Development of a Potassium Super Gradiometer for Earthquake Research and Other (Exploration) Applications

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Overview

- Introduction to Current Methods
- Detectability of Earthquakes by Magnetic Methods
- Short Base (Gradient) Measurements
- Potassium SuperGradiometer
- Instrumentation
- Summary

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Magnetics for Earthquakes

- Based on theory of:
  - – Piezomagnetism and / or electrokinetics
  - – Gradual pressure build-up prior to earthquakes or “events”

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Monitoring Systems (1)

- <u>Traditional Methods</u>
  - Magnetic sensors (0.1 nT sensitivity)
  - Long base measurements
    - Only sporadic detection of precursors

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Monitoring Systems (2)

- <u>Recent Work</u>
  - Induction coils
    - Improved sensitivity to 25 pT
    - Vector measurements (3 components)
    - Limited bandwidth (0.01 Hz)
    - Skin effect problems
    - Skin depth approximately 30 km @ 0.01 Hz

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Monitoring Systems (3)

- SuperGradiometer delivers sensitivity needed for Short Base work
- Background noise is 50 fT for 1 reading / second
- Can increase sensitivity further by placing sensors at specific distances, say 50 to 100m, which gives 1 fT/m gradient sensitivity
  - No skin effect
- Evaluating SuperGrad for long-term drift and elimination of man-made noise

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Detectability of Earthquakes by Magnetic Methods

- Assuming earthquakes create dipolar anomalies, we can calculate their detectability:

$$B = \frac{\mu_o M (1 + 3 \cos^2 \alpha)^{1/2}}{4\pi r^3}$$

- Where B is measured magnetic induction, μo is magnetic permeability, M is magnetic moment, and α is the angle between radius vector, **r**, and dipole direction.
- r is distance from hypocenter to the observation point

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Magnetic Moment (1)

- Assuming $\cos^2 = 0$ for simplicity, the previous equation can be solved for M, Magnetic Moment, as follows:

$$M = \frac{4\pi r^3 B}{\mu_0}$$

- Results are extended to look at data from the Loma Prieta earthquake of 1989 which clearly shows magnetic precursors.

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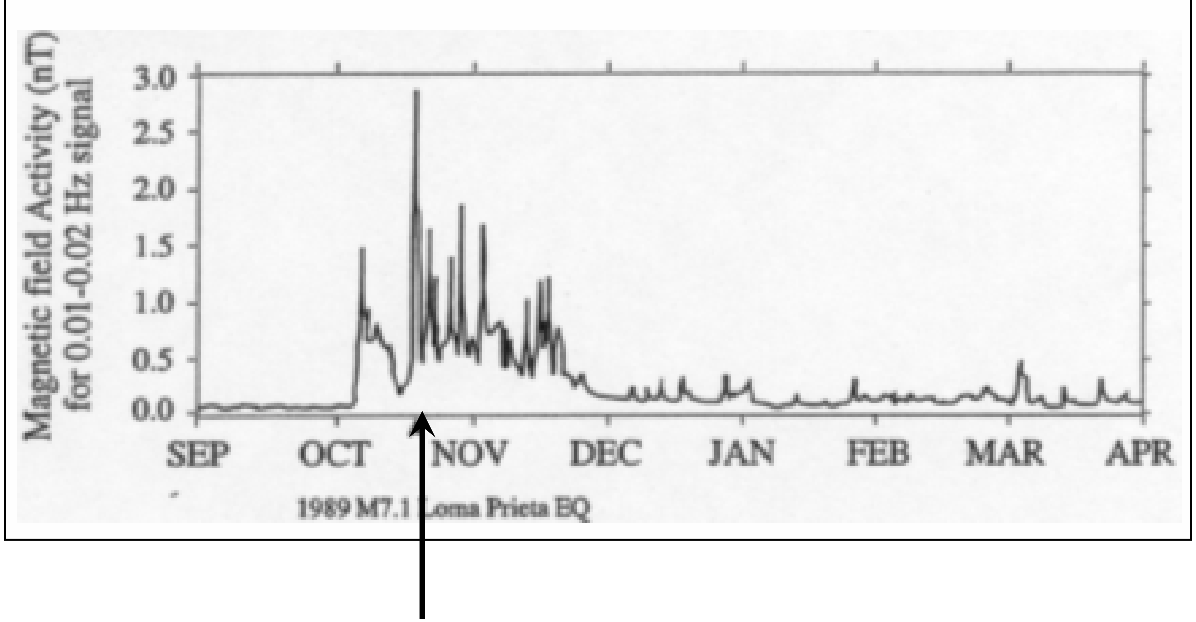
Magnetic Moment (2)



Loma Prieta Precursor

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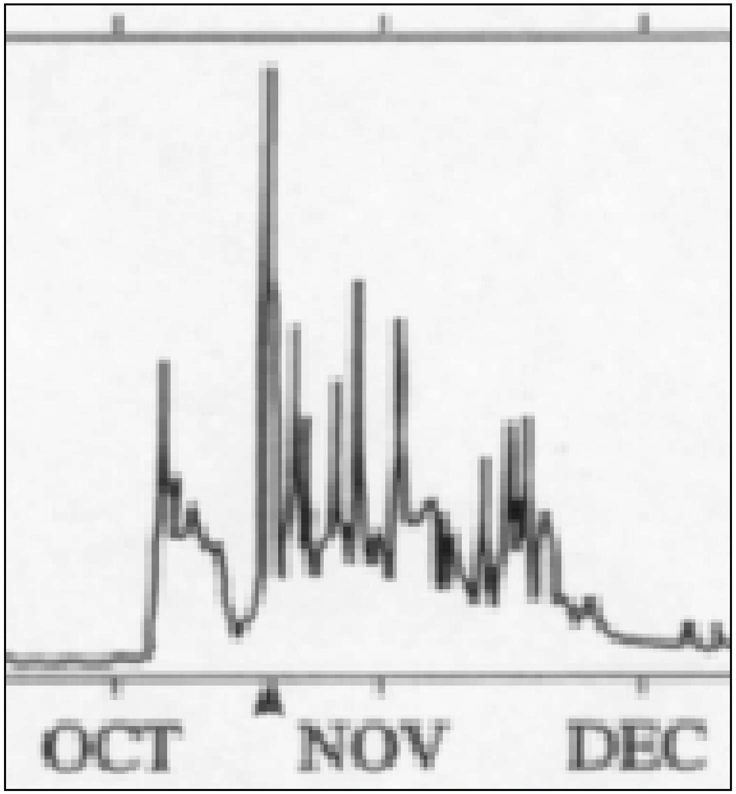
Magnetic Moment (3)

Loma Prieta - M7.1

- B=2.8 nT anomaly at 17 km depth to hypocenter
- 1.7 x 10^{11} Am^2 magnetic moment or 3.2 x 10^{11} Am^2 (corrected for skin effect)

San Juan Bautista - M5.1

- 20 pT anomaly at 9.4 km depth to hypocenter
- 1.7 x 10^8 Am^2 magnetic moment or 2.6 x 10^8 Am^2 (corrected for skin effect)



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Radius Calculation (1)

- Note the 3rd potential drop off of the magnetic field and the 4th potential of the magnetic gradient with radius:

$$r = \left(\frac{\mu_o M}{4\pi B} \right)^{1/3} \qquad r = \left(\frac{3\,\mu_o M}{4\pi\, dB/dr} \right)^{1/4}$$

- Extreme sensitivity needed to measure (dB / dr)
- Prospects for elimination of man-made noise are better

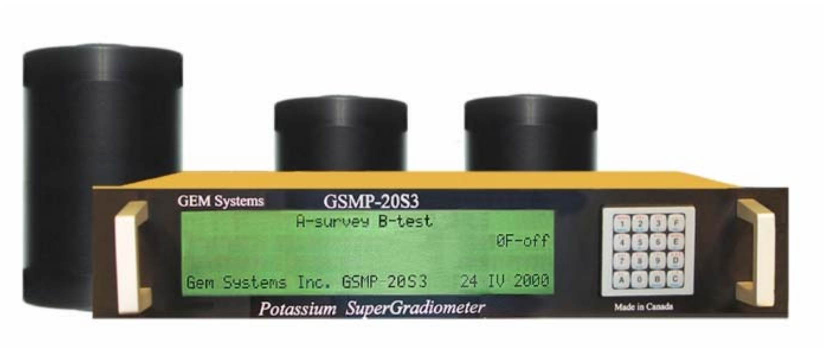
Radius Calculation (2)

		Detectable Distance (kilometres)		
Magnitude	**Magnetic Moment (Am^2)**	**Magnetometer (0.1 nT)**	**Induction Coils (25 pT, skin depth 30 km)**	**SuperGrad (0.1 fT/m)**
9	1.2×10^{14}	493	150	771
8	3.8×10^{12}	156	90	325
7	1.2×10^{11}	46.8	46.6	137
6	3.8×10^{9}	15.6	20.0	57.8
5	1.2×10^{8}	4.7	7.2	24.4
4	3.8×10^{6}	1.6	2.4	10.3

Maximum distance at which an event can be detected by different sensors

Instrumentation

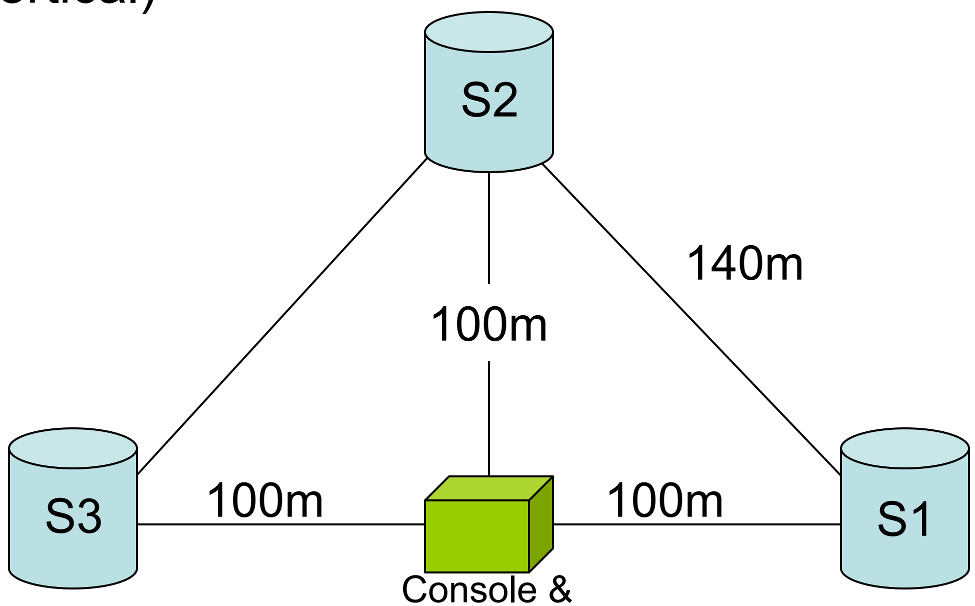
- Based on optically pumped Potassium method
- Very high sampling (up to 20 samples / second)



- Also designed for minimal heading error, high absolute accuracy and reliability

SuperGrad Array

- 3 sensors arranged according to terrain (horizontal or vertical)



- Sensor spacing up to 140m
- Long term integration is promising

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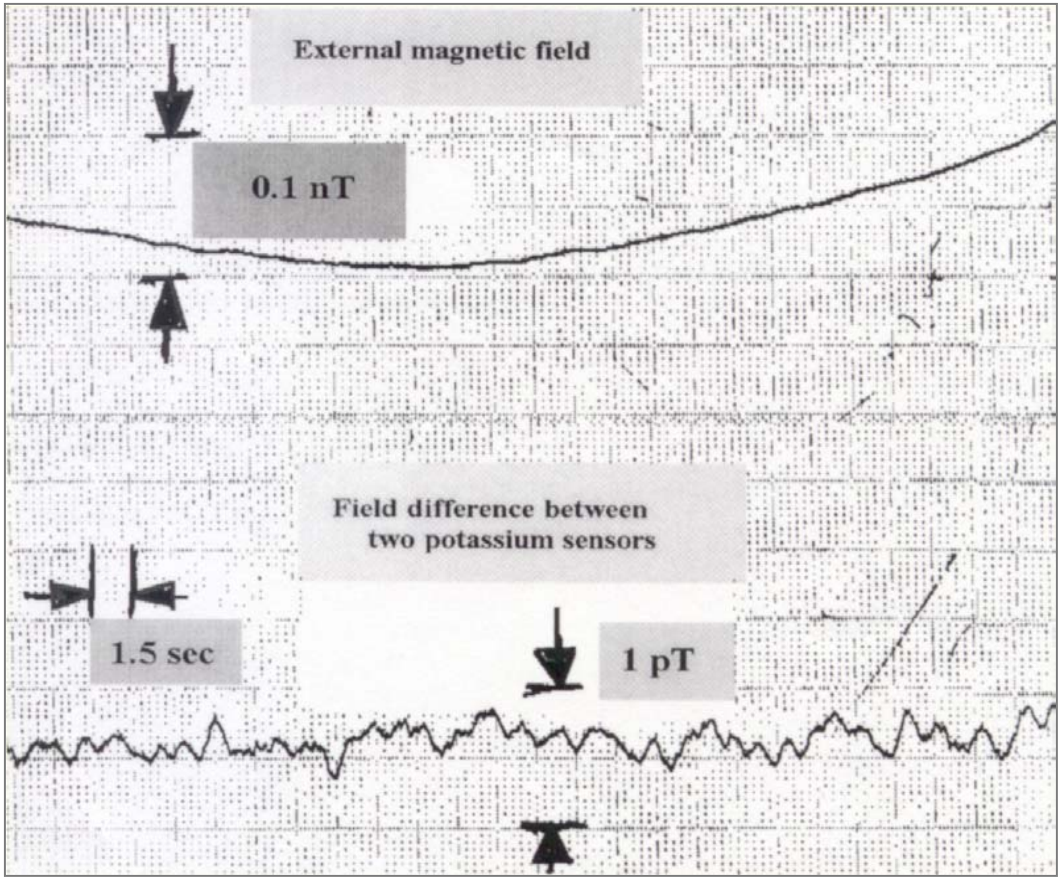
Data (1)



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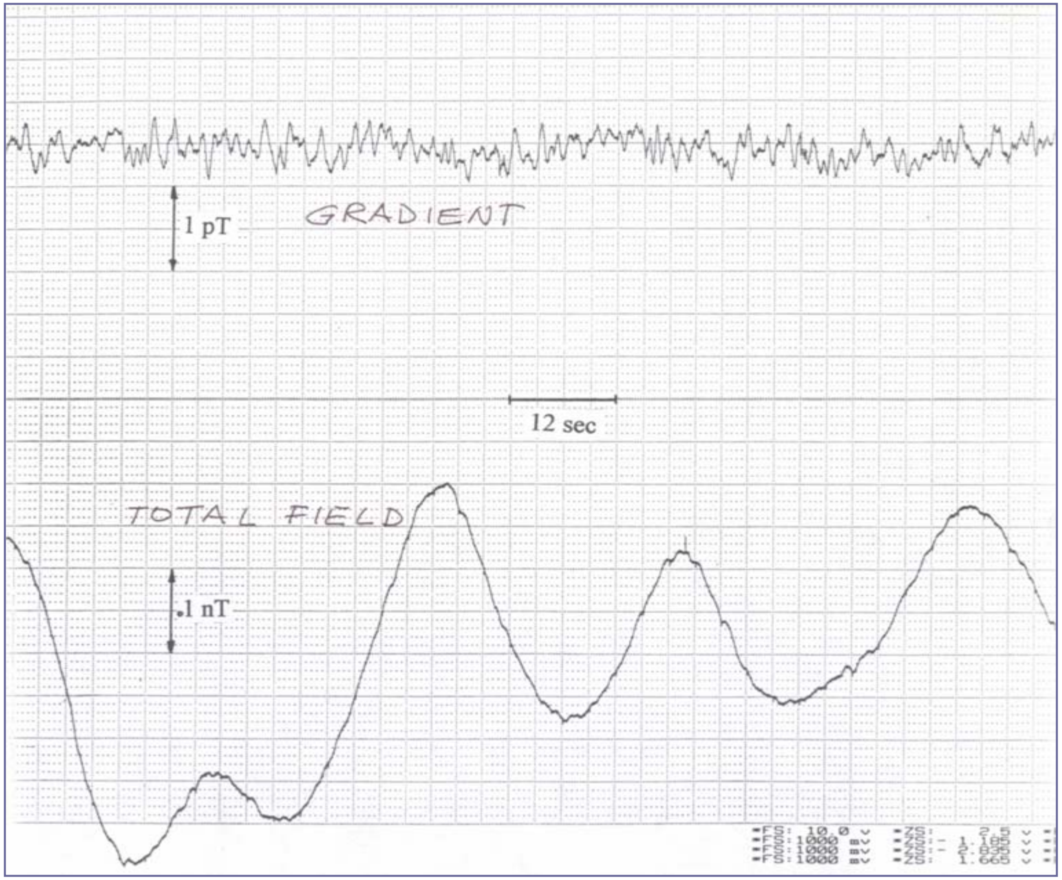
Data (2)



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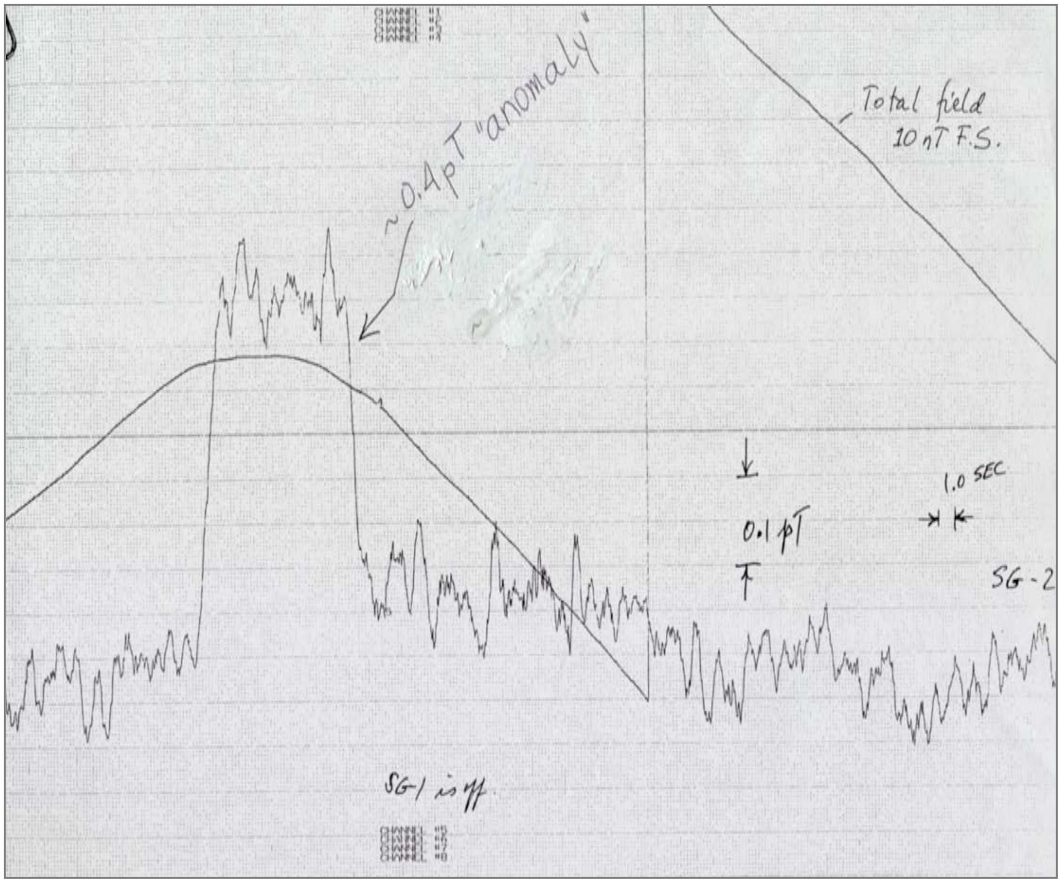
Data (3)



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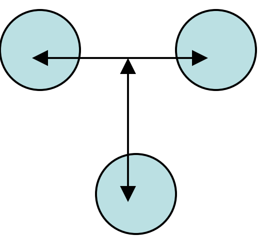
Exploration Applications

Applicability of SuperGradiometer in



- Airborne gradiometer with short distance (ex. 1 foot) between the sensors to resolve to 0.15 pT / m $Hz^{1/2}$

- Paleomagnetics – Detectability of 4×10^{-9} Am^2 dipoles

Summary

- Based on earlier assumptions (and not considering geometrical effects), we can conclude:
  - Magnetometers of 0.1 nT sensitivity can detect only the strongest earthquakes (M >7)
  - Induction coils are good for M>6
  - SuperGradiometer (SGrad) in Fast mode is effective for M>6
  - SGrad in Slow mode is effective for M>5
  - SGrad is suitable for detection of extremely small dipoles
  - SG can form multisensor gradiometers with small sensor distances