PSSeismic Modeling and Expression of Common Fold-Thrust Belt Structures*

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Abstract

Seismic modeling can be used to understand the expression of common fold-thrust structures in seismic time and depth sections, and to avoid pitfalls in the seismic interpretation of natural structures. Modeling of seismic time sections using both post-stack and pre-stack time migration was conducted for fault-bend and fault-propagation folds. Time-migrated and stacked models of fault-bend folds with low angle fault ramps provide a good rendition of the geometry of hanging wall beds for both pre-growth and syngrowth sections. Because of the typically low dips of both the front and back limbs, the beds are well imaged and can be accurately migrated to their correct positions. Footwall beds typically show pull up of reflectors, particularly under the front limb and the crest. The fault ramp and a segment of the upper flat can also appear to be folded. This can result in the erroneous interpretation of these features as subthrust structures, if the velocity effects are not completely corrected in depth sections.

Seismic modeling of fault-propagation folds for models with constant front-limb angles and trishear models results in many more uncertainties. Although the back limb and crest of the structure are typically well imaged, the front limbs are characterized by wide zones with no data. This effect is significantly more pronounced for steep front limb angles for both constant front limb angle models and trishear models with low propagation to slip ratios. Footwall beds are characterized by low amplitude reflectors and exhibit a pronounced pull up. This can result in their interpretation as upturned beds against the fault. Furthermore, poor velocity information at the anticlinal and synclinal bends on the front limb can result in overmigration or undermigration of reflectors. This can result in an incorrect estimation of the extent of fault propagation through the front limb. Trishear models with relatively small slips, on the other hand, exhibit good imaging of some of the upper units, because the front limb dips are relatively low.

Although depth migration can correct for many of the velocity related pitfalls discussed above, the processing is dependent on accurate velocity models. Therefore, an understanding of the key pitfalls observed in the seismic models is critical in developing accurate interpretations of natural structures.

Seismic modeling and expression of common fold-thrust belt structures

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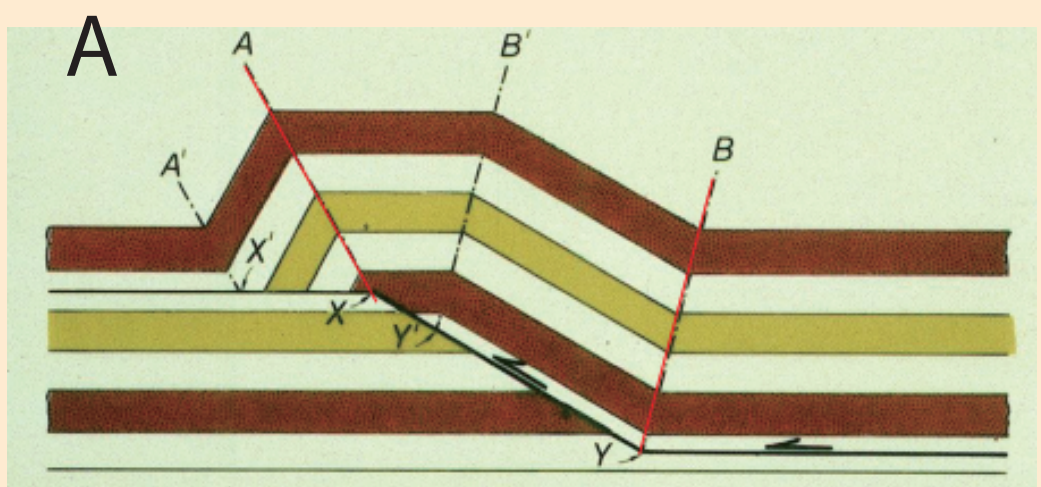
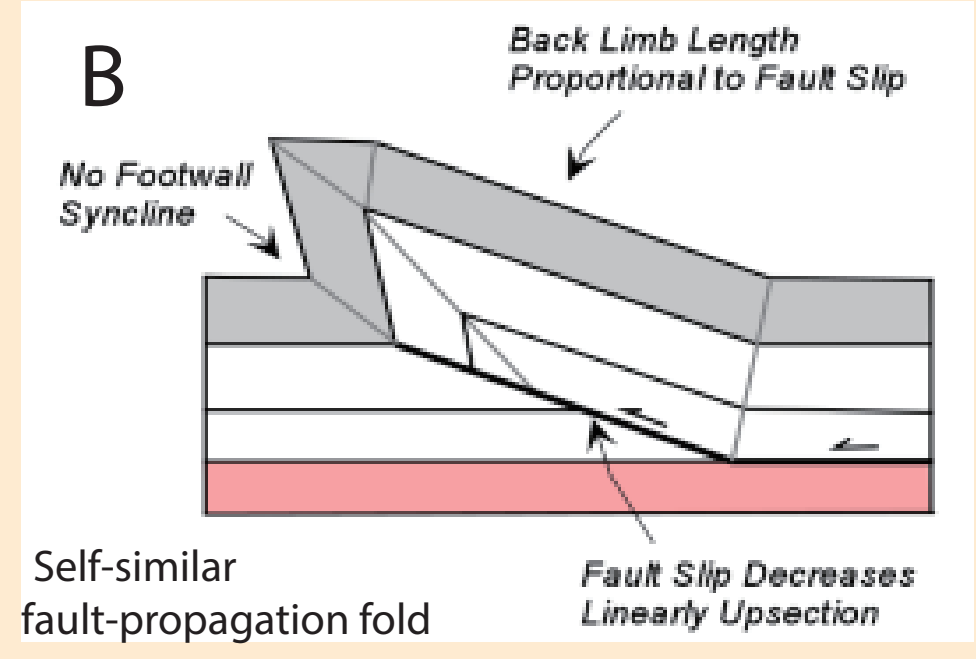
Introduction

Seismic modeling can be used to understand the expression of common fold-thrust structures in seismic line and depth sections, and to aware of pitfalls in the seismic interpretation of natural structures. Modeling of seismic time sections using pre-stack time migration was conducted for fault-bend folds and fault-propagation folds (self-similar and trishear model). The fault-bend fold model features a gentler front limb compared to other models (Figure A). The self-similar fault-propagation fold model has overturned front limb with constant thickness which is the same as the layer thickness of the backlimb and horizontal bedding (Figure B). The trishear fault-propagation fold model features a small footwall syncline (Figure C). The length of the backlimb is proportional to fault slip and the front limb structure is controlled by the propagation to slip (P/S) ratio. Nine trishear fault-propagation fold models with various fault slip and P/S ratio were studied.

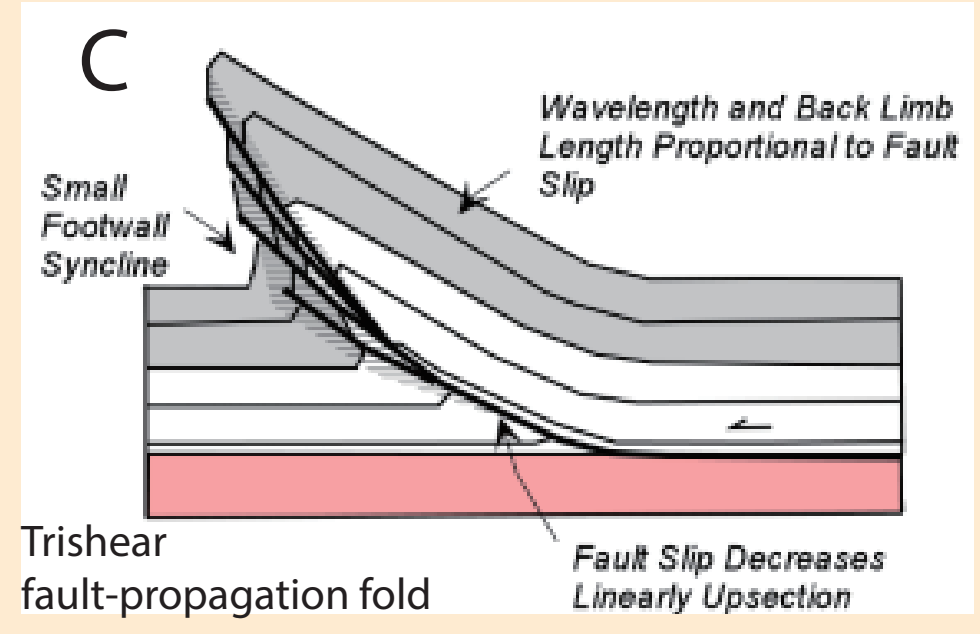
The velocity model of each structure in depth was built in Tesseral 2D software and the shot gathers were acquired by running the forward modeling. The velocity picking and pre-stack Kirchhoff time migration were conducted in VISTA. The processing procedure of this study is following a typical 2D seismic processing procedure trying to replicate a real-life processing scenar-io. The pre-stack time migrated data of each structural model was analyzed afterwards. In terms of trishear fault-propagation fold models, the characteristics of trishear models with increasing fault slip and models with increasing P/S ratio were discussed separately. Moreover, this study involves the analysis of the velocity picking error that might happen in real-life processing case where the velocity of the steep angle bedding is hard to pick.



Fault-bend fold



Self-similar fault-propagation fold



Trishear fault-propagation fold

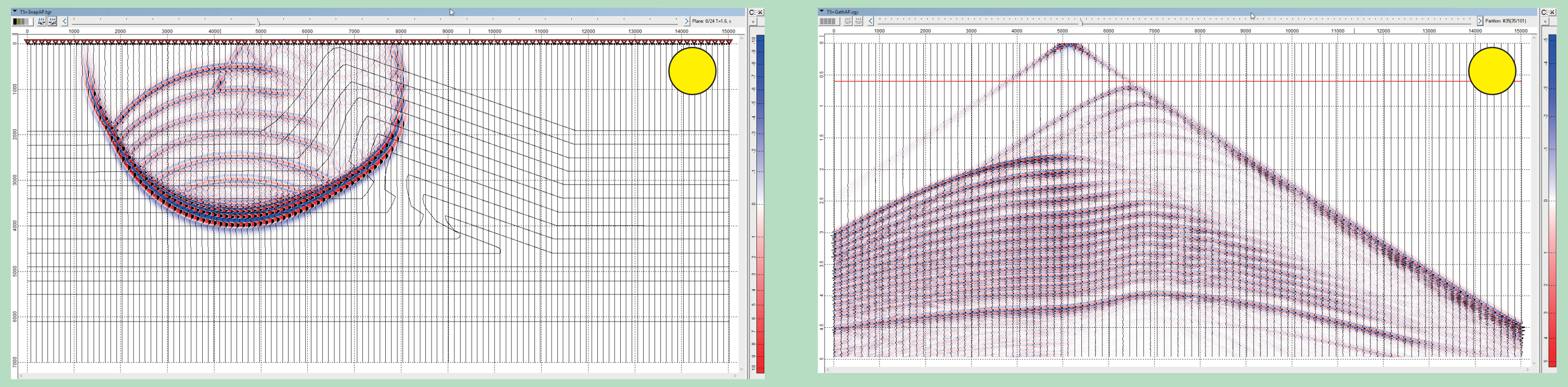
Objectives

- The characteristics of seismic models of common fold-thrust structures.
- The differences between the results of different models and the causes of them.
- The key pitfalls of pre-stack time migration observed from the pre-stack time migrated results.
- The effects of the velocity picking error on the pre-stack time migration for the complex structures like the front limb of a trishear fault-propagation fold.

Methods and Parameters

The velocity models in depth were built in Tesseral 2D program. And the acoustic wave forward modeling was conducted in the same program. The shot gathers and wave propagation files are saved and ready for processing and further analysis. All the velocity models are sharing the same frame which is 15000 m long and 7000 m deep and the same amount of layers. And the typical velocity increment is 200 m/s. The lowest layer velocity is 2000 m/s and the highest layer velocity is 5200 m/s. The trishear fault-propagation fold models covers cases of fault slip from 1000 m to 3000 m and P/S ratio from 2 to 4. The detailed parameters of the acoustic forward modeling are shown in the table.

Wave form	Frequency	Source No.	Receiver No.	Source interval	Receiver interval
Ricker	25 Hz	101	301	150 m	50 m

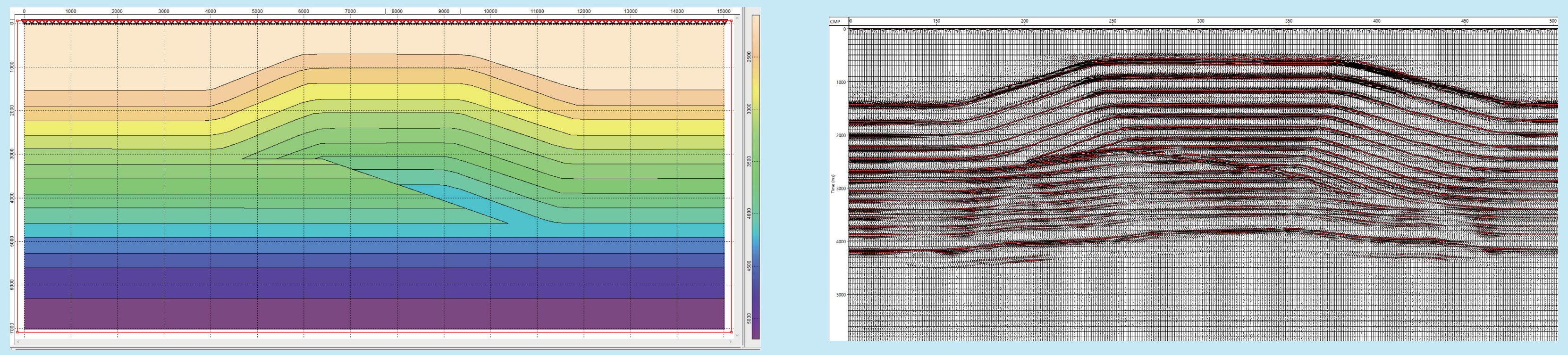


Screenshots of Tesseral 2D showing the propagation of waveform (left) and shot gather (right) from the source located at 5000 m. It is obvious that the reflection from the frontlimb is dim.

The velocity picking and pre-stack Kirchhoff time migration were managed in VISTA program. The processing procedure is following a typical 2D seismic processing procedure trying to achieve the best possible image.

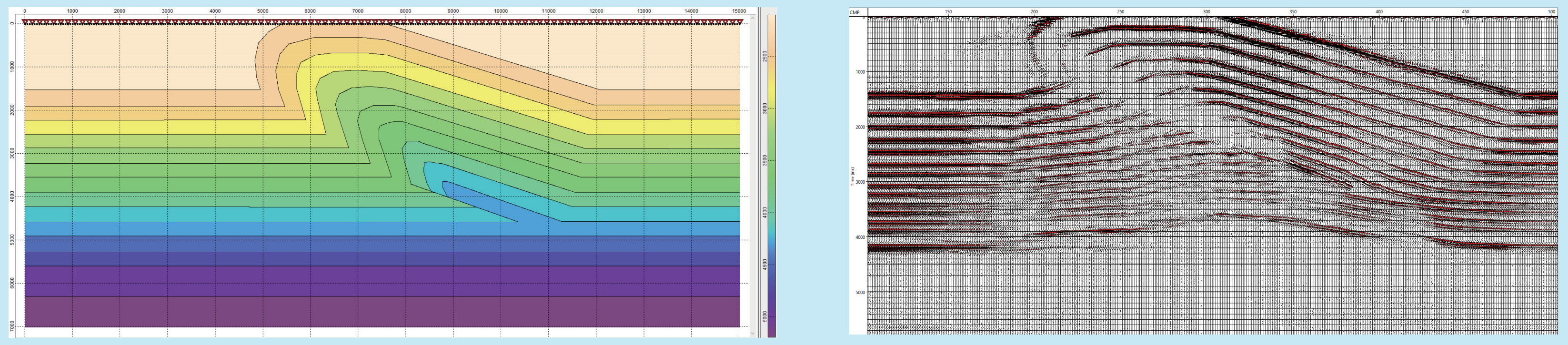
Results and Analysis

Fault-bend fold



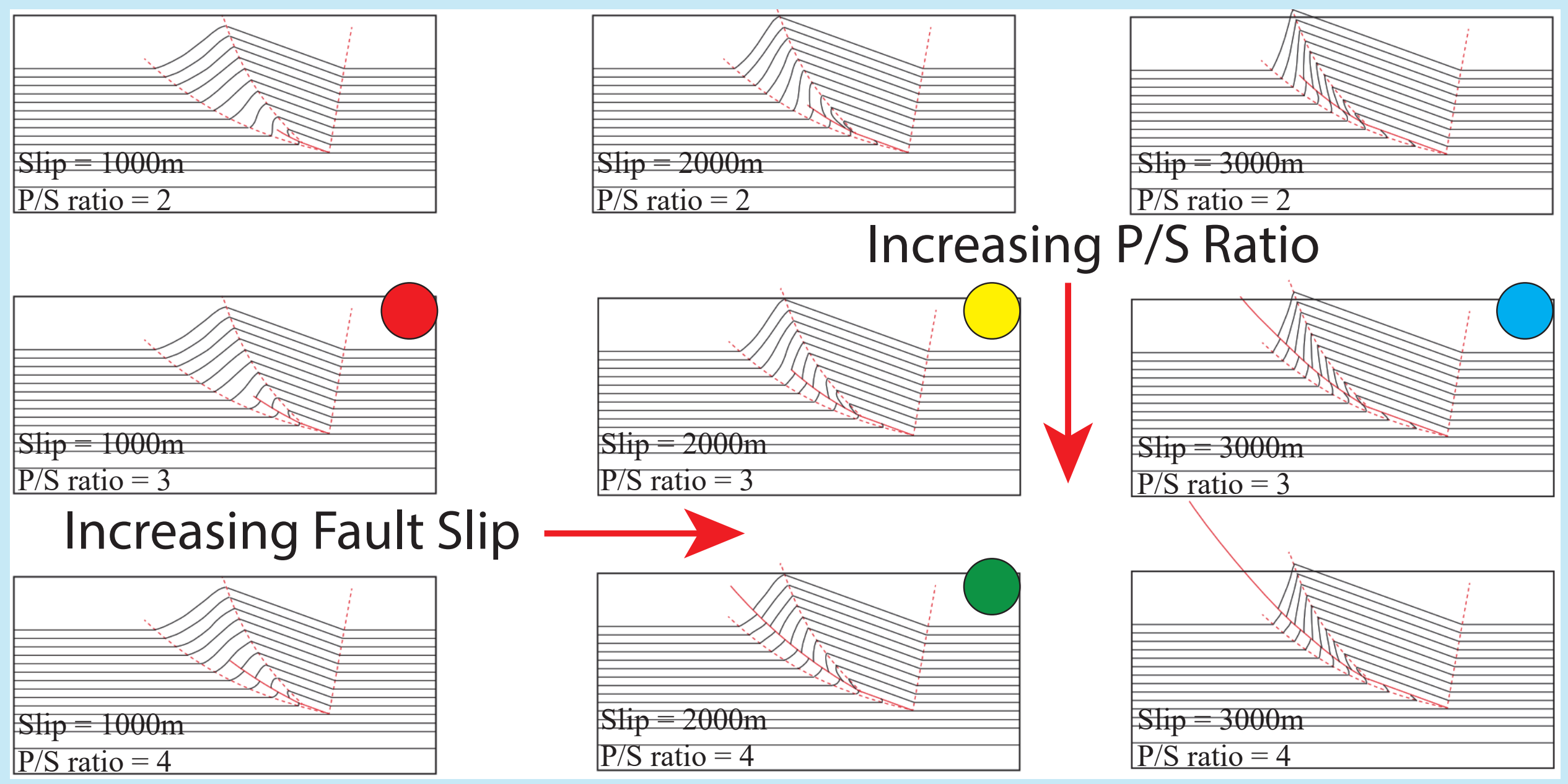
A fault-bend fold is characterized with a detachment connected with another detachment by a thrust ramp (20° in this case). Therefore, it has flat-ramp-flat type of feature for the fault. The key feature that distinguish it from a fault-propagation fold under seismic is the gentle dipping front limb. In the pre-stack time migrated data, the front limb and backlimb are well imaged. The pull-up effect is noticeable. It is caused by the lateral average velocity changes for the crest.

Self-similar fault-propagation fold



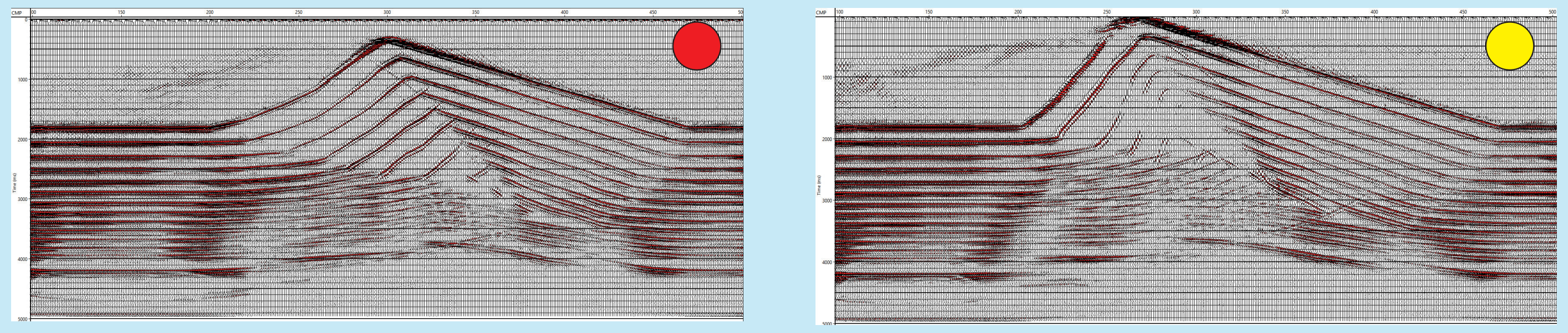
A self-similar fault-propagation fold is featured with an overturned front limb. That makes the imaging of the frontlimb of the fault-propagation fold structure not good. This “gap” could be easily misinterpreted as a damaged thrust fault zone. Compared to the fault-bend fold, the pull-up effect is more distinct because of higher crest.

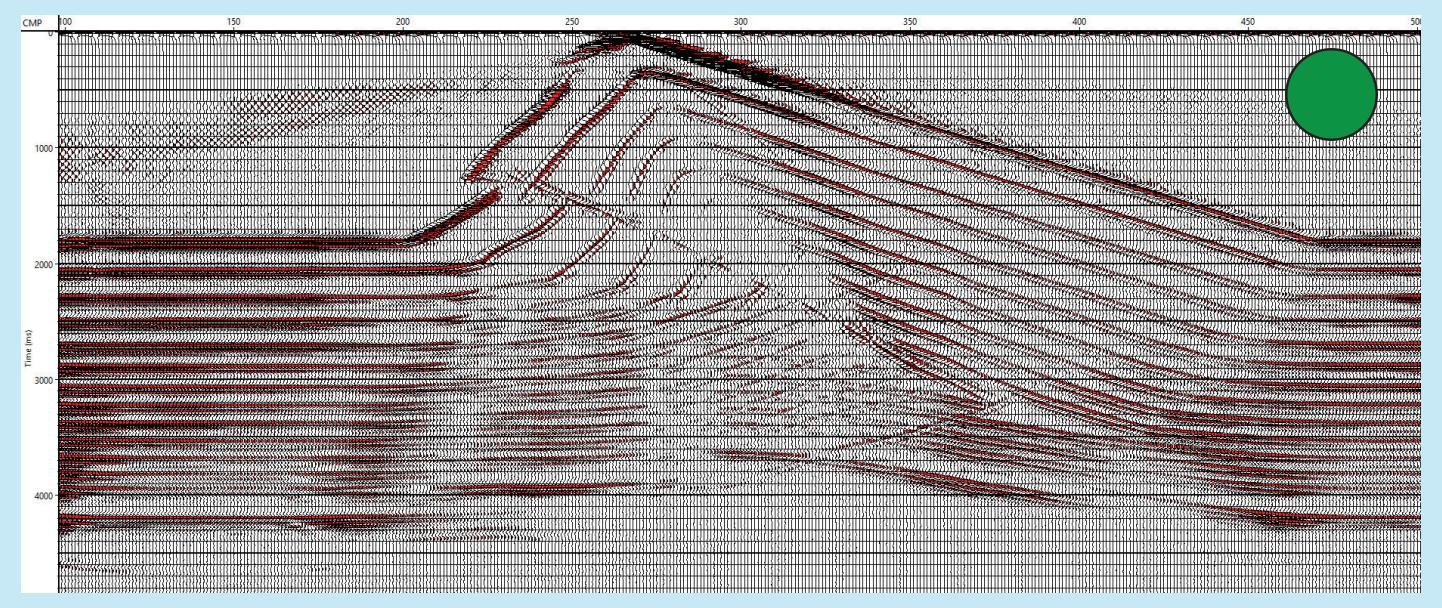
Trishear fault-propagation fold



With increasing P/S ratio, the fault length will increase. The dips of the frontlimbs are decreasing with increasing P/S ratio. The axial surfaces bounding the trishear zone remain the same position. The length of the backlimb will remain the same as well.

With increasing fault slip, if the P/S ratio is constant, the fault length will increase and the fault trajectory will be curving up. The front limb will experience thinning with increasing fault slip. The dip of the front limb will increase as well. The length of the backlimb will increase with the increasing fault slip.

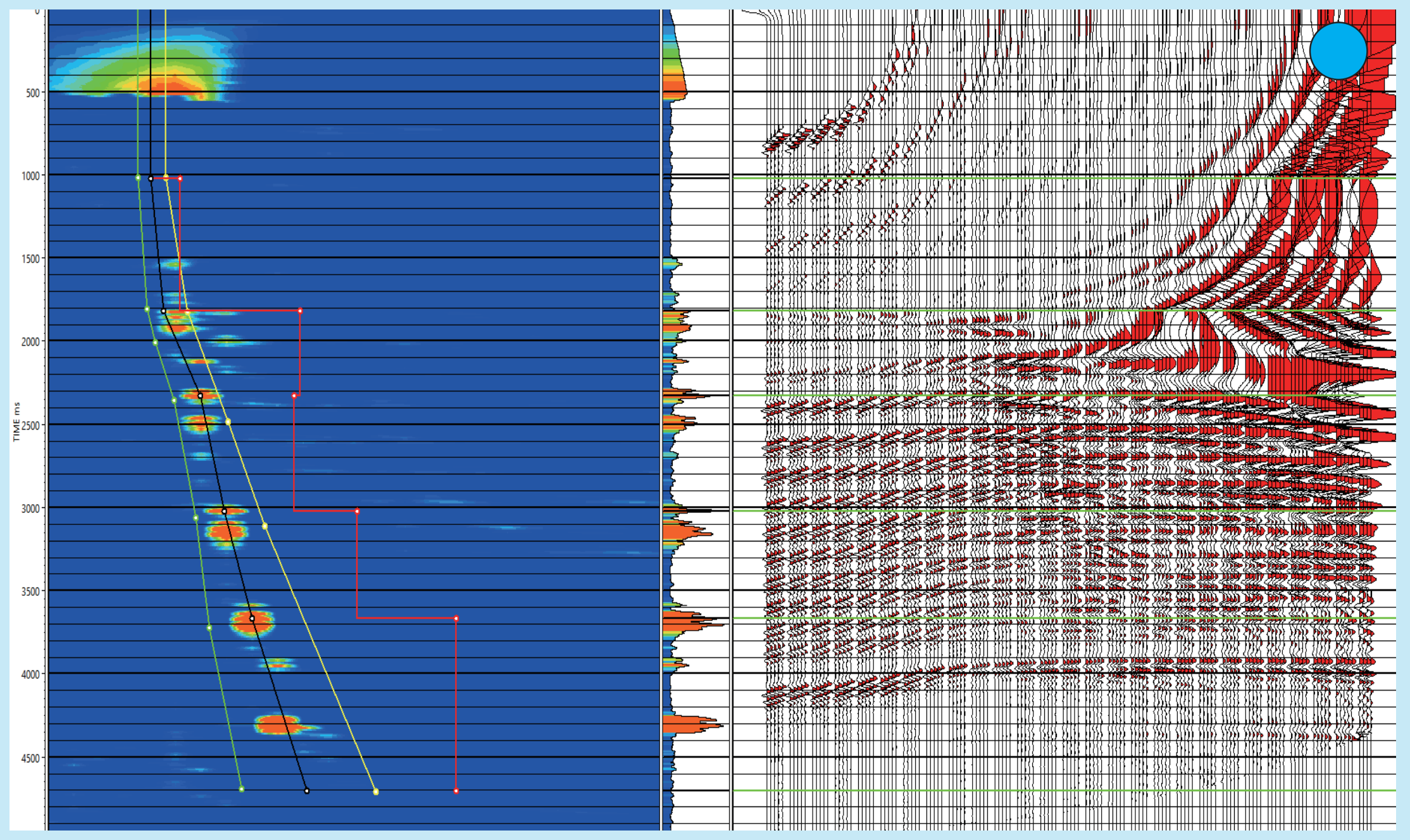




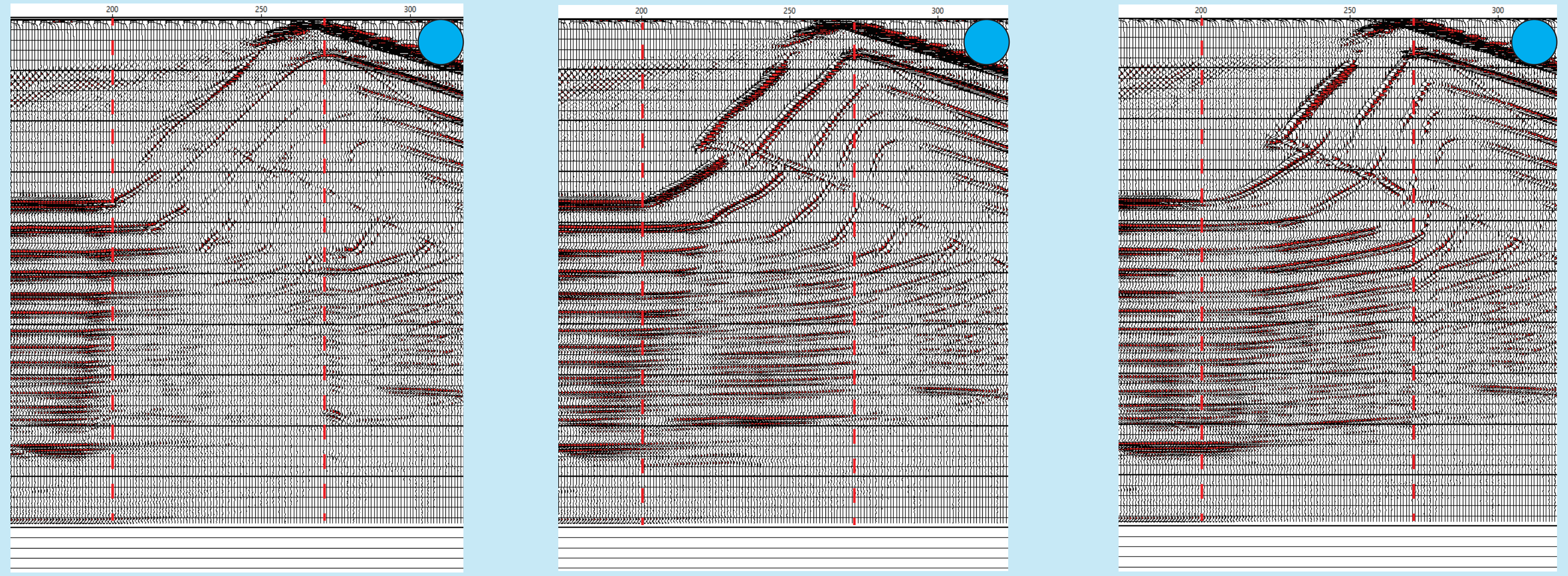
*Different markers represent different models ● ● ● ●

Backlimbs are general imaged better because of the shallow dip. Within the trishear zone, as the depth getting deeper, the front limbs are imaged worse and worse because of steeper dip as well as losing energy. With increasing P/S ratio, the frontlimbs can be imaged better because of shallower dips. However, increasing fault slip has an opposite effect. Fault reflections are segmented because there is no velocity difference between either side of the fault for part of the faults. The reflection coefficient is opposite for the fault reflection compared to the bedding reflection because they have opposite velocity contrast. The length of the fault reflector is longer and more continuous with higher fault slip and P/S ratio. There is a distinct pull up effect under the fold because the horizontal velocity differences within the fold. Below the frontlimb, there is a stair case pull up effect because of the lateral increasing of the bedding velocity towards the center of the crest. And the highest pull up effect will move further towards the front as the fault slip increases.

Velocity error effects



This is an example of the velocity analysis panel for CMP 220. The velocity between CMP 200 and 270 was modified. On the left is the semblance panel where the velocity was picked and the right is showing the offset gather. Three velocity lines are showing three possible velocity picks which are correct velocity (black), the velocity 10% lower (green) and the velocity 10% higher (yellow). In a real processing case, the semblance might not show the focus as good as this, and that is why it is valueble to study the effects of the incorrect velocity picking on the pre-stack time migration.



Compared to the pre-stack time migrated result with the correct velocity (center), lower velocity (left) leads to undermigration which is presented by lose of focus and the leftward movement or pulling up of the frontlimb. Higher velocity (right) leads to overmigration showing the frontlimb steepening and shifting to the right.

Conclusions

- The fault-bend fold with gentle fault dip can be imaged quite well after pre-stack time migration.
- The overturn of the front limb in the self-similar fault-propagation fold cannot be imaged properly.
- The pull up effect caused by the lateral velocity cannot be solved by pre-stack time migration.
- For trishear fault-propagation fold, with lower fault slip or higher P/S ratio, front limb has lower dip; therefore can be imaged better.
- The length of the fault reflector is longer and more continuous with higher fault slip and P/S ratio in trishear fault-propagation folds.
- The reflection coefficient is opposite for the fault reflection compared to the bedding reflection because of the opposite velocity contrast.
- For the front limb reflectors, lower velocity can lead to undermigration while higher velocity will cause overmigration.

Works in Plan

- Modification on trishear models
- Faulted and unfaulted detachment fold models
- More studies on how the velocity errors affect the pre-stack time migraton on different part of the thrust fold-thrust belt structures.
- Pre-stack depth migration and the comparison to the pre-stack time migration results
- Seismic forward modeling for 3D structural models

Acknowledgement

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