PAPER CHECK · SUBDUCTION AND THE DEEP EARTH

One rock went down warm, then cold: a refinement of subduction science, not its overthrow

A team led by the University of Göttingen found inclusions of coesite about 1 to 4 µm across, one imaged at about 0.8 µm [1 §2][1 Fig. 2b], in the garnets of one eclogite from Goodenough Island, Papua New Guinea, and dated its descent to between about 5.1 and 4.4 million years ago [1 §4]. The rock went down warm, about 470 °C per gigapascal to a depth of about 45 km, then cold and fast to beyond 90 km, and the authors propose that such warm shallow paths "might be common", "challenging the use of peak metamorphic conditions as indicator for subduction zone thermal structures" [1 Abstract][1 §5]. SO News said a "tiny freckle on a micro crystal" had beaten "a century of science" and "your entire concept of rock solid subduction, temperature by depth" [2 00:02:07-00:02:21]. The rock's deep conditions agree with the models of mature subduction zones [1 §5], and the shallow mismatch it documents is an old one, put in global numbers in 2015 [4 §3.4][5].

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OUR ANALYSIS marks our own reasoning and calculations, and the verdicts are our assessment. Everything else comes from the numbered sources; for the paper [1], § gives one of its five main-text sections, Fig. a figure or panel, ED Fig. an extended-data figure and Methods its methods section.

A real finding about one rock, inflated into the fall of subduction science

OUR ASSESSMENT

~0.8 µm
the coesite inclusion imaged in the paper's Fig. 2b, in the middle growth zone of a garnet; the press release calls it "a bit smaller than 1 µm" [1 Fig. 2b][3 garnet caption]

700 °C at ~45 km
the garnet core's conditions, 1.5 ± 0.2 GPa and 700 ± 20 °C: warmer than thermal models of mature subduction zones predict at that depth [1 §3][1 §5]

4.4 Ma
million years ago, the age of the rock's ultrahigh-pressure stage by 17 zircon dates, "among Earth's youngest coesite eclogites" [1 §4]

THE CLAIMS

OVERSTATED
Speek beats a century of science
The presenter: "Could you imagine a century of science, the world's best, billions and grant money, and your entire concept of rock solid subduction, temperature by depth, gets beat like they're the Miami Dolphins by a tiny freckle on a micro crystal." [2 00:02:07-00:02:21]

The rock's deep conditions "agree with model predictions of the thermal structure of mature, modern-style subduction zones"; only its shallow stage is warmer, and the authors explain that by shear heating or a young subduction zone, "both being an inherent feature of all subduction systems" [1 §5]. What they challenge is reading a whole path from the peak point alone [1 Abstract]: Shear heating has been invoked for subduction zones hotter than expected since at least 1978, and a 2015 compilation found exhumed rocks 100–200 °C warmer on average than the models [4 §3.4][5]. The modern subduction concept dates from 1968 [11], and this is one sample [1 §2]. See sections 4 and 5.

OVERSTATED
No idea what's beneath our feet
The presenter: "They really don't know what's going on beneath our feet any more than they do in the vastness of space." [2 00:02:24-00:02:30]

The finding was made with settled knowledge: at this rock's temperatures coesite forms only above 2.7–3.0 GPa [1 §3], zircon can be dated by uranium–lead decay [1 §4], and the rock's peak conditions landed where the models of mature subduction zones put them [1 §5]. The paper names its open questions, the size of shear heating and the thermal state of young subduction zones [1 §5], and cites a 2024 paper titled "We don't know when plate tectonics began" for the debate on when plates began [1 §1][14]. Open questions at the edge are not ignorance of the whole. See section 4.

TRUE
One-micrometre coesite speck
The presenter: "We are going down to one micrometer. That's the size of many bacteria. That's way smaller than a red blood cell." [2 00:01:52-00:02:02]

The imaged coesite inclusion is "~0.8-µm sized", and the single-mineral coesite inclusions range from about 4 to 1 µm [1 Fig. 2b][1 §2]. An *E. coli* cell is 1.26 µm wide and 1.6–3.9 µm long [15]; a red blood cell is about 7–8 µm across [16]. See section 2.

CONTEXT
Hard to be a scientist today
The presenter: "Oof. Hard to be a scientist these days." [2 00:02:21-00:02:24]

An aside. The authors chose the region because it is "ideally suited to test such assumptions", tested one and reported the result [1 §1]; the journal's named reviewers include the first author of the 2015 compilation subtitled "Rocks are hotter than models" [1 Peer review][5]. Testing an assumption, and reporting where it fails, is the job. See section 6.

TRUE
Warm, then cold: one rock's path
The paper: "the prograde subduction path was initially warm with an apparent average gradient of approximately 470 °C GPa^{-1} until a depth of about 45 km, before switching to a cold thermal regime with ultrafast subduction rates of greater than 60 mm yr^{-1} (vertical component)" [1 Abstract]

Quartz-only garnet cores and coesite-bearing garnet mantles, melt inclusions, zirconium-in-rutile thermometry and 17 zircon dates support the path, and the arithmetic checks out [1 §3][1 §4]. The caveats, mostly the authors' own: one lens [1 §2]; a core pressure estimated from the garnet's composition, under an upper limit of 2.5 GPa from its melt inclusion, and only a lower bound for the mantle [1 §3]; lithostatic depths; and ages tied to garnet zones by trace elements [1 §4]. See section 3.

PARTLY TRUE
Contradicts the thermal models
Jan Schönig., in the University of Göttingen's press release: "Finding this change from hot to cold subduction was unexpected as this contradicts our current thermal models of subduction zones." [3 §1]

True of the steady-state models of mature subduction zones: the core sits "clearly offset to higher temperatures" from them [1 §5][3 Fig. 5a], and models with shear heating stay, in the paper's words, "still lower than those observed" [1 Fig. 5b]. But a time-dependent model of a young subduction zone, by co-author Holt and Condit, gives paths with "strong similarities" to the rock's [3 Fig. 5c][8], and the paper words its challenge more narrowly, as one to the use of peak conditions [1 Abstract]. See section 6.

1 · THE PAPER

One eclogite from Goodenough Island, read inclusion by inclusion

Eight authors from Göttingen, Cagliari, Potsdam, Graz, Perth, Syracuse and Miami studied a single partially retrogressed eclogite from the D'Entrecasteaux Islands of eastern Papua New Guinea, the youngest place on Earth where ultrahigh-pressure rocks are known to be coming back to the surface [1 §1][1 Author information]. The paper is a peer-reviewed article in *Nature Geoscience*, published on October 1, 2026, open access under CC BY 4.0 [1]. Its question is whether a rock that reached the depths of coesite, more than 90 km down, got there along a cold path, as the field assumes from such rocks' peak conditions: "direct evidence for such a cold prograde evolution is lacking" [1 Abstract].

STEP 1
Sampling
Sample 03118b is "a small lens (~90 cm × 30 cm) of mafic bulk rock composition hosted by felsic gneiss" at eastern Talába Bay on southern Goodenough Island (9° 28′ 55.84″ S, 150° 14′ 46.99″ E), collected by co-author Suzanne Baldwin [1 §2][1 Contributions]. It is a retrogressed eclogite: about 38% garnet and 22% quartz, with omphacitic clinopyroxene, plagioclase, amphibole, rutile and minor phases [1 §2].

STEP 2
Looking inside garnet
Raman spectroscopy mapped the inclusions in the garnets at steps of 0.20 µm with a 100× objective [1 Methods]; Quartz, rutile, zircon, apatite and crystallized melt droplets occur in all three growth zones of the garnets; coesite only in the middle zone, the mantle; omphacite and titanite only in the core [1 §2].

STEP 3
Pressure and temperature
Coesite in the mantle but only quartz in the core means the core grew below, and the mantle above, "the quartz-to-coesite transition located at 2.7–3.0 GPa" [1 §3]. A melt inclusion from the core re-homogenized to glass at 750 °C and 2.5 GPa, an upper limit for the core's pressure; zirconium in rutile gave temperatures for both zones, and the garnet's composition fixed the core's pressure: 1.5 ± 0.2 GPa and 700 ± 20 °C for the core, above 2.9 GPa and 800 ± 25 °C for the mantle [1 §3][1 Fig. 3].

STEP 4
Dating
Zircon occurs only as micrometre-sized inclusions in garnet, freed by dissolving the host; 26 of the largest grains, about 10 µm across, were dated by ion microprobe and 17 kept, after excluding eight with too little radiogenic lead and one probably foreign grain at 362 million years [1 §4][1 Methods]. They span 5.1 ± 0.2 to 3.1 ± 0.1 million years ago, and their trace elements tie the 5.1–4.4 interval to the climb from ≤1.5 to >2.9 GPa, "corresponding to vertical rates of >60 mm yr^{-1} assuming lithostatic pressure" [1 §4].

ZIRCON GRAINS DATED
17 of 26
eight excluded for radiogenic lead below 90%, and one grain of 362 ± 6 million years, "probably xenocrystic"; uncertainties are two standard errors [1 Methods]

THE DESCENT
5.1 → 4.4 Ma
million years ago: from garnet-core growth at ≤1.5 GPa to the ultrahigh-pressure stage at >2.9 GPa, by the zircons' heavy rare earths [1 §4]

VERTICAL RATE
>60 mm/yr
"ultrafast" in the paper's words: the vertical component of the descent, assuming lithostatic pressure [1 Abstract][1 §4]

In the authors' words
UHP is ultrahigh pressure; HP high pressure; T/P the ratio of temperature to pressure, a geothermal gradient; GPa a gigapascal, the pressure under about 30 km of rock.

> *"This assumption stems from peak metamorphic conditions of ultrahigh-pressure rocks, which indicate low subduction gradients of less than 330 °C GPa^{-1}, but direct evidence for such a cold prograde evolution is lacking."*
>
> Schönig et al. (2026) [1 Abstract]

> *"Our most recent example of HP and UHP rock formation and exhumation occurs in eastern Papua New Guinea, making the region ideally suited to test such assumptions."*
>
> Schönig et al. (2026) [1 §1]

> *"The age of about 4.4 Ma for the UHP stage is considerably younger than the about 7.1 Ma UHP stage for the coesite eclogite at Tumagabuna Island, making it among Earth's youngest coesite eclogites."*
>
> Schönig et al. (2026) [1 §4], on the earlier find at Tumagabuna Island [9]

What the paper says it challenges, in full
The abstract ends: "We propose that high geothermal gradients at shallow levels of deep subduction systems might be common, challenging the use of peak metamorphic conditions as indicator for subduction zone thermal structures." [1 Abstract] The introduction puts it as a caution: the authors "caution that peak metamorphic conditions alone may be insufficient to deduce the prograde evolution and geodynamic setting of UHP rock formation" [1 §1]. And the conclusion: the identification of UHP metamorphism "is not unequivocal evidence that subduction was exclusively cold and evolved at a thermal steady state" [1 §5]. The target is an inference, reading a rock's whole descent from its deepest point; not subduction, and not the models of its deep thermal structure, with which the rock agrees (section 4).

2 · THE SPECK

A micrometre of coesite, and how it was found

The presenter opened with the scale bar: "Folks, can you see those scales there? We are going down to one micrometer. That's the size of many bacteria. That's way smaller than a red blood cell." [2 00:01:49-00:02:02] That part is right. The paper's Fig. 2b shows "an ~0.8-µm sized monomineralic coesite below the polished surface" of a garnet, and the press release's caption calls the inclusion "a bit smaller than 1 µm – approximately one hundredth the size of the thickness of a human hair" [1 Fig. 2b][3 garnet caption].

THE IMAGED COESITE
~0.8 µm
single-mineral coesite inclusions are about 4 to 1 µm; two-mineral coesite-and-quartz inclusions about 5 µm [1 Fig. 2b][1 §2]

AN *E. COLI* CELL
1.26 µm
wide, in every growth condition measured (± 0.16 µm), and 1.6 to 3.9 µm long depending on how fast the cells grow [15]

A RED BLOOD CELL
7–8 µm
"quite small cells, with a mean diameter of only about 7–8 micrometers", a standard textbook value [16]

How a speck that small is found
The presenter skipped "the obvious question of how these guys even spotted this tiny little speck" [2 00:02:00-00:02:07]. The Methods answer it. A Raman spectrometer with a 532-nm laser and a 100× objective scanned the garnets point by point, "a step size of 0.20 µm × 0.20 µm (Fig. 2b)" with one second per spectrum, to map inclusions sitting below the polished surface [1 Methods]. Coesite has its own Raman spectrum, shown beside the image [1 Fig. 2e]. The team knew where to look: co-authors had already found coesite inclusions in garnet from the beach placer beside the sample site, in 2021 [10 Abstract][1 §1].

OUR ANALYSIS
Why a speck can carry a result
Coesite is a form of silica that, at this rock's temperatures, forms only at pressures above the quartz-to-coesite transition, 2.7–3.0 GPa [1 §1], which is why the paper calls it "Unequivocal evidence for UHP metamorphism" [1 §1]. Sealed inside a garnet, a grain of it tends to survive the trip back up when it is small: the paper reads the larger size of the two-mineral coesite-and-quartz inclusions, about 5 µm, against 4 to 1 µm for the all-coesite ones, as agreeing "with the hypothesis that inclusion size is an important factor for coesite preservation" [1 §2]. So smallness is not a weakness of the evidence but a condition of its survival. What the paper adds to the speck is where it sits: in the garnet's middle zone, with quartz-only cores inside it, which turns a single pressure marker into a sequence [1 §3].

3 · THE PATH

Warm to about 45 km, then cold and fast to beyond 90 km

Put the two garnet zones on a pressure–temperature diagram and the shape of the descent appears: the core formed at about 700 °C and 1.5 GPa, warmer than thermal models of mature subduction zones allow at that depth; the mantle formed at about 800 °C above 2.9 GPa, where those models put it [1 §3][1 §5]. The chart is adapted from the paper's Figs. 3 and 5a, from the numbers in its text.

The rock's pressure–temperature path beside the models

Temperature in degrees Celsius; pressure in gigapascals, with the paper's depths for lithostatic pressure

~470 °C/GPa
the apparent average gradient of the shallow path, to about 1.5 GPa [1 Abstract][1§ 5]

~280 °C/GPa
the gradient "implied by the peak conditions alone" [1 §5]

<300 °C/GPa
"typical" gradients in models of "mature, modern-style subduction zones" [1 §5]

<400 °C/GPa
"even the warmest subduction zones (Mexico and Cascadia)" in those models [1 §5]

Adapted from Fig. 3 and Fig. 5a of [1]. CC BY 4.0, and drawn from the numbers in its text rather than traced: the garnet cores at 1.5 ± 0.2 GPa and 700 ± 20 °C, the garnet mantle above 2.9 GPa at 800 ± 25 °C, the quartz-to-coesite transition at 2.7–3.0 GPa, the apparent shallow gradient of about 470 °C GPa^{-1} and the peak-only gradient of about 280 [1 §3][1 §5]. The transition is the paper's range; at this rock's temperatures, drawn flat across the chart, in the paper's Fig. 3 the boundary rises slightly with temperature [1 Fig. 3]. The gray wedges stand for the paper's summary of thermal models of mature, modern-style subduction zones, "typical temperature–pressure (T/P) gradients <300 °C GPa^{-1}" with the warmest, Mexico and Cascadia, "<400 °C GPa^{-1}" [1 §1]; they are drawn as straight lines of constant gradient, where the paper's Fig. 5a shows the models as curved paths that warm sharply near 2.5 GPa. The mantle's shape is open at the top because its pressure is a minimum, and the dates come from the zircons [1 §4]. Depths are the paper's [1 Abstract][1 §5].

OUR ANALYSIS
The arithmetic, and what the numbers rest on
The paper's gradients follow from its two points: 700 °C over 1.5 GPa is 467 °C per gigapascal, the "~470" of the text, and 800 °C over 2.9 GPa is 276, its "~280" [1 §3][1 §5]. For a rock density of 3,300 kg/m^3 (under lithostatic pressure, 1.5 GPa is about 46 km and 2.9 GPa about 90 km, the paper's "about 45 km" and "depths >90 km" [1 Abstract][1 §5]). The climb from 1.5 to 2.9 GPa, about 43 km, took 0.7 million years (zircon ages of 5.1 and 4.4 Ma): about 62 mm per year, the paper's ">60 mm yr^{-1}" [1 §4]. Everything checks.

The limits are the authors' own. The melt-inclusion experiment, run at 750 °C and 2.5 GPa, gives only an upper limit for the core's pressure: "the pressure represents a maximum value". The core's best estimate of 1.5 ± 0.2 GPa comes from where the garnet's composition isopleths cross the core's temperatures [1 §3]. The mantle's pressure is only a lower bound, because the isopleths "do not enable conditions of garnet mantle formation to be determined" above 1.8 GPa, and the solidus's location "is uncertain at pressures >1.8 GPa" [1 §3]. The paper calls the gradient an "apparent average" [1 Abstract]. The depths and the rate assume lithostatic pressure [1 §4]. The zircons were dated as separates, so their ages are tied to the garnet zones by their trace elements, "with reasonable certainty" [1 §4]. None of this undoes the sequence, which rests on the simplest observation in the paper: quartz only in the cores, coesite in the mantles [1 §3].

4 · NEW AND STANDING

What is new, and what stands

The paper joins a long-running debate, and cites it: subduction-related rocks "often record warmer conditions than models predict" [1 §5], a mismatch argued over for decades and put in global numbers in 2015 (section 5). What it brings is a rock that holds both a warm shallow stage and a cold deep stage, with dates.

New
A direct record of the shallow part of an ultrahigh-pressure rock's descent, where "mineralogical evidence clearly ascribed to the prograde path is generally lacking" [1 §1]. A change of gradient inside one rock, warm then cold, rather than a single peak point; the paper reads the same shape in prograde paths reported from two older ultrahigh-pressure terranes, Sanbagawa and Dabie–Sulu [1 §5][1 Fig. 5a]. One of the youngest coesite eclogites known, at about 4.4 million years, with zircon ages that time its descent between the two stages [1 §4]. The press release's own placing of the novelty: "Rocks that record higher temperature conditions than expected have been reported before, but this is the first time a journey from a shallow to a deep depth with an accompanied change to relatively colder gradients has been shown so clearly." [3 §3]

Standing
Subduction itself: the paper's setting is "the subduction of a rifted continental fragment of Australian provenance" [1 §1], and it notes that the Pacific and Australian plates converge obliquely today "at a rate of ~ 110 mm yr^{-1}", above the 100 mm per year beyond which, it says, temperatures "might have been even higher" with shear heating [1 §5]. The deep thermal structure: the mantle's conditions "agree with model predictions of the thermal structure of mature, modern-style subduction zones" [1 §5]. Coesite as a depth marker and zircon as a clock, the tools of the result [1 §3][1 §4]. And the two explanations the authors offer are not new physics but mechanisms "both being an inherent feature of all subduction systems" [1 §5]; both were already weighed in 1992 [18 Abstract].

The debate the paper joins
Three statements of the same mismatch, from 2018 and 2023.

> *"Some commonly referenced thermal-mechanical models of current subduction zones imply temperatures that are 100-500 °C colder at 30-80 km depth than pressure-temperature conditions determined thermobarometrically from exhumed metamorphic rocks."*
>
> Kohn et al. (2018), whose title says shear heating "reconciles" them [6 Abstract]

> *"Compilations of the maximum pressure-temperature conditions in exhumed rocks indicate significantly warmer conditions than those predicted by thermal models. This could be due to preferential exhumation of rocks from hotter conditions … Alternatively, the models might underestimate the forearc temperatures by neglecting certain heat sources."*
>
> van Keken et al. (2018) [7 Abstract]

> *"The lawsonite eclogite data and a significant proportion of the blueschist data fall within the range of global models, but the near-steady-state models cannot explain the warmest exhumed rock data."*
>
> van Keken and Wilson (2023), the review the paper takes its model gradients from [4 §3.4]

Explanation 1: friction on the plate boundary
Shear heating: rock sliding past rock at the plate interface dissipates energy as heat. The paper notes that "it has been argued that thermal models of mature subduction zones incorrectly neglect such important heat sources" [1 §5]: Kohn and colleagues found that forearc heat flow needs "An additional heat source—likely shear heating", and that "Adding such shear stresses to thermal models quantitatively reproduces the pressure–temperature conditions recorded by exhumed metamorphic rocks" [6 Abstract]. Others find that "reasonable amounts of shear heating" warm the oceanic crust by "less than 50 °C", an effect "rather skin deep", and infer that typical exhumed blueschists and eclogites come from warm settings, young oceanic plates or "the warmer initial stages of subduction" [7 Abstract][4 §3.4]. In the paper's Fig. 5b, the thermal structure with shear heating "more closely resembles the shape of the observed P-T path, but modelled temperatures are still lower than those observed"; they "might have been even higher" if convergence exceeded 100 mm per year, friction was unexpectedly high or the sinking plate was young [1 §5][1 Fig. 5b].

Explanation 2: a subduction zone still young
Thermal models of mature subduction zones describe a steady state. A time-dependent model by co-author Holt and Condit finds that pressure–temperature conditions on the slab "exhibit substantial variability throughout the various phases of subduction: initiation, free sinking, and mature subduction" [8 Abstract]. In the paper's Fig. 5c the observed path has "strong similarities to the numerically predicted paths for rocks entering the subduction zone ~ 5–12 Myr after subduction initiation", and the rate of over 60 mm per year fits rocks entering 8–13 million years after it [1 §5][1 ED Fig. 4]. The authors note small differences, "the observed path is slightly steeper and the modelled timescale somewhat longer", which they expect from an "idealized, non-site-specific" model [1 §5]. The idea is not new either: in 1992 Peacock allowed for blueschist terrains that "represent material metamorphosed during the early stages of subduction (first 5–10 m.y.) while the thermal structure is still evolving" [18 Abstract].

OUR ANALYSIS
Which explanation? The paper does not choose, and does not need to
The authors call the two "reasonable and non-mutually exclusive mechanisms" and leave "quantifying the relative contributions of the two mechanisms" outside the study [1 §5]; other work disputes how much heat friction can deliver to the slab's crust [7 Abstract][4 §3.4]. Either way, the shallow warmth has an explanation in known physics, which is the opposite of the episode's picture. What the paper does change is a habit of inference: a cold peak point no longer proves a cold path, so "considering T/P gradients of peak metamorphic conditions for reconstructing Earth's geodynamic evolution might be misleading" [1 §5]. That matters for arguments about when modern, cold subduction began on Earth, which lean on such gradients [1 §5]; it does not question that plates subduct today, and at depth this rock agrees with the models.

5 · A CENTURY?

"A century of science": a 58-year-old idea and a decades-old debate

The presenter counted "a century of science, the world's best, billions and grant money" on the losing side [2 00:02:07-00:02:12]. In the dated record, from the sources we could resolve, the subduction concept and its thermal models are younger than a century, the observations behind them a little older, and the mismatch this paper adds to has been argued over for decades.

The years behind the claim

YEAR	WHAT HAPPENED	SOURCE
1928–35	Kiyoo Wadati shows earthquakes deeper than 300 km beneath central Honshu in 1928, and in 1935 draws "lines representing equal focal depths of the intermediate and deep earthquakes, which would later be called the Wadati-Benioff zone"	[20]
1968	"Seismology and the new global tectonics", by Isacks, Oliver and Sykes, in the *Journal of Geophysical Research*: the plate-tectonics revolution in which the modern concept of subduction was framed	[11]
1970–71	Early thermal models of a descending slab: Minear and Toksöz's "Thermal regime of a downgoing slab and new global tectonics" and Oxburgh and Turcotte's "Thermal Structure of Island Arcs" in 1970, and "Temperature field and geophysical effects of a downgoing slab" in 1971	[19][12], [13]
1978	Shear heating is proposed as the cause of arc volcanoes, an early case of what the 2023 review calls "a long-time favorite ad hoc explanation" for subduction zones hotter than expected; arc volcanoes are now explained by the hot mantle wedge and fluids from the slab	[4 §3.4]
1990	Molnar and England, "Temperatures, heat flux, and frictional stress near major thrust faults": the paper's source for shear heating along the plate interface	[17][1 §5]
1992	Peacock sets the temperatures of blueschists against model paths with and without shear heating: without it, the paths are "very cold"; with low stresses, the rocks could come from "the early stages of subduction"	[18 Abstract]
1996–2009	Global databases of rocks exhumed from oceanic subduction zones are compiled, later set against the models' predicted temperatures	[4 §3.4]
2008	A coesite eclogite at Tumagabuna Island, Papua New Guinea, later dated to an ultrahigh-pressure stage of about 7.1 million years ago	[9][1 §4]
2015	A global compilation of exhumed blueschists and eclogites, subtitled "Rocks are hotter than models": on average, the rock record is 100–200 °C warmer below the forearc than the models predict	[5][4 §3.4]
2018	Forearc heat flow is found to need "An additional heat source—likely shear heating"; a second study finds that reasonable shear heating adds "less than 50 °C" and infers that exhumed rocks come preferentially from warm settings, young plates or the first stages of subduction	[6 Abstract][7 Abstract]
2021	Time-dependent models show slab conditions varying through "initiation, free sinking, and mature subduction"; coesite is found in garnet sand on the beach beside this paper's sample site	[8 Abstract][10 Abstract]
2023	The review the paper draws its model gradients from finds that "the near-steady-state models cannot explain the warmest exhumed rock data"	[4 §3.4]
2026	This paper: one rock with a warm shallow stage and a cold deep stage, dated, and a proposal that such paths "might be common"	[1 Abstract]

For the papers of 1968–71 we read titles and records only: [11], [12], [13] and [19]. For those of 1990 and 1992 we read the abstracts as deposited with Crossref [17][18]. The 2015 paper is cited by its title [5], and the 1978 work as the 2023 review describes it [4 §3.4].

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Standing
Subduction itself: the paper's setting is "the subduction of a rifted continental fragment of Australian provenance" [1 §1], and it notes that the Pacific and Australian plates converge obliquely today "at a rate of ~ 110 mm yr^{-1}", above the 100 mm per year beyond which, it says, temperatures "might have been even higher" with shear heating [1 §5]. The deep thermal structure: the mantle's conditions "agree with model predictions of the thermal structure of mature, modern-style subduction zones" [1 §5]. Coesite as a depth marker and zircon as a clock, the tools of the result [1 §3][1 §4]. And the two explanations the authors offer are not new physics but mechanisms "both being an inherent feature of all subduction systems" [1 §5]; both were already weighed in 1992 [18 Abstract].

The debate the paper joins
Three statements of the same mismatch, from 2018 and 2023.

> *"Some commonly referenced thermal-mechanical models of current subduction zones imply temperatures that are 100-500 °C colder at 30-80 km depth than pressure-temperature conditions determined thermobarometrically from exhumed metamorphic rocks."*
>
> Kohn et al. (2018), whose title says shear heating "reconciles" them [6 Abstract]

> *"Compilations of the maximum pressure-temperature conditions in exhumed rocks indicate significantly warmer conditions than those predicted by thermal models. This could be due to preferential exhumation of rocks from hotter conditions … Alternatively, the models might underestimate the forearc temperatures by neglecting certain heat sources."*
>
> van Keken et al. (2018) [7 Abstract]

> *"The lawsonite eclogite data and a significant proportion of the blueschist data fall within the range of global models, but the near-steady-state models cannot explain the warmest exhumed rock data."*
>
> van Keken and Wilson (2023), the review the paper takes its model gradients from [4 §3.4]

Explanation 1: friction on the plate boundary
Shear heating: rock sliding past rock at the plate interface dissipates energy as heat. The paper notes that "it has been argued that thermal models of mature subduction zones incorrectly neglect such important heat sources" [1 §5]: Kohn and colleagues found that forearc heat flow needs "An additional heat source—likely shear heating", and that "Adding such shear stresses to thermal models quantitatively reproduces the pressure–temperature conditions recorded by exhumed metamorphic rocks" [6 Abstract]. Others find that "reasonable amounts of shear heating" warm the oceanic crust by "less than 50 °C", an effect "rather skin deep", and infer that typical exhumed blueschists and eclogites come from warm settings, young oceanic plates or "the warmer initial stages of subduction" [7 Abstract][4 §3.4]. In the paper's Fig. 5b, the thermal structure with shear heating "more closely resembles the shape of the observed P-T path, but modelled temperatures are still lower than those observed"; they "might have been even higher" if convergence exceeded 100 mm per year, friction was unexpectedly high or the sinking plate was young [1 §5][1 Fig. 5b].

Explanation 2: a subduction zone still young
Thermal models of mature subduction zones describe a steady state. A time-dependent model by co-author Holt and Condit finds that pressure–temperature conditions on the slab "exhibit substantial variability throughout the various phases of subduction: initiation, free sinking, and mature subduction" [8 Abstract]. In the paper's Fig. 5c the observed path has "strong similarities to the numerically predicted paths for rocks entering the subduction zone ~ 5–12 Myr after subduction initiation", and the rate of over 60 mm per year fits rocks entering 8–13 million years after it [1 §5][1 ED Fig. 4]. The authors note small differences, "the observed path is slightly steeper and the modelled timescale somewhat longer", which they expect from an "idealized, non-site-specific" model [1 §5]. The idea is not new either: in 1992 Peacock allowed for blueschist terrains that "represent material metamorphosed during the early stages of subduction (first 5–10 m.y.) while the thermal structure is still evolving" [18 Abstract].

OUR ANALYSIS
Which explanation? The paper does not choose, and does not need to
The authors call the two "reasonable and non-mutually exclusive mechanisms" and leave "quantifying the relative contributions of the two mechanisms" outside the study [1 §5]; other work disputes how much heat friction can deliver to the slab's crust [7 Abstract][4 §3.4]. Either way, the shallow warmth has an explanation in known physics, which is the opposite of the episode's picture. What the paper does change is a habit of inference: a cold peak point no longer proves a cold path, so "considering T/P gradients of peak metamorphic conditions for reconstructing Earth's geodynamic evolution might be misleading" [1 §5]. That matters for arguments about when modern, cold subduction began on Earth, which lean on such gradients [1 §5]; it does not question that plates subduct today, and at depth this rock agrees with the models.

5 · A CENTURY?

"A century of science": a 58-year-old idea and a decades-old debate

The presenter counted "a century of science, the world's best, billions and grant money" on the losing side [2 00:02:07-00:02:12]. In the dated record, from the sources we could resolve, the subduction concept and its thermal models are younger than a century, the observations behind them a little older, and the mismatch this paper adds to has been argued over for decades.

The years behind the claim

YEAR	WHAT HAPPENED	SOURCE
1928–35	Kiyoo Wadati shows earthquakes deeper than 300 km beneath central Honshu in 1928, and in 1935 draws "lines representing equal focal depths of the intermediate and deep earthquakes, which would later be called the Wadati-Benioff zone"	[20]
1968	"Seismology and the new global tectonics", by Isacks, Oliver and Sykes, in the *Journal of Geophysical Research*: the plate-tectonics revolution in which the modern concept of subduction was framed	[11]
1970–71	Early thermal models of a descending slab: Minear and Toksöz's "Thermal regime of a downgoing slab and new global tectonics" and Oxburgh and Turcotte's "Thermal Structure of Island Arcs" in 1970, and "Temperature field and geophysical effects of a downgoing slab" in 1971	[19][12], [13]
1978	Shear heating is proposed as the cause of arc volcanoes, an early case of what the 2023 review calls "a long-time favorite ad hoc explanation" for subduction zones hotter than expected; arc volcanoes are now explained by the hot mantle wedge and fluids from the slab	[4 §3.4]
1990	Molnar and England, "Temperatures, heat flux, and frictional stress near major thrust faults": the paper's source for shear heating along the plate interface	[17][1 §5]
1992	Peacock sets the temperatures of blueschists against model paths with and without shear heating: without it, the paths are "very cold"; with low stresses, the rocks could come from "the early stages of subduction"	[18 Abstract]
1996–2009	Global databases of rocks exhumed from oceanic subduction zones are compiled, later set against the models' predicted temperatures	[4 §3.4]
2008	A coesite eclogite at Tumagabuna Island, Papua New Guinea, later dated to an ultrahigh-pressure stage of about 7.1 million years ago	[9][1 §4]
2015	A global compilation of exhumed blueschists and eclogites, subtitled "Rocks are hotter than models": on average, the rock record is 100–200 °C warmer below the forearc than the models predict	[5][4 §3.4]
2018	Forearc heat flow is found to need "An additional heat source—likely shear heating"; a second study finds that reasonable shear heating adds "less than 50 °C" and infers that exhumed rocks come preferentially from warm settings, young plates or the first stages of subduction	[6 Abstract][7 Abstract]
2021	Time-dependent models show slab conditions varying through "initiation, free sinking, and mature subduction"; coesite is found in garnet sand on the beach beside this paper's sample site	[8 Abstract][10 Abstract]
2023	The review the paper draws its model gradients from finds that "the near-steady-state models cannot explain the warmest exhumed rock data"	[4 §3.4]
2026	This paper: one rock with a warm shallow stage and a cold deep stage, dated, and a proposal that such paths "might be common"	[1 Abstract]

For the papers of 1968–71 we read titles and records only: [11], [12], [13] and [19]. For those of 1990 and 1992 we read the abstracts as deposited with Crossref [17][18]. The 2015 paper is cited by its title [5], and the 1978 work as the 2023 review describes it [4 §3.4].

OUR ANALYSIS
The modern concept of subducting slates belongs to the late 1960s. 58 years before this paper; early thermal models of a downgoing slab to 1970–71. 55 to 56 years [11][19]. Some roots are older, and the presenter's "century" can fairly reach them: deep earthquakes beneath Japan were shown in 1928, and by 1935 Kiyoo Wadati had drawn the inclined zone they form [20], the zone now used to trace subducting slabs [21 §2.2]. But the thermal models this paper tests descend from those of the 1970s, and at depth the rock agrees with them [1 Fig. 5a][1 §5].

Nor is the rock's shallow warmth a sudden upset. Shear heating has been invoked for subduction zones hotter than expected since 1978 [4 §3.4], blueschists were set against model paths with and without it in 1992 [18 Abstract], and in 2015 the rock record was found 100–200 °C warmer than the models on average [5][4 §3.4]. The