

On the “Natural Battery” Hypothesis for the Hessdalen Lights: A Quantitative Reassessment

MASSIMO TEODORANI, Ph.D. – Astrophysicist

ORCID: <https://orcid.org/0009-0000-7706-7455>

Abstract

Monari et al. (2013) proposed that a large-scale “natural battery”, formed by oxidizing sulfide/iron deposits on one side of Hessdalen valley (Norway) and reducing copper deposits on the other, generates the electrical charge responsible for the Hessdalen luminous phenomenon (HLP). The hypothesis has since been repeated in television and popular-science coverage as if it were an established explanation, despite never having appeared in a peer-reviewed journal. We revisit the proposal on its own physical terms. Drawing on the well-characterised electrochemistry of geobatteries and self-potential (SP) anomalies in mineralised terrain (Sato & Mooney, 1960; Revil et al., 2010), we show explicitly, with supporting calculations and a figure, that (i) the electromotive force such a system can plausibly generate falls roughly six orders of magnitude short of what is required to ionise air at any geologically plausible length scale, and (ii) even if a sufficient potential were somehow achieved, a geobattery is at best a candidate energy source or triggering mechanism, and offers no account of the morphology, colour, mobility, or duration of the reported light phenomena. We further show that a documented multi-decade decline in witness reports is not predicted by a static geological source, and that the one natural mechanism with laboratory support for rock-to-air charge transfer has already been excluded for Hessdalen on seismological grounds. We conclude that the “natural battery” idea is a reasonable, testable hypothesis — not a theory — and that in its current, unreviewed form it does not constitute an explanation of the Hessdalen lights.

1. The hypothesis, restated fairly

Hessdalen has been the subject of organised scientific investigation since the original Project Hessdalen field campaign (Strand, 1984), which first deployed instrumentation to systematically document the luminous phenomenon. Subsequently, researchers from various countries took turns conducting research in the Hessdalen Valley.

Monari, Montebugnoli and Serra (2013, Italian Committee Project Hessdalen) propose that the juxtaposition of iron/zinc sulfide deposits on the western side of Hessdalen valley and copper/iron deposits on the eastern side sets up the geological equivalent of a galvanic cell: oxidation at one pole, reduction at the other, with groundwater acting as the electrolyte connecting them. The resulting charge separation and current flow is invoked as the ultimate source of the strong, transient electric fields reported in the valley, which are in turn proposed to drive the luminous phenomenon.

This is, in itself, a legitimate and interesting starting point. Geobatteries are real, well-documented electrochemical systems, routinely exploited in mineral exploration through the self-potential (SP) method, and Hessdalen's geology — a gabbro intrusion flanked by sulfide-bearing metamorphic rock, exactly the kind of contact-metamorphic, redox-contrasted setting where SP anomalies are expected

— makes the underlying premise geologically sensible. The problem is not the concept. The problem is what it can and cannot deliver, quantitatively.

The hypothesis has enjoyed sustained, largely uncritical popular exposure in Italy for well over a decade, including in *Focus* magazine (Bignami, 2012; 2026) and, most recently, in a national television segment on Rete 4 presenting the phenomenon under the framing “Sfere di luce: armi terrestri segrete?” (*Le grandi domande di Freedom*, 11 August 2026, presented by Roberto Giacobbo). None of this coverage cites the peer-reviewed geophysical literature on Hessdalen (e.g. Vargemezis et al., 2024) or engages with the quantitative objections raised here and, informally, by Samset in 2014 (Christensen, 2014).

2. How much charge can a geological battery actually produce?

It is worth noting that the natural-battery hypothesis has already drawn informal but pointed skepticism from at least one independent physicist. When the idea was first popularised via *New Scientist* in 2014, Norwegian physicist Bjørn H. Samset (CICERO Center for International Climate Research) told ScienceNorway that he had *not seen any convincing computations of the phenomena*, that the valley's dimensions were *too great* a distance for the proposed mechanism, and that the associated claim of a cold, low-temperature plasma was self-contradictory (Christensen, 2014). Samset has not, to our knowledge, published a dedicated paper on the Hessdalen phenomenon; his objection exists only in this interview. The present paper independently arrives at the same conclusion — insufficient energy at the relevant length scale — but replaces Samset's qualitative assessment with an explicit, referenced quantitative bound.

The electrochemistry of sulfide-hosted geobatteries has been characterised in detail since Sato & Mooney's (1960) original model and refined by decades of SP prospecting work (see Table 1). Field self-potential anomalies over massive sulfide bodies typically run from a few tens to a few hundred millivolts, occasionally approaching 1 V for unusually large, well-connected ore bodies. Crucially, Revil et al. (2010) note that the anomaly cannot physically exceed the redox-potential difference between the anodic and cathodic poles of the system — a hard thermodynamic ceiling on the order of a few hundred millivolts for a single ore-body pair.

Table 1

Quantity	Typical / maximum value	Source	Notes
Self-potential (SP) anomaly over sulfide ore body	100–1000 mV (rarely >1 V)	Sato & Mooney (1960); Revil et al. (2010)	Bounded above by the redox-potential difference between anodic and cathodic zones (theoretical ceiling ≈ 0.4 V for a single geobattery pair)
Dielectric breakdown field of air (STP)	≈ 3 MV/m (30 kV/cm)	Kuffel, Zaengl & Kuffel (2000)	Field needed for a self-sustaining avalanche/arc in ambient air
Corona (visible glow) onset field, sharp points	≈ 0.2 –1 MV/m locally	Peek (1929); Kuffel, Zaengl & Kuffel (2000)	Requires strong local field concentration at a small-radius conductor tip

Even granting Monari et al. the most generous possible reading — a large-scale, valley-spanning geobattery with sustained current flow through a fractured, water-saturated gabbro/sulfide contact — the potential difference available is, at most, of order 1 volt across kilometres of rock and groundwater. That is the electromotive force of a single AA battery, distributed over a horizontal distance of several kilometres.

3. The gap between a geobattery and a luminous discharge

To ionise air and sustain a visible discharge, the electric field must approach the dielectric breakdown strength of air — about 3 MV/m (30 kV/cm) under standard sea-level conditions, or, in the most favourable geometry (a sharp point concentrating field lines, per Peek's law for corona), field strengths locally in the range of hundreds of kV/m. Both figures are given in Table 1.

Compare this to what a 1 V geobattery can deliver. Spread across even a very short characteristic length of 1 metre near the ground surface, 1 V produces a field of only 1 V/m — roughly six orders of magnitude below the breakdown field of air. To reach corona-onset field strengths of order 10^5 – 10^6 V/m from a 1 V source, the effective radius of curvature of the *emitting structure* would have to be on the order of micrometres — a geometry with no plausible geological analogue at the scale of a mineralised fracture zone, let alone a 6×12 km area of valley. There is no proposed mechanism, in Monari et al. (2013) or in the geophysical literature since, for concentrating a sub-volt geobattery potential by six orders of magnitude at the ground–atmosphere interface.

In short: the “natural battery” as described is not merely insufficient, it is insufficient by a margin so large that no known focusing or amplification mechanism in near-surface geology closes the gap. This is the central, and in our view decisive, quantitative objection to the hypothesis as an explanation of luminous phenomena. My calculation does not claim that electrochemical systems can never produce local electric-field enhancement. Rather, it establishes the burden of proof: any proposed mechanism must demonstrate, quantitatively, how a sub-volt- to volt-scale distributed geobattery can concentrate its potential by approximately five to six orders of magnitude into a localized atmospheric emission region while delivering sufficient current and power to produce and sustain the observed luminosity. No such mechanism is specified by Monari et al. (2013), nor has one been demonstrated for Hessdalen in the subsequent geophysical literature.

3.1 Explicit calculation

For a uniform field approximation, $E = V/d$, where V is the potential difference and d the characteristic gap (or, equivalently, the radius of curvature of a field-concentrating point, per the point-charge/sharp-conductor approximation used in Peek's law; Peek, 1929). Table 2 solves this relation for the d required to reach the corona-onset field ($\approx 2 \times 10^5$ V/m) and the dielectric-breakdown field ($\approx 3 \times 10^6$ V/m; Kuffel, Zaengl & Kuffel, 2000), for potentials spanning the entire plausible geobattery range, from the thermodynamic single-pair ceiling of Revil et al. (2010) up to a deliberately generous 5 V.

Table 2

Assumed potential V	d for corona onset ($E = 2 \times 10^5 \text{ V/m}$)	d for dielectric breakdown ($E = 3 \times 10^6 \text{ V/m}$)	Geological plausibility of d
0.1 V (typical field SP anomaly)	0.5 μm	0.033 μm	None — sub-micron
0.4 V (Revil et al. 2010 ceiling)	2.0 μm	0.133 μm	None — sub-micron
1 V (large field anomaly)	5.0 μm	0.333 μm	None — sub-micron
5 V (unrealistically generous upper bound)	25.0 μm	1.667 μm	None — sub-micron to low tens of μm

Even at the most generous end of this range (5 V — five times the thermodynamic ceiling for a single ore-body pair), the required emitter radius or gap is under 2 micrometres to reach dielectric breakdown, and under 25 micrometres to reach corona onset. There is no proposed, or plausible, geological structure at Hessdalen — fracture aperture, mineral grain boundary, or otherwise — that could concentrate a distributed, kilometre-scale groundwater-electrolyte current down to a single micrometre-scale emission point while retaining the full source voltage across that point. Figure 1 shows the same relation graphically across the full range of relevant length scales, from atomic dimensions to the size of the valley itself, making clear that the entire geologically plausible domain (millimetres to kilometres, shaded) lies many orders of magnitude below both threshold fields.

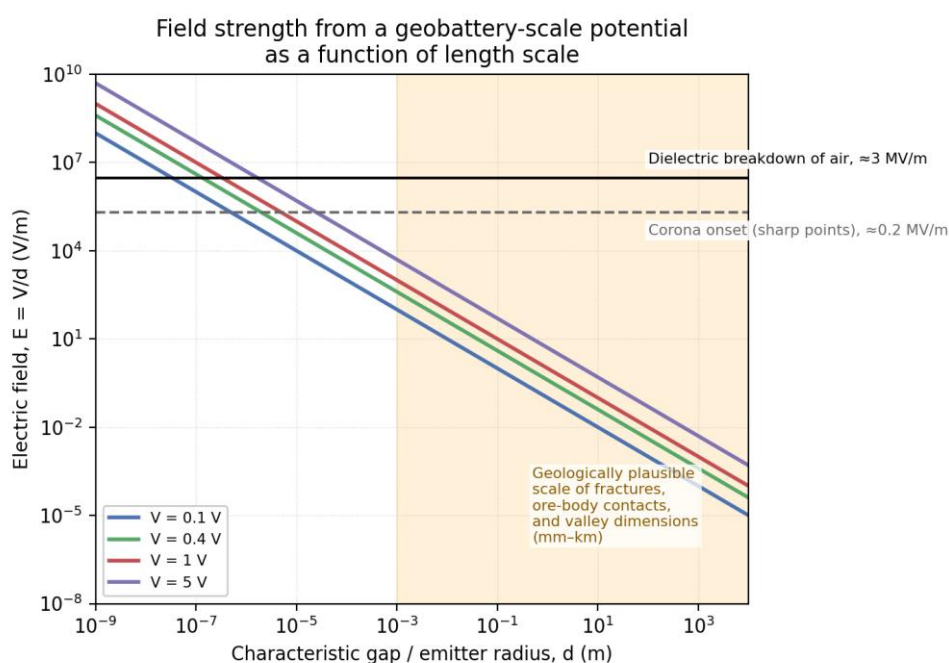


Figure 1. Electric field $E = V/d$ as a function of characteristic length scale d , for geobattery potentials from 0.1 to 5 V. The shaded region marks the geologically plausible range of gap sizes (fracture apertures to valley-scale distances). Horizontal lines mark the corona-onset field (Peek, 1929) and the dielectric-breakdown field of air (Kuffel, Zaengl & Kuffel, 2000). At no geologically plausible length scale does a geobattery-scale potential approach either threshold.

3.2 The one directly reported field measurement

Monari et al. (2013) report a single supporting field measurement: an Electric Field Meter (EFM) record taken at Peder's Farm, at roughly 600 m elevation, over about one week in September 2010, giving an

average field of ≈ -500 V/m against an *expected* fair-weather value of ≈ -650 V/m, a ≈ 150 V/m discrepancy which the authors interpret as a possible signature of an external (geological) potential source.

Two points are worth making about this figure, one contextual and one decisive. First, contextually: the standard fair-weather atmospheric electric field at ground level is well established in the atmospheric-electricity literature at roughly 100–150 V/m (American Meteorological Society, 2012; MacGorman & Rust, 1998), and it decreases rapidly with altitude, typically falling below ~ 10 V/m within a few hundred metres above the surface. A reported 500–650 V/m at ~ 600 m elevation is therefore already well above the standard fair-weather profile, which by itself says only that local conditions (topography, a farm building or mast acting as a field-concentrating structure, aerosol content, or a single week of atypical weather) can substantially perturb the local field — a routine finding in atmospheric-electricity fieldwork, not necessarily evidence of a geological source. A single one-week campaign, without repeat measurement or a control site to isolate topographic and instrumental effects, cannot on its own establish that the ~ 150 V/m residual is geological in origin rather than a product of these well-known local confounds.

Second, and decisively for the argument of this paper: even setting the attribution question aside entirely and taking the *full* reported 500–650 V/m at face value as a genuine, geologically sourced anomaly — the most generous possible reading of Monari et al.'s own data — it remains roughly three orders of magnitude below the corona-onset field ($\approx 2 \times 10^5$ V/m) and roughly four orders of magnitude below the dielectric-breakdown field of air ($\approx 3 \times 10^6$ V/m; see Table 1). In other words, the only field measurement offered in support of the hypothesis, even read in the most favourable possible way, independently confirms rather than closes the gap derived analytically in Section 3.1: it is an atmospheric potential-gradient measurement, not a ground-coupled discharge field, and it falls far short of what visible ionisation requires.

3.3 A stronger, but inapplicable, analogue: stress-activated charge carriers

A markedly stronger natural charge-generation mechanism does exist in the peer-reviewed geophysical literature, and it is worth addressing directly so that this rebuttal is not read as denying that stressed rock can, under any circumstances, generate air-ionising fields. When igneous rock is subjected to increasing mechanical stress, dormant “peroxy” bonds in the mineral matrix break and release highly mobile positive-hole (p-hole) charge carriers; under rapid loading these carriers can reach a locally degenerate, plasma-like charge density capable of propagating to the surface and ionising the surrounding air — the leading mechanism proposed for real, photographed co-seismic “earthquake lights” (St-Laurent, Derr & Freund, 2006). The effect has direct laboratory support: loaded gabbro, granite and anorthosite tiles generate self-sustained currents with peak densities reported up to several thousand pA/cm³ under rapid stress-rate increases (St-Laurent, Derr & Freund, 2006; Scoville, Sornette & Freund, 2015).

This mechanism is qualitatively different from, and substantially stronger than, the static redox geobattery invoked by Monari et al. (2013): it is a dynamic, stress-driven charge avalanche rather than a fixed voltage divided by a fixed distance, and — unlike the natural-battery hypothesis — it has independent laboratory support and a documented observational record. If any natural geological

process at Hessdalen were capable of bridging the orders-of-magnitude gap identified in Sections 3.1–3.2, this is a far more promising candidate mechanism than a sub-volt geobattery.

However, the mechanism's applicability to Hessdalen has already been considered, and explicitly rejected, in the peer-reviewed literature central to this rebuttal. Vargemezis et al. (2024) directly evaluated a stress-activation/piezoelectric explanation for the Hessdalen phenomenon and concluded that seismicity in Norway, and particularly in Hessdalen valley, is too weak to sustain it. Gabbro and basalt are indeed present in the valley's geology, satisfying the mineralogical precondition, but the mechanism additionally requires active tectonic loading at a non-negligible stress rate, and Hessdalen sits in a low-seismicity, intraplate setting within the Scandinavian Caledonides, with no documented pattern of local seismic activity coincident with reported sightings.

The implication cuts against, rather than for, the natural-battery hypothesis. The one mechanism in the literature that has actually been shown, in the laboratory and in the field, to generate air-ionising charge from rock has been argued to be inapplicable at Hessdalen for want of the tectonic driving force it requires. A fortiori, the comparatively weaker, purely electrochemical, and permanently static geobattery mechanism proposed by Monari et al. — which lacks even this dynamic avalanche pathway — is even less able to close the gap quantified in Sections 3.1 and 3.2.

4. A temporal problem: the declining trend in witness reports

A further, independent line of evidence bears on the plausibility of the natural-battery hypothesis: the long-term trend in reported Hessdalen light sightings. Figure 2 shows witness reports per year from 1996 to 2021, compiled by the author from case reports listed on the official Hessdalen phenomenon website and originally presented to the Galileo Project in 2021 (Teodorani, unpublished presentation, 2021), with a smoothed trend line. The record shows a clear decline — from double-digit annual counts in the mid-to-late 1990s to consistently low single-digit counts by the 2010s and early 2020s, with a local minimum near zero around 2011–2012.

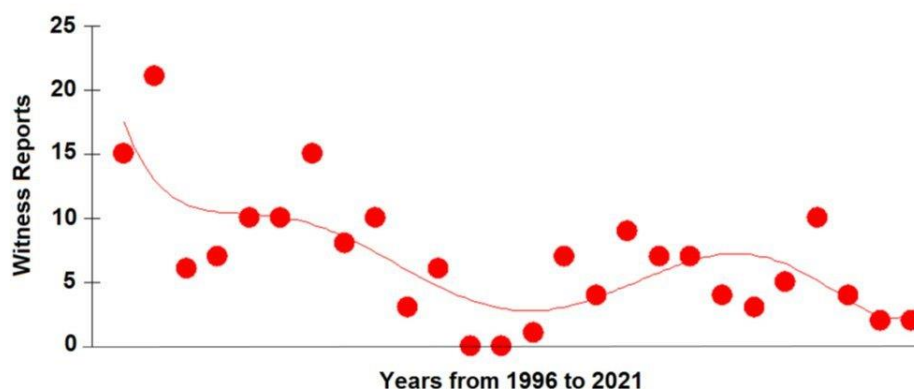


Figure 2. Annual witness reports of the Hessdalen luminous phenomenon, 1996–2021, in the radius of 0.1-5 Km, with a smoothed trend line. Case counts compiled by the author from reports listed on the official Hessdalen phenomenon website; originally presented to the Galileo Project, 2021 (unpublished).

This trend is not predicted by, and is arguably in tension with, the natural-battery hypothesis. The geological structures invoked by Monari et al. (2013) — sulfide and oxide mineral bodies, and the redox chemistry that drives a geobattery — change on weathering and diagenetic timescales of

thousands to millions of years. Over a 25-year observation window, the ore bodies' composition, their contact geometry, and the resulting thermodynamic driving potential should be, to first approximation, *constant*. Groundwater level and seasonal recharge could modulate current flow somewhat, but there is no proposed mechanism by which a static geological energy source would produce a multi-decade secular decline of the kind shown in Figure 2. If the natural battery were the principal driver of the phenomenon, a stationary or fluctuating-but-non-trending frequency of sightings would be the more natural expectation.

We note, in fairness, that a declining number of witness reports is also consistent with non-geophysical factors having little or nothing to do with the phenomenon's true occurrence rate: reduced media attention following the initial wave of interest in the late 1990s, fewer active field investigators and monitoring campaigns in later years, changes in reporting infrastructure, or a shrinking and ageing local population resulting in fewer regular observers. Against these factors, however, one should also consider the likely countervailing effect of the steady increase in tourism in the valley over the past decade, which has potentially expanded the pool of visitors who might serve as witnesses.

In any fact, I do not claim that the decline in Figure 2 demonstrates a corresponding decline in the physical occurrence rate of the phenomenon. Rather, the observation constitutes a consistency problem for the natural-battery hypothesis: if the geological source is effectively static on the timescale considered here, the model provides no obvious reason for the number of reported events to exhibit a persistent multi-decade decline. Proponents of the hypothesis have not, to our knowledge, addressed this issue quantitatively. At minimum, the burden falls on the hypothesis either to show that reporting effort remained sufficiently stable over the period for the trend to contain information about the underlying phenomenon rate, or to provide a mechanism by which a substantially stationary geological source could produce such a temporal pattern in observations.

5. A ubiquity problem

Redox-contrasted sulfide/oxide mineralisation of the kind invoked at Hessdalen is not rare. It is the physical basis of the self-potential exploration method used routinely in mining districts worldwide — Broken Hill, the Iberian Pyrite Belt, the Bathurst camp, and thousands of smaller prospects all host geobatteries of comparable or larger magnitude to whatever may exist at Hessdalen. If a sub-volt-scale geobattery were sufficient to generate recurring atmospheric luminous phenomena, we would expect luminous phenomena to be common wherever such ore bodies occur near the surface. They are not. This asymmetry — a proposed cause that is geologically common, paired with an effect that is extraordinarily rare — is itself evidence against sufficiency, independent of the field-strength argument above.

6. Even if granted, what does it actually explain?

A final point, made in a spirit of fairness rather than additional attack: even if one were to accept, for the sake of argument, that some unspecified amplification mechanism closes the six-order-of-magnitude gap described in Sections 3, 3.1, 3.2 and 3.3, the natural-battery hypothesis would still only address the question of energy source or triggering condition. Drawing on the original instrumented field campaign (Strand, 1984) and the long-term systematic photographic and visual survey reported

in Teodorani (2004) — together the most extensive characterisation of the phenomenon's observed properties — it says nothing about:

- why the resulting phenomenon takes the form of a discrete, bounded, mobile light rather than a diffuse glow or a conventional spark/arc;
- the reported colours and their variability;
- durations from seconds to roughly an hour, and the physical mechanism sustaining a luminous body over that timescale without a continuously replenished energy input at breakdown-field intensity; or
- the apparent horizontal mobility of the lights across the sky, which a static ground-based charge accumulation does not naturally produce.

A charge source, even a sufficient one, is not a theory of ball-lightning-like luminosity. Confusing the two — presenting a (quantitatively unsupported) triggering hypothesis as if it were a complete physical explanation of the phenomenon's morphology — is the central overreach we wish to flag, independent of the magnitude problem above.

7. Conclusion

The natural-battery idea is a reasonable and logically coherent starting hypothesis, consistent with the known geology of Hessdalen valley, and we do not dispute that geobatteries of the kind described genuinely exist there in some form. Our objection is quantitative and definitional, not dismissive: (a) the electromotive force such a system can plausibly generate falls short of what is needed to ionise air by roughly six orders of magnitude, with no proposed mechanism to close that gap, and this shortfall persists even under the most favourable reading of the one directly reported field measurement (Section 3.2); (b) comparable geobatteries are common in mineralised terrain worldwide without any associated luminous phenomena, which argues against sufficiency; (c) even a successful charge-generation mechanism would explain, at most, a triggering condition — not the luminosity, morphology, colour, duration, or mobility of the reported lights; (d) the observed multi-decade decline in witness reports (Section 4) is not obviously predicted by a hypothesis grounded in an essentially static geological energy source, and has not, to our knowledge, been addressed quantitatively by proponents of the hypothesis; and (e) the one natural mechanism with genuine laboratory and observational support for rock-to-air charge transfer — stress-activated positive-hole currents (Section 3.3) — has already been evaluated and excluded for Hessdalen on seismological grounds by Vargemezis et al. (2024), leaving the comparatively weaker natural-battery mechanism with no empirically supported pathway to the required field strengths. After more than a decade of public presentation — including national television and popular science coverage — as a practically definitive explanation, without peer-reviewed publication or independent quantitative verification, I believe the hypothesis should be explicitly reframed as speculative and provisional, pending (i) direct field measurement of achievable currents and potentials in situ, (ii) a stated mechanism for local field concentration by several orders of magnitude, (iii) a separate, physically grounded account of light-ball formation and persistence, and (iv) an account of the declining long-term sighting trend consistent with a static-source model.

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