution of a
thrust belt, we put forward four analogue models. Each
model consists of two weak layers, at two different
stratigraphic levels. The weak layers being used to simulate
detachment layers are composed of silicone putty, whereas
the competent rocks are simulated by quartz sand. The
depths of the weak layers are varied for various models, so
as to investigate the effects of depth of detachment layers
on deformation styles (Fig. 3).

3.1 Set-up and boundary conditions

The right edge of the models was fixed. Models were
laterally shortened from left to right by a motor with a
velocity of 5.4 cm/h. This process was simulating that of
compression from southeast to northwest in the South
China Block in late-Mesozoic. The other two sides are free.

3.2 Analogue materials

The complicated rock combination was simplified into
four types, and was simulated by four kinds of analogue
materials: (1) Moist sand, a Mohr-Coulomb material with
density of 1800 kg m\(^{-3}\) and an angle of internal friction
between 35° and 40°, was composed of sand mix with 5.6% of
water, had a higher cohesion (1000-5000 MPa) than dry
sand; (2) Dry sand, a Mohr-Coulomb material with a
diameter vary from 0.1 mm to 0.3 mm, a density of 1700 kg
m\(^{-3}\) and an angle of internal friction between 30° and 32°;
(3) Silicone, Laboratory tests on this material indicated a
Newtonian behavior with viscosity of 1×10^3 Pa s at room
temperature (28 °C), a density of about 950-1000 kg m\(^{-3}\);
(4) More viscous silicone (Sand + Silicon, Laboratory tests
on this material indicated a Newtonian behavior with
viscosity of 10^5 Pa s at room temperature (28 °C), a density
of 1200 kg m\(^{-3}\).

4 Comparison Analogue Models With Natural
Examples

The modeling results display most of the characteristics
described for natural structural styles of Mesozoic multi-
layer over-thrust system in South China such as fault
related folds, detachment folds, fault bend folds and flat-
ramp-flat geometries. If similarity conditions are satisfied,
this good correspondence indicates a similarity in dynamic
processes, which means that the models can be used to
understand better the mechanics of the geological
processes. From a geometrical point of view, the
detachment folds, flat-ramp-flat geometries, fault bend
folds can be qualitatively compared with patterns known
from field examples of the Mesozoic multi-layer over-
thrust system in South China (Fig. 4).

5 Conclusions
Both modeling results and natural examples indicate that the structure and evolution of the Mesozoic over-thrust system in South China are generally dominated by the deep-seated structures, and locally complicated by the shallow-seated structures. The structural dimension and style greatly depend on the depth of detachment; deep-seated structures are systematically larger than shallow-seated structures. Deep-seated detachment layers nucleate large structures such as major detachment thrusts and large duplexes. However, shallow-seated detachment layers nucleate small structures such as numerous splay faults, shallow imbricates, detachment folds and fault related folds. Moreover, the structural styles of the cap formation are mainly depending on the depth of the shallow-seated detachment layers. Besides, the presence of detachment layers give rise to decoupling between deeper and shallower structures. Therefore, two detachment layers nucleate two sets of structures at different levels, with different geometrical characteristics and significance.

Analogue modeling results suggest that the brittle or competent layers at deep levels were deformed by major reverse faults, and fault bend folds whose flat-ramp-flat geometry depends on competency contrast among strata; the upper brittle layers were always characterized by reverse faults, fault propagation folds, shallow imbricates, detachment folds and passive roof thrust, which are nucleated in the upper weak ductile layers. Detachment folds always occurred in the thin cap formation above or at
the front of the fault bend fold. The passive roof thrust always occurred in the thick cap formation, and has an opposite thrusting direction. Ductile or incompetent layers played a role of accommodating those deformation styles.

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