UNIVERSITÀ DEGLI STUDI FIRENZE

DST DIPARTIMENTO DI SCIENZE DELLA TERRA

Forecasting landslide at slope-scale: past achievements, present challenges and future perspectives

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Early Warning System (EWS)

1. Design:
- Geological knowledge
- Risk scenarios
- Design criteria
- Choice of geo-indicators

2. Monitoring:
- Instruments installation
- Data collecting
- Data transmission
- Data elaboration

3. Forecasting:
- Data interpretation
- Comparison with thresholds
- Forecasting methods
- Warning

4. Education:
- Risk perception
- Safe behaviours
- Response to warning
- Population involvement

Forecast: Determination of the time, place and magnitude of a certain event

Intrieri, E., Gigli, G., Casagli, N., & Nadim, F. (2013). Brief communication" Landslide Early Warning System: toolbox and general concepts".

Forecasting methods based kinematic parameters

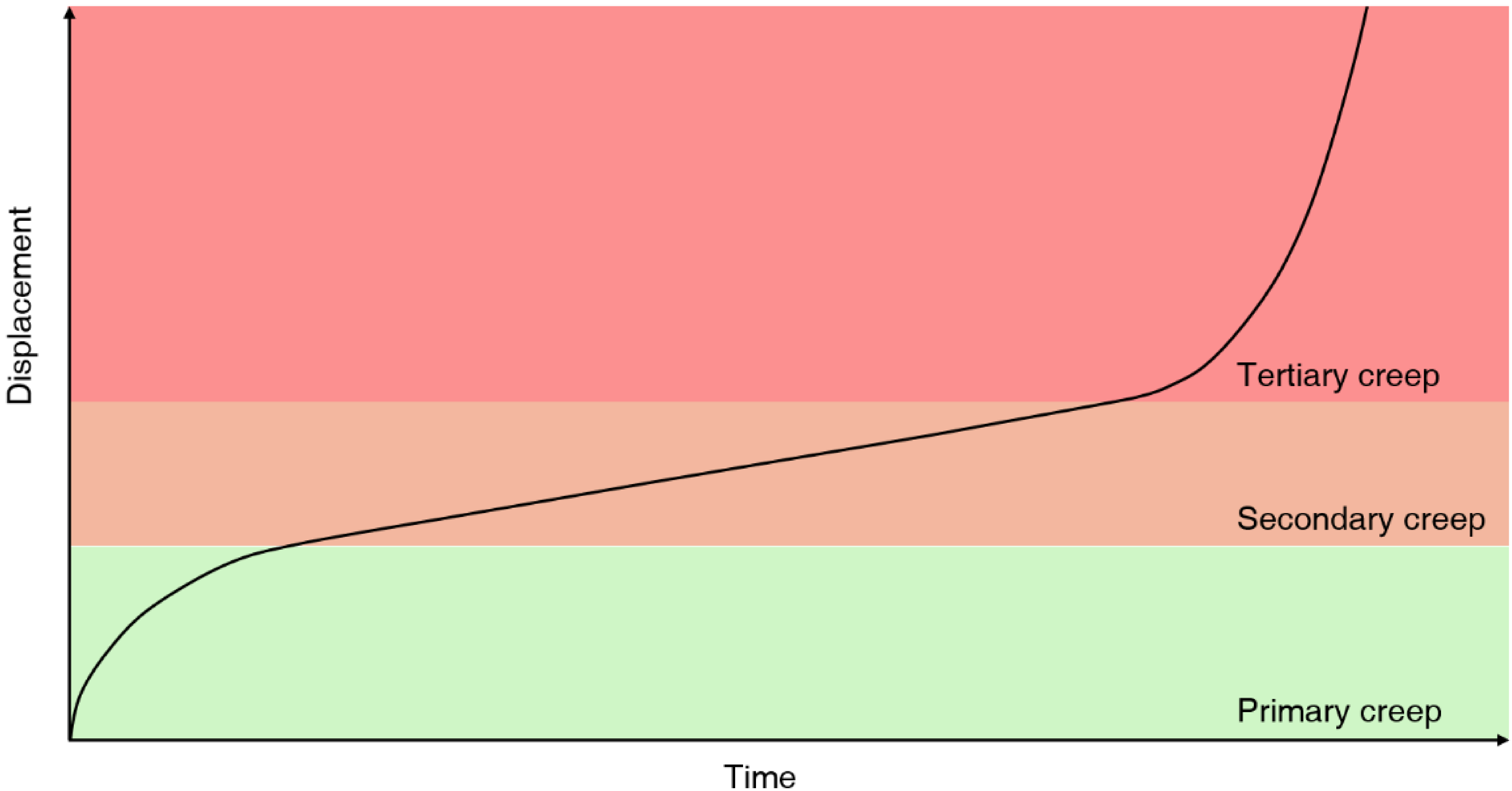
- Empirical methods
- Semi-empirical methods

Other methods are often associated with landslide prediction:

- Numerical methods
- Methods for the definition of thresholds

Empirical methods

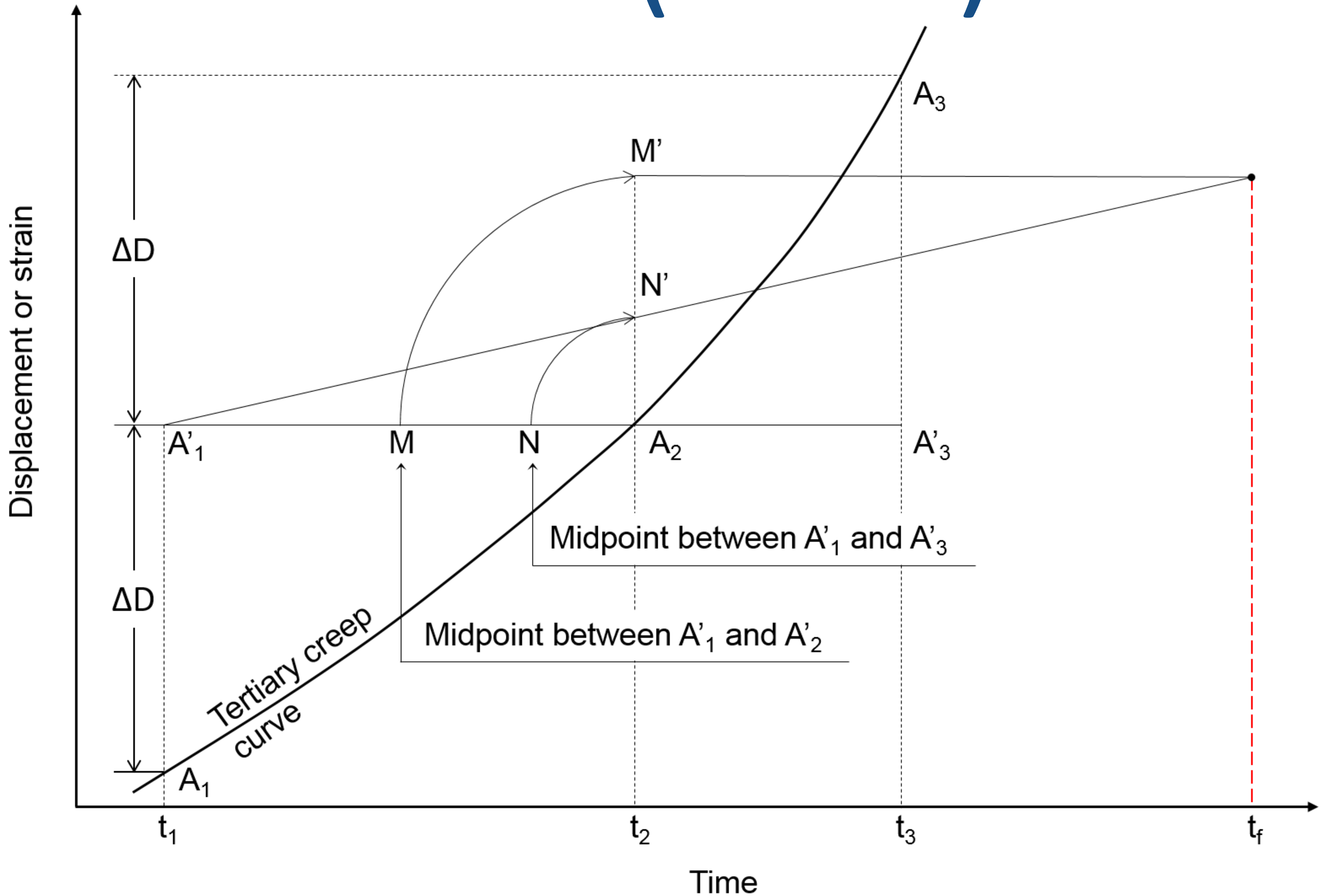
Creep


Displacement
Tertiary creep
Secondary creep
Primary creep
Time

The failure process

- Models and experiments on rock specimens that display brittle creep behaviour have revealed the existence of power-law relationships between the time of failure and the applied stress, where a number of constants that depend on the rock properties and ambient conditions also play a role, including the strength of the rock, temperature, water saturation and chemical-corrosion processes.
- When scaling up to a more complex system (such as a landslide), tertiary creep still typically assumes the shape of a power law.
- The increasing length of the propagating cracks increases the stress intensity at the tip of the crack itself and, therefore, the velocity of further crack propagation. Such a self-feeding process creates the striking non-linearity of tertiary creep.

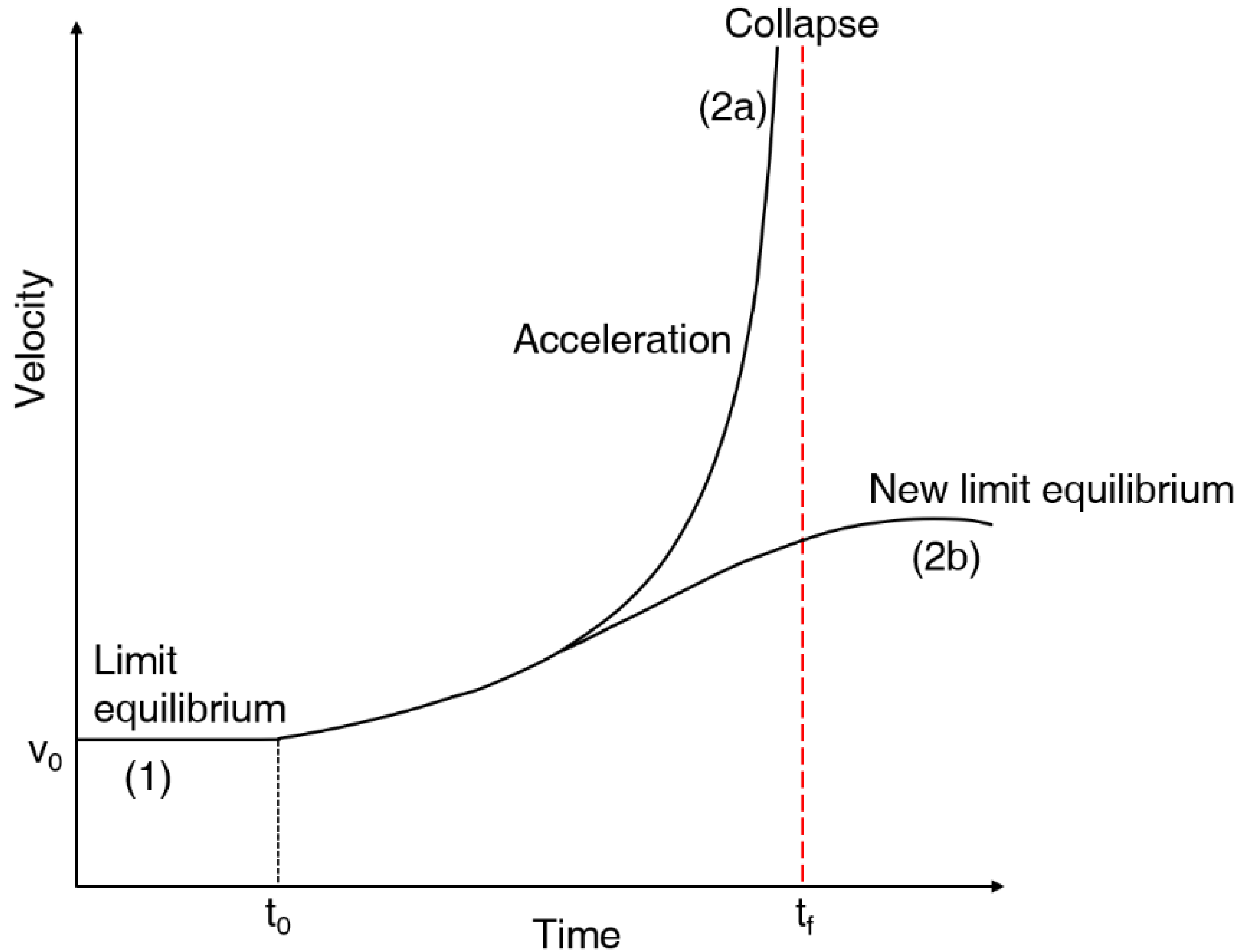
Saito (1969)



$$t_f = \frac{t_2^2 - t_1 \cdot t_3}{2t_2 - (t_1 + t_3)}$$

Saito, M. (1969). Forecasting time of slope failure by tertiary creep. In Proc. 7th Int. Conf on Soil Mechanics and Foundation Engineering, Mexico City (Vol. 2, pp. 677-683).

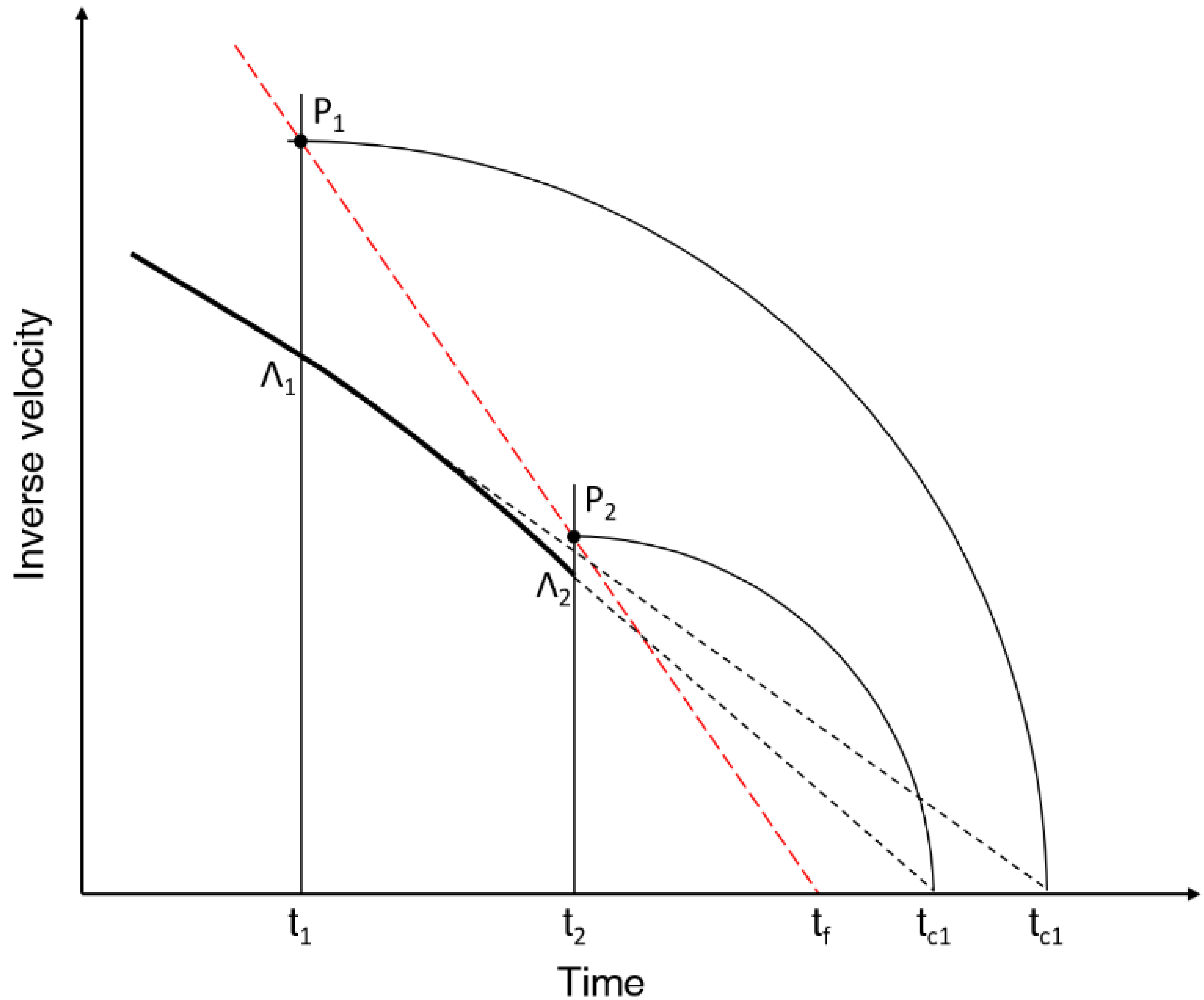
Fukuzono (1985)



Fukuzono, T. (1985). A method to predict the time of slope failure caused by rainfall using the inverse number of velocity of surface displacement. Landslides, 22(2), 8-13_1.

Fukuzono (1985)

$1/v = \Lambda$



$$t_f = \frac{t_2\,(\Lambda_1) - \ t_1\,(\Lambda_2)}{\Lambda_1 - \ \Lambda_2}$$

Application on hard, brittle rock

Hungr | Petley

Rose, N. D., & Hungr, O. (2007). Forecasting potential slope failure in open pit mines–contingency planning and remediation. International Journal of Rock Mechanics and Mining Sciences, 44, 308-320.

- "Given ductile, accelerating creep occurring under constant effective stress conditions in soil, rock and other materials, the inverse velocity plot would in fact be expected to be linear"
- "The timing of [brittle rock] failure cannot be anticipated by means of displacement monitoring"

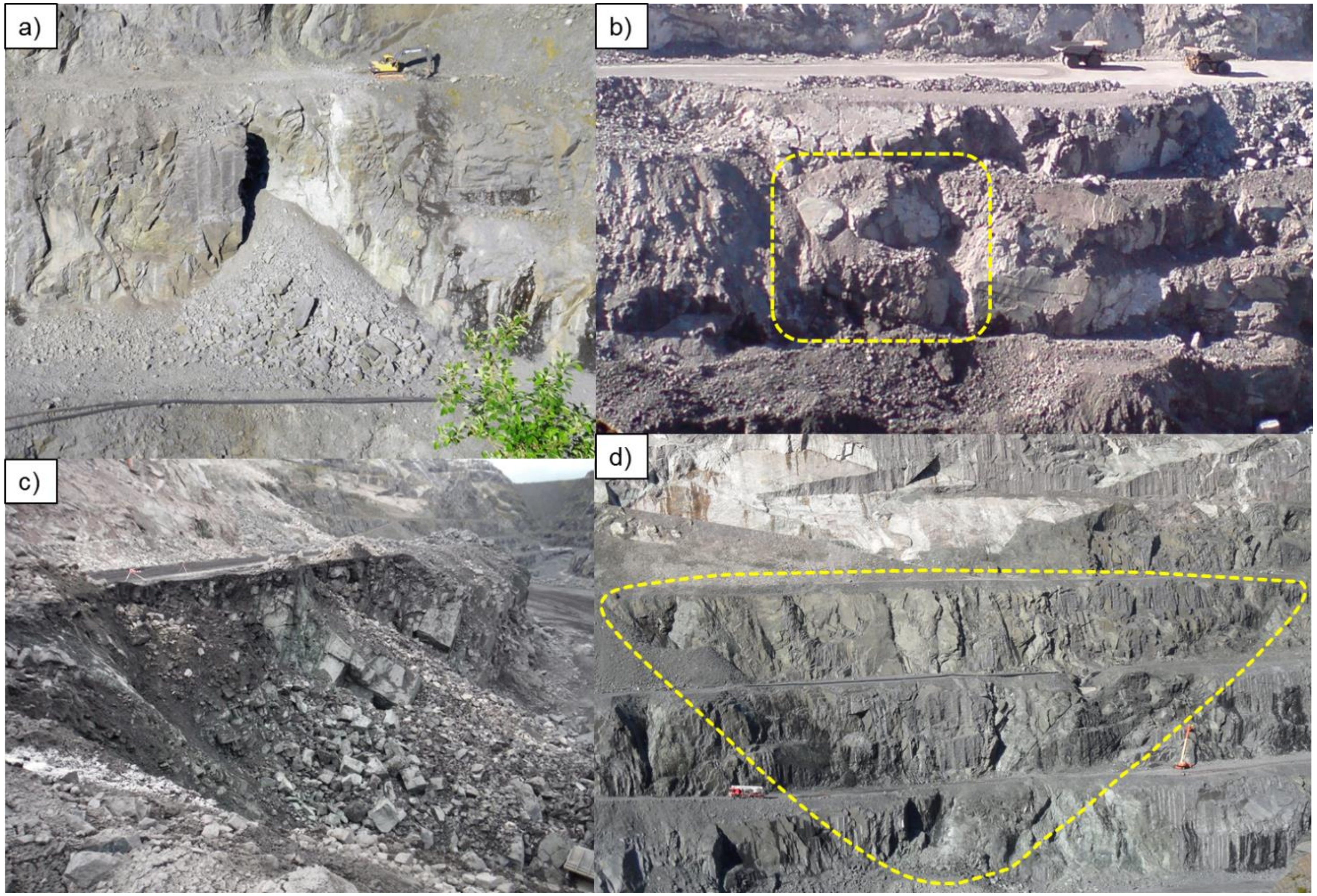
Petley, D. N. (2004). The evolution of slope failures: mechanisms of rupture propagation. Natural hazards and earth system sciences., 4(1), 147-152.

- "Saito linearity is the result of brittle deformation processes associated with the formation of the shear surface [(first time rupture)]"
- "Where the process occurring at depth is ductile, or indeed consists of sliding on existing surfaces, [...] an asymptotic trend might be expected [(reactivation)]"
- "It is not possible to use Saito linearity to predict failure in non-brittle materials"

Ground-based interferometry

Modern GB-InSAR apparatuses, capable of acquiring in less than one minute, enable the early warning of rigid (brittle) rock failures

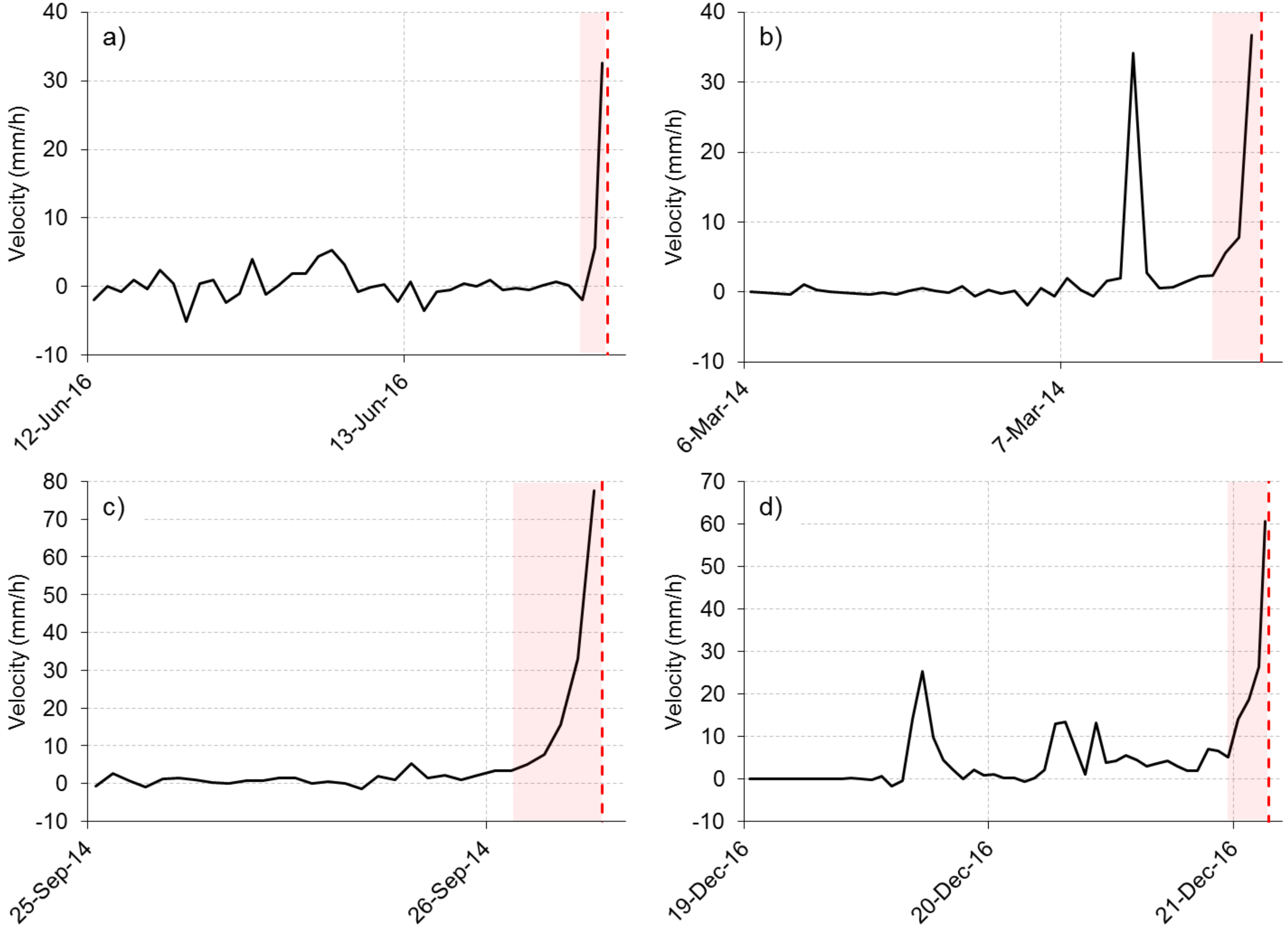
Open-pit mine in hard rock



60 < RMR < 80

Carlà, T., Farina, P., Intrieri, E., Botsialas, K., & Casagli, N. (2017). On the monitoring and early-warning of brittle slope failures in hard rock masses: Examples from an open-pit mine. Engineering Geology, 228, 71-81.

Open-pit mine in hard rock



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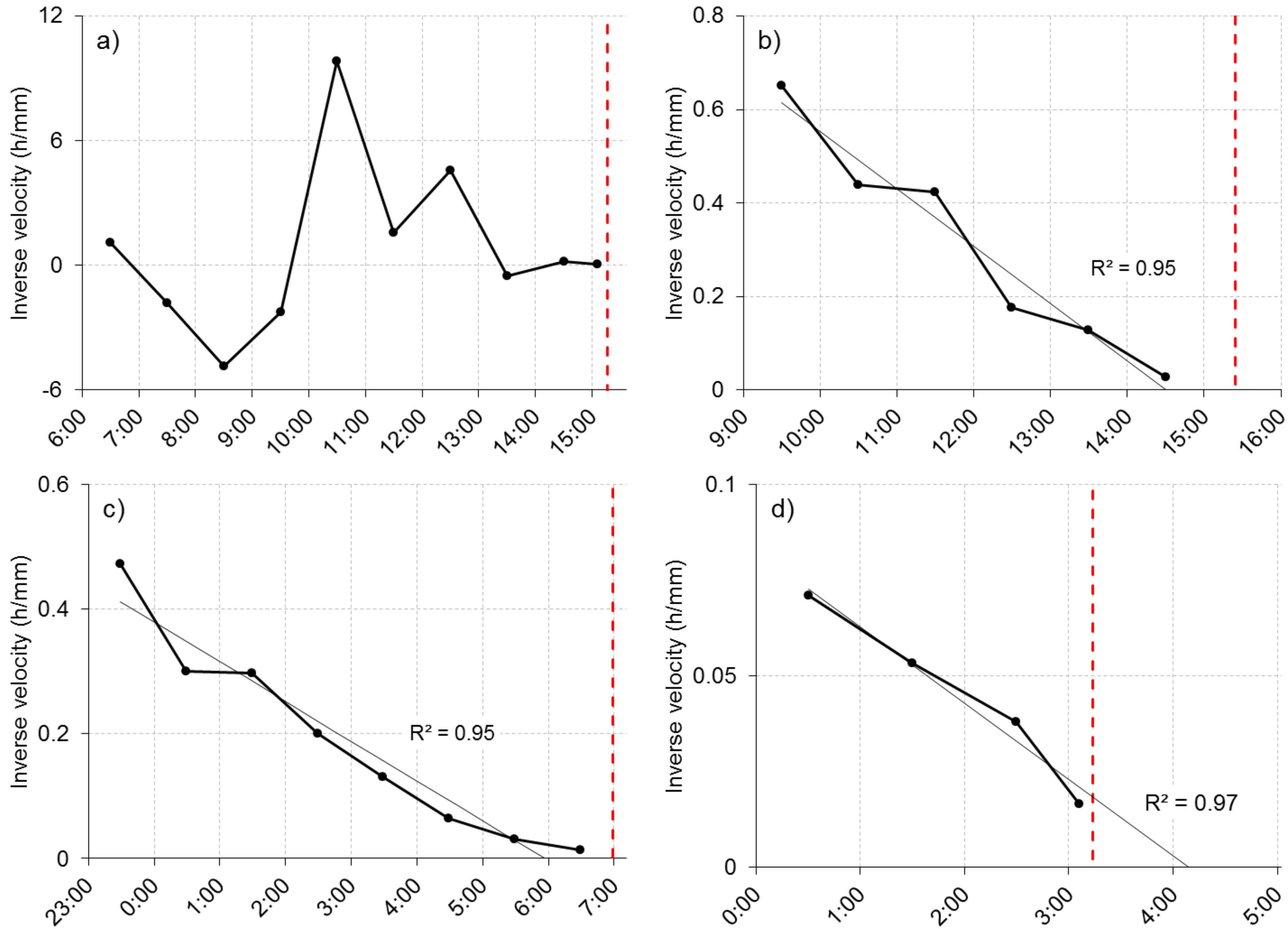
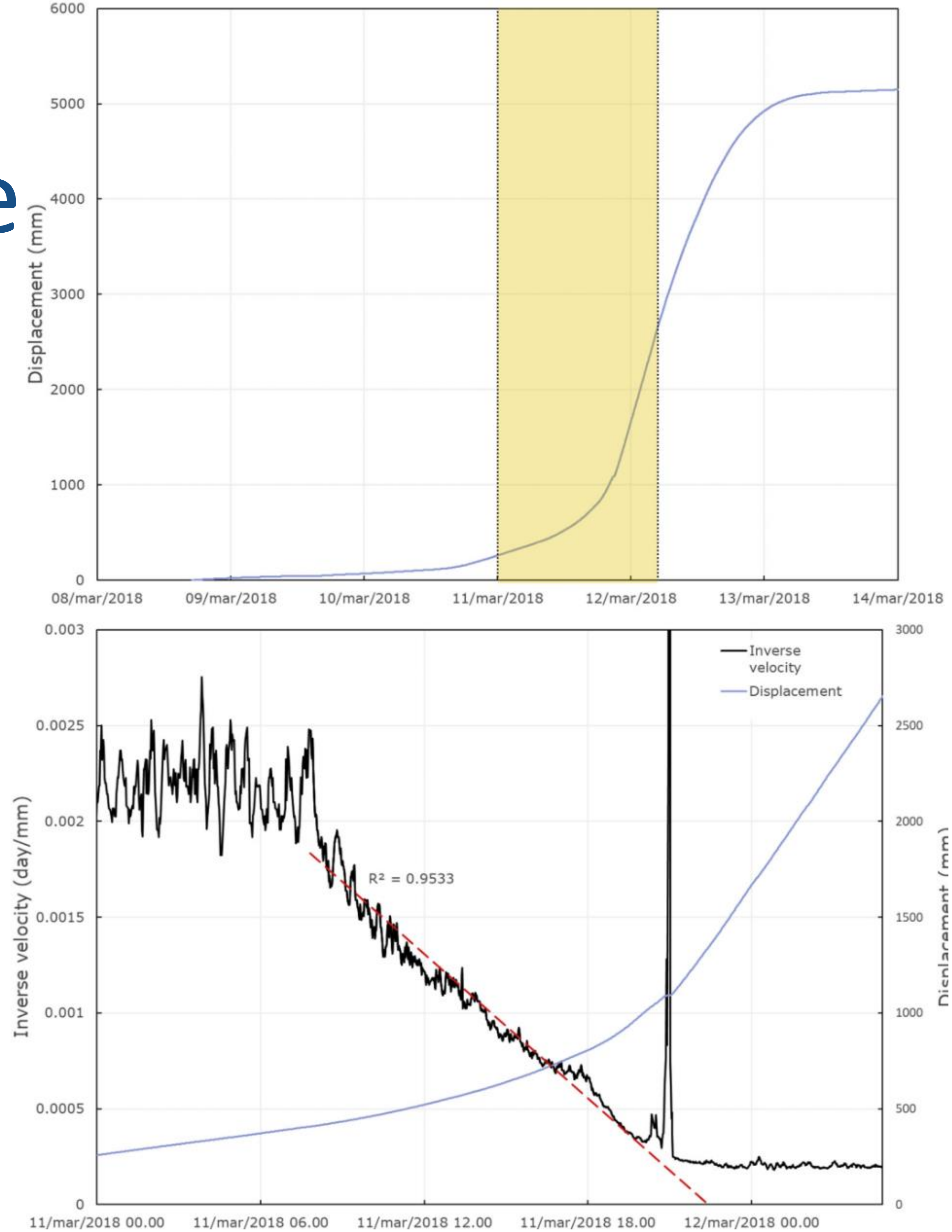
Open-pit mine in hard rock



Carlà, T., Farina, P., Intrieri, E., Botsialas, K., & Casagli, N. (2017). On the monitoring and early-warning of brittle slope failures in hard rock masses: Examples from an open-pit mine. Engineering Geology, 228, 71-81.

Forecasting slow-moving earthflows? The case of Marano landslide

Marano landslide



Intrieri, E., Carlà, T., & Gigli, G. (2019). Forecasting the time of failure of landslides at slope-scale: A literature review. Earth-Science Reviews, 193: 333-349.

Conclusions

- Forecasting methods are based on physical behaviours that are found in a variety of phenomena, materials, volumes, geometries, parameters.
- Landslides can also be forecasted when external forces are acting on them and accelerations that fit a power law can also be observed in cases where fracturing does not occur at all.
- The relationships between the kinematics and time of failure of a slope have been adequately described, but a robust link between geomorphological, geotechnical, and geomechanical features and kinematics (or other parameters acting as collapse indicators) is still missing.
- New insights could be derived from joint contributions from different research and industry fields, such as engineering geology, rock mechanics, materials science, open-pit mining, and remote sensing.

For a detailed dissertation

https://www.sciencedirect.com/science/article/pii/S001282521830518X

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Forecasting the time of failure of landslides at slope-scale: A literature review

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A R T I C L E I N F O

Keywords:
Failure prediction
Creep
Early warning
Slope stability
Velocity thresholds

A B S T R A C T

Forecasting the time of failure of landslides at slope-scale is a difficult yet important task that can mitigate the effects of slope failures in terms of both human lives and economic losses. Common applications include public safety situations, where the risk is represented by dwellings built near active landslides or unstable cut slopes that threaten streets and railways, and open-pit mines, for which accurate warnings are fundamental to safeguard workers and simultaneously avoid unnecessary interruptions of the extraction activities.

The scientific literature is populated by many methods, guidelines and approaches regarding forecasting the time of failure or defining the conditions of imminent collapse. Thus, obtaining a synoptic view of the advantages and limitations of these different methodologies has become difficult. At the same time, innovations in technology have opened new possibilities to the application of such techniques, which are examined here.

This paper discusses and classifies these methods, addressing their respective differences and peculiarities to foster the usage even of less popular methods without overlooking the more scientific aspects and issues of landslide forecasting. Finally, an overview of the future trends and challenges is presented to contribute to the debate around this important topic.