Crustal Fluid and Earthquake Activity in Northern Thailand: Insights from Magnetotelluric Surveys

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1. INTRODUCTION

Northern Thailand has experienced several moderate-to-strong intraplate earthquakes over the past three decades, including the 1994 Phan, 2014 Mae Lao, and 2019 Wang Nuea events. These occurred along active fault zones within a complex tectonic framework shaped by past subduction and crustal accretion. Despite this seismicity, geophysical imaging particularly of crustal fluids remains limited.

Crustal fluids reduce fault strength by elevating pore pressure, influencing both the location and timing of earthquake rupture. Magnetotelluric (MT) surveys, which detect subsurface electrical conductivity, offer a unique means to image these fluid pathways from near-surface to the lower crust. In Thailand, only a few groups have employed MT, yet recent studies show its strong potential for earthquake hazard assessment.

2. METHODOLOGY

We integrated MT datasets from campaigns between 2015 and 2024, processed with robust remote reference techniques and inverted using 3D resistivity modelling. Surveys targeted major fault zones: Mae Chan Fault Zone (MCFZ), Mae Lao Segment (MLS), Phayao Fault Zone (PFZ), and Wang Nuea area. Geological maps, seismicity records (1994–2024), and fault data were integrated for interpretation.

3. RESULTS

3.1 Mae Lao Earthquake (2014)

A large conductive anomaly was imaged beneath the MLS, extending from the lower crust into the seismogenic zone. This is interpreted as a deep fluid conduit that weakened the fault prior to the Mw 6.3 earthquake.

3.2 Wang Nuea Earthquake (2019) — Highlight Case

Our retrospective MT study (Amatyakul et al., 2024) revealed that the Wang Nuea earthquake sequence occurred above a deep conductive corridor linking a lower crustal fluid reservoir to a previously unrecognized fault segment. This conductor is part of a broader interconnected fluid system imaged across northern Thailand. The findings demonstrate MT's capability to:

- Retrospectively explain earthquake locations in terms of crustal fluid pathways.
- Identify hidden fault–fluid connections before they rupture.
- Provide critical input for **prospective hazard mapping**, especially in intraplate settings.

3.3 Regional Structure

MT images reveal extensive conductive belts following ancient suture zones and geothermal provinces, likely representing persistent deep fluid reservoirs from relict subduction.

3.4 Regional Structure

Conductive anomalies correspond to fluids from:

1. **Magmatic/mantle-derived volatiles** from partial melts.
2. **Metamorphic dehydration** of lower crustal rocks.
3. **Sedimentary basin brines** from compaction/heating.
4. **Hydrothermal circulation** near geothermal systems.
5. **Relict subduction fluids** in hydrated mantle and crust.

4. IMPLICATIONS FOR SEISMIC HAZARD

- MT effectively maps fluid-rich zones prone to earthquake initiation.
- Retrospective case studies show its explanatory power; prospective deployment could locate future hazard zones.
- We propose establishing a **nationwide MT survey program targeting active faults.**

5. CONCLUSIONS

Magnetotelluric imaging in northern Thailand has identified crustal fluid pathways associated with major earthquakes. The Wang Nuea case exemplifies MT's value for seismic hazard assessment, underscoring the need for systematic MT surveys across Thailand.