Docket No.: R.23-01-007
Date: June 30, 2023
Commissioner: Douglas
ALJ: Seybert
Witness: Dr. Peter Bird

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Implementing Senate Bill 846 Concerning Potential Extension of Diablo Canyon Power Plant Operations	R.23-01-007 (Filed January 14, 2023)

OPENING TESTIMONY OF DR. PETER BIRD ON BEHALF OF SAN LUIS OBISPO MOTHERS FOR PEACE ON PHASE 1 TRACK 2 ISSUES

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VERIFICATION

The statements in the foregoing document are true and correct to the best of my knowledge. The facts presented in the forgoing document are true and correct to the best of my knowledge, and the opinions expressed therein are based on my best professional judgment.

I declare under penalty of perjury under the laws of the state of California that the foregoing is true and correct. Executed on June 30, 2023, in Los Angeles, California.

George Peter Bird

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I. STATEMENT OF QUALIFICATIONS

My name is Peter Bird. I am a Professor of Geophysics and Geology, Emeritus, at the University of California at Los Angeles (UCLA). I am qualified by training and experience as an expert in the fields of tectonophysics and seismicity. A copy of my curriculum vitae is attached as Exhibit A. I have a Ph.D. in Earth and Planetary Sciences from the Massachusetts Institute of Technology (1976) and a B.A. in Geological Sciences from Harvard College (1972). For over 46 years, I have been a Professor of Geophysics and Geology at UCLA. I have published 76 academic papers, mostly about tectonics and seismicity, including the tectonics and seismicity of California. I have also been a member or officer of several professional organizations relating to my expertise, including the Geological Society of America, the American Geophysical Union and the Southern California Earthquake Center. The former two organizations have recognized my work with two fellowships and an award.

I have broad expertise in the fields of geology and geophysics, with a focus on plate motion and plate deformation. Over the past 48 years, I have authored or contributed to a number of academic papers on computer modeling methods and applications, including studies of the ongoing (neotectonic) deformation in California.

In 2012, I participated in a Senior Seismic Hazards Analysis Committee (SSHAC) workshop sponsored by PG&E and run by Lettis Consultants International, regarding seismic hazard at the Diablo Canyon Power Plant. I presented results on both strike-slip and compressional deformation rates affecting the region, which were derived from my latest computer models of neotectonics (prepared for the Southern California Earthquake Center's project Unified California Earthquake Rupture Forecast version 3, and also for the US Geological Survey's 2013 Update to the National Seismic Hazard Model).

II. PURPOSE AND BASIS OF TESTIMONY

I have been retained by San Luis Obispo Mothers for Peace (SLOMFP) to provide testimony relevant to the currently-ongoing, legally-mandated deliberations of the California Public Utilities Commission (CPUC) in regard to possible extension of operations of the Diablo Canyon Power Plant (DCPP), as set forth in the CPUC's Order Instituting Rulemaking of 2023.01.20, and the Administrative Law Judge's Ruling of 2023.04.23. My review of the DCPP case has also involved the review of other relevant documents, including Pacific Gas & Electric Co.'s (PG&E's) Geologic Map of the Irish Hills and Adjacent Area (*Pacific Gas & Electric,* 2014), submitted to the U.S. Nuclear Regulatory Commission (NRC) in 2014 as part of PG&E's Central Coastal California Seismic Imaging Project (CCCSIP) (NRC Accession No. ML14260A028); PG&E's Technical Summary for the CCCSIP (NRC Accession No. ML14260A028); PG&E's 2015 DCPP Seismic Source Characterization Report, Version A[1]; PG&E's 2015 enclosure summary Seismic Source Characterization (SSC), Parts 1 & 2[2]; PG&E's 2018 Seismic Probabilistic Risk Assessment (SPRA)[3]; the NRC Staff's 2019 review letter for the

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[1] Pacific Gas and Electric Company (PG&E), 2015. Seismic Source Characterization for the Diablo Canyon Power Plant, San Luis Obispo County, California; report on the results of SSHAC level 3 study, Rev. A, March; 652 pages plus Appendices. Available online at http://www.pge.com/dcpp-ltsp; downloaded 2023.05.11. (Hereinafter referred to as "SSC for DCPP".)

[2] PG&E Letter DCL-15-035 re: Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident: Seismic Hazard and Screening Report (Mar. 11, 2015) (NRC Accession No. ML15071A045).

[3] PG&E Letter DCL-18-027 re: Seismic Probabilistic Risk Assessment for the Diablo Canyon Power Plant, Units 1 and 2 – Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1: Seismic of the (sic) Near-Term Task force Review of Insights from the Fukushima Dai-Ichi Accident (Apr. 24, 2018) (NRC Accession No. ML18120A201).

SPRA[4]; and the NRC's 2020 letter closing out the post-Fukushima seismic review for Diablo Canyon.[5]

My testimony is relevant to two studies which CPUC is currently conducting regarding the DCPP facility, plus additional studies that might potentially be ordered by NRC:

a. The Administrative Law Judge's Ruling describes a study by the Diablo Canyon Independent Safety Committee (DCISC) intended to assess whether existing estimates of seismic hazard are complete and reliable. In this connection, *"The DCISC's most recent Fact Finding Reports (See Attachments A-C to this ruling) do not recommend any upgrades or additional actions to address seismic safety or issues of deferred maintenance. Do parties have any comments on these Fact Finding Reports or recommendations as they relate to the Commission's obligations under Pub. Util. Code Section 712.8(c)(2)(B)?"* I will provide arguments and evidence (below) to show that seismicity near DCPP has been significantly underestimated, and that active earthquake faults may underlie the plant at shallow depths, implying materially higher seismic hazard. I believe that these considerations argue for a new SSHAC SSC study of seismic hazard, using updated scientific methods.
b. As stated on page 3 of the Order Instituting Rulemaking, *"... the Commission may establish earlier retirement dates if any of the following conditions occur: ... The*

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[4] Letter from Louise Lund, NRC to James M. Welsch, PG&E, re: Diablo Canyon Power Plant, Unit Nos. 1 and 2 – Staff Review of Seismic Probabilistic Risk Assessment Associated with Reevaluated Seismic Hazard Implementation of the Near-Term Task Force Recommendation 2.1: Seismic (EPID No. L-2018-JLD-0006) (Jan. 22, 2019) (NRC Accession No. ML18254A040).

[5] Letter from Robert A. Bernardo, NRC, to James M. Welsch, PG&E, re: Diablo Canyon Power Plant, Unit Nos. 1 and 2 – Documentation of the Completion of Required Actions Taken in Response to the Lessons Learned From the Fukushima Dai-Ichi Accident (May 8, 2020) (NRC Accession No. ML20093B934).

Commission determines the conditions of NRC's license renewal, or any seismic safety or other safety upgrades recommended by the Diablo Canyon Independent Safety Committee (DCISC), includes costs that are too high to justify …". It is reasonable to foresee that increased seismic hazard in the revised SSC which I advocate will lead to increased risks of external seismic accidents in a revised SPRA based on that SSC, and that there will be substantial extra costs to correct these problems by strengthening the plant.

c. Page 4, question 1(c) of Administrative Law Judge's Ruling asks, *"Generally speaking, what are the types of activities the U.S. Nuclear Regulatory Commission (NRC) might include as potential conditions of license renewal?"* If this Testimony is judged to have merit, it might logically lead to NRC requirements for new SSC and SPRA studies on the DCPP by PG&E.

III. EXECUTIVE SUMMARY OF TESTIMONY

The 2015 Seismic Source Characterization[1] (SSC) for Diablo Canyon Power Plant (DCPP) was deficient and biased in 3 ways: (1) Fault slip-rates were selected subjectively and in isolation, without modern deformation-modeling (as used by USGS) to guarantee that all fault slip-rates and rates of distributed permanent deformation are self-consistent, and also consistent with geodetic-velocity and stress-direction data; (2) Seismicity from unexpected, undetected, and/or subterranean ruptures between the known faults was modeled based on projection of a few decades of microseismicity, ignoring globally-calibrated relationships between long-term tectonic strain-rate and (typically higher) long-term-mean seismicity which includes seismic crises; and (3) Despite several arguments and proposals for a thrust fault at shallow depths under DCPP with slip-rate of ~1 mm/a, no such seismic source was included. The SSC study should be redone, and the result is expected to show significantly higher hazard. This will, in turn, require a new Seismic Probabilistic Risk Assessment for DCPP, which can be expected to show higher risk of seismic external accidents. Such consequences will probably result in a choice between shutdown and expensive reinforcements.

IV. DETAILED PROFESSIONAL OPINION

Both PG&E and the DCISC are currently relying on the 2015 Seismic Source Characterization[1] (SSC) prepared in response to the Nuclear Regulatory Commission's mandate to re-evaluate seismic and tsunami hazards after the Fukushima disaster. That SSC study noted, but then did not make quantitative use of, then-published and available scientific developments in measurement and computation of the parameters for those and other fault sources, including:

a. measurement of crustal motion by permanent and campaign Global Positioning System (GPS) receivers [*e.g.*, *Shen et al.*, 2003; *Kreemer et al.*, 2003, 2014; *Kreemer*, 2016], and
b. computation of long-term crustal strain rates and fault slip rates by computer modeling (including kinematic finite-element models) of crustal motion measurement data, in combination with geologic and stress data [*e.g.*, *Bird*, 2009; *Field et al.*, 2013, 2014; *Parsons et al.*, 2013]. Such deformation-modeling was used as the basis for fault slip-rates across the western conterminous United States in the USGS National Seismic Hazard Model Updates of 2013 and 2023 *[ibid]*.

NRC regulations governing the SSHAC process required the team to assess the "center, body, and range of technically defensible interpretations" of seismic sources. Accordingly, workshops were held and the literature was surveyed, and these two potential constraints (a, b) above were discussed in introductory chapters of the SSC for DCPP. (Specifically, GPS data was discussed in sections 4.3.2.5 and 5.1.6. Also, my NeoKinema deformation model, and several others, were summarized.) However, there is no evidence that such constraints were applied in the creation of the final seismic source model(s). Without an overall relative-velocity constraint (or "deformation-rate budget") from GPS, and without a set of (alternative) computed deformation models to show how fault rakes and slip rates resulting from known stress-directions might balance to achieve this constraint, the geometric linkages and statistical covariances between fault slip-rates (and distributed permanent deformation) were lost. Then the rake and slip-rate of each fault was selected through an isolated, potentially subjective argument. Such an old-fashioned approach allows an overall bias to accumulate unchecked.

The SSC also failed to make alternative calculations of hazard based on recent initiatives in seismic hazard estimation. These new methods do not assume a complete inventory of active faults is available, but instead compute the expected long-term seismicity across the map area from crustal rates of permanent strain and fault slip rates (if and where available) using a calibration of global shallow seismicity categorized by plate-tectonic setting [*Bird & Kagan*, 2004; *Bird & Liu*, 2007; *Bird et al.*, 2010; *Bird et al.*, 2015]. Two motivations for the development of such models were that:

a. a number of recent large earthquakes in the California region (Landers 1972 m7.3, Northridge 1994 m6.7, Hector Mine 1999 m7.1, El Mayor-Cucupah 2010 m7.2, Ridgecrest 2019 m6.5 + m5.4 + m7.1, Ferndale 2022 m6.4) have occurred on rupture surfaces where no seismogenic fault, or only short and apparently disconnected faults, had previously been recognized; and

b. the discovery that the global distribution of shallow earthquakes was such that they spread in bands of half-width 257 km around plate boundary faults of the Continental Transform Fault (CTF) type [*Bird & Kagan*, 2004].

PG&E's failure to utilize these modern methods led to incomplete and biased results, both in terms of underestimated tectonic strain rates and overestimated minimum distances of active faults from DCPP. The distance between the plant and the potential earthquake rupture and the situation of the plant in the hanging-wall of a thrust fault are both important factors affecting the peak acceleration at the plant; this is recognized in the ground-motion-prediction equations that are routinely used in the Probabilistic Seismic Hazard Analysis process [*e.g.*, *Campbell & Bozorgnia*, 2014].

The Irish Hills and the San Luis Range are a dextral-transpressional orogen that has formed since ~3.5 million years (or mega annus, Ma) [*Page et al.*, 1998], or possibly since 7.8~6 Ma [*Atwater & Stock*, 1998; *Bird & Ingersoll*, 2022] when the motion of the Pacific plate changed its direction to become more compressional relative to North America. This means that the region can be expected to be cut by a number of both strike-slip and thrust (compressional) faults.

Evidence of this ongoing compression includes:

a. The Pismo syncline is the primary structural feature within the Irish Hills [*Pacific Gas & Electric*, 2014]. Here beds have been rotated ~45°, which figure is supported by both mapped surface dips in outcrops (PG&E 2014 geologic map), and by the overall dip of unit Tmo Obispo Formation in the borehole-controlled cross-section of Figure 13-17 of the SSC for DCPP[1]. This folding began after deposition of the youngest strata in the core of the fold (Tmpm), and prior to deposition of the Squire Member of the (Pliocene) Pismo Formation (Tpps), probably ~5 Ma (para. 12). This folding implies upper-crustal strains of ~0.8, and mean strain-rates of ~0.8 / 5 Ma = 5×10^{-15} per second (/s). This is ~10× faster than rates of "off-modeled-fault" (or "continuum") deformation that are typical in the long-term neotectonics of the western US [5×10^{-16} /s per *Bird*, 2009]. This high rate of permanent straining implies a high rate of faulting and of earthquakes, even if the specific fault traces and fault planes have not yet been identified.

b. According to the geologic map of Fig. 13-16 and associated cross-section C-C' (Fig. 13-17), the apparent throw (vertical offset) of stratigraphic unit Tmo Obispo Formation is 1.6~2.2 km across the Shoreline fault trace. (This measurement is illustrated in my attached Figure 1.) None of this can be explained by strike-slip on the Shoreline fault, because its slip-rate is very low and because regional strikes of bedding are roughly parallel to it. Instead, the simplest explanation is thrust-faulting, either on the Shoreline fault (if it is not actually vertical), or on another northeast-dipping fault plane, such as a NW extension of the San Luis Bay thrust fault, that shares the surface trace of the Shoreline fault. Assuming a typical thrust-fault dip of 25°, the amount of slip required to create this throw is (1.6~2.2 km) / sin(25°) = 3.8~5.2 km. Then, assuming this occurred since ~5 Ma (para. 12, 13a above), the mean rate of slip on the inferred thrust fault has been 0.76~1.04 mm/a. To the northwest of section C-C' the throw of unit Tmo becomes much less, but the area of neotectonic uplift of the Irish Hills (Figure 7-4) continues to the northwest; so there the thrust fault probably does not terminate but merely deforms unit Tmo into a fault-initiation anticline above it. (In this area, complex older deformation associated with intrusions of Tmod diabase obscures the Pliocene-Quaternary structure, and makes balanced-section methods inapplicable.) I interpret that this inferred thrust fault continues, with the same rake and offset, northwest to the Hosgri fault.

c. The neotectonic uplift rate of the whole Irish Hills region is uniform at 0.2 mm/a (Fig. 7-4). Because the Franciscan Complex basement is weak, and because there is no large isostatic gravity anomaly over the Irish Hills [*Simpson et al.*, 1986], this uplift process should be modeled with Airy isostasy. The implied rate of crustal thickening is then about 6 times larger, or about 1.2 mm/a. If this crustal thickening is occurring on a single thrust fault of dip 25°, then its rate of slip should be (1.2 mm/a) / sin(25°) = 2.8 mm/a. Or, if the crustal thickening is driven by two oppositely-vergent and overlapping thrust faults (as in my schematic section, Figure 1 at the end of this testimony), then each should have a slip-rate of ~1.4 mm/a. Obviously, more complex models with more thrust faults can be devised, but the implication for total strain and seismicity due to thrust-faulting will remain unchanged.

d. The southwestern front of the Irish Hills is a topographic scarp with a smooth arcuate shape, mirroring the slightly-lower scarp on the northeast which has been formed by slip on the Los Osos thrust fault. This suggests that a thrust fault may also be present under the southwestern front, at or near the coastline

e. The 2003 San Simeon magnitude (m) 6.6 and 1983 Coalinga m6.2 earthquake both had thrust mechanisms [Global Centroid Moment Tensor Catalog, *Ekström et al.*, 2012]. This is evidence of highly-compressive horizontal stresses in the Coast Ranges region, suggesting a likelihood of seismic thrust-faulting in other locations as well.

f. SSW-NNE directions of most-compressive stress shown by data in the World Stress Map [*Mueller et al.*, 1997; *Heidbach et al.*, 2008, 2016], and by interpolation of stress directions using the method of *Bird & Li* [1996], are almost perpendicular to the traces of the regional fault grain (Shoreline, San Luis Bay, and Los Osos fault traces).

This strongly suggests that currently these faults are either purely or dominantly thrust faults.

g. Models of neotectonic deformation, informed and guided by GPS velocity data, include such long-term compression. Specifically, *Shen & Bird* [2022] computed a suite of kinematic finite-element (F-E) models of neotectonics across the western US based on geodetic, geologic, & stress data with program NeoKinema. Their preferred model, which is being incorporated into the 2023 update of the USGS National Seismic Hazard Model, shows convergence of crustal blocks on both sides of the Irish Hills/San Luis Range region at velocities of ~1 mm/a, for a total of ~2 mm/a of local convergence[6].

Given the evidence cited above for active horizontal compression, thrust faults and resulting thrust-faulting earthquakes must be expected. The lack of nearby, mapped low-angle thrust fault traces in the SSHAC dataset does not justify omission of gently-dipping thrust-fault seismic sources, given that:

a. The basement of the Irish Hills is a tectonic collage of Franciscan Complex (KJf and its member units) and Cretaceous sandstone (Ks). The former is a mixture of exotic ultramafics, volcanics, cherts, and limestones (and metamorphosed equivalents)

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[6] This model did not predict any thrusting on the Shoreline fault because prior data dictated strike-slip only. It predicted only 0.258 mm/a of shortening (P) on the Los Osos fault, which conclusion was primarily controlled by restrictive prior data provided by USGS (P = 0.245±0.2 mm/a). Therefore, 90% of this model shortening occurred as distributed permanent deformation. The model F-E grid had only two NW-SE-trending rows of finite-elements between the Hosgri fault and the Oceanic-West Huasna fault, limiting spatial resolution. Computation of alternative models with much finer local grids and relaxed prior constraints on fault offset-rates would be valuable.

scraped off the subducted Farallon plate. The latter (Ks) represents trench deposits derived from the Cretaceous magmatic arc in the Sierra Nevada region, which were deposited on the subducting Farallon plate and then quickly re-accreted to North America. This accretionary melange was built as a stack of thrust nappes [*Wakabayashi*, 1999] that formed in a dextral-transpressional subduction environment in Jurassic-Paleogene times [*Atwater*, 1970; *Cloos*, 1982]. Many contacts mapped within this basement (and many others in the subsurface where they cannot be mapped) are low-angle thrust faults which are available for reactivation.

b. Bedding-plane slip is the dominant mode of compression in layered sedimentary and volcanic rocks such as the Paleogene and Neogene units that overlie the Franciscan/Cretaceous basement in the Irish Hills [*Pacific Gas & Electric*, 2014]; but bedding-plane slip produces no visible or mappable offsets of rock lithologies.

c. The 2015 m7.8 Nepal earthquake showed that low-angle thrust faults can produce devastating shaking without leaving any mappable surface rupture.

In my professional opinion, the most reasonable base model for seismic sources threatening DCPP would begin with two outwardly-vergent thrust faults under the Irish Hills, both with slip-rates of approximately 1 mm/a, and with dips of approximately 25°: the blind Los Osos fault on the northeast, and an inferred thrust fault possibly sharing the trace of the Shoreline fault on the southwest. The right-lateral Hosgri fault would then become a tertiary, but still important, source of seismic hazard.

In the discursive text introducing the 2015 SSC model(s) for DCPP, uplift of the Irish Hills by thrust-faulting is nominally considered, in 3 alternative Fault Geometry Models (FGMs) labelled OV, SW, and NE (Outwardly-Vergent, SouthWest, and NorthEast). Despite this acknowledgement, the actual {fault trace, dip, rake, & slip-rate} dataset which led to the computed seismic hazard model had thrust-faulting minimized to an inexplicable degree. Thrusting appeared in only three places:

a. The blind Los Osos thrust fault, which was arbitrarily assigned a steep dip of 50~80° (Figures 7-27, -28, -29 of SSC for DCPP) so that its seismogenic portion lies to the northeast of DCPP, rather than under it. Note that no dextral component of neotectonic slip on this fault can be used to motivate a steep dip, because of the finding on p. 4-7 of the SCC for DCPP that, *"LiDAR and field-reconnaissance-based evaluation of streams crossing lineaments and fault associated with the Los Osos fault zone along the northeastern margin of the Irish Hills concluded that there was no evidence of a strike-slip component…"*. Also, this fault is classified as "Reverse" in the USGS Quaternary Fault & Fold Database; to clarify, this database does not observe any consistent distinction between the terms "reverse" and "thrust." On p. 8-54, there is mention of a model with a more reasonable alternative dip of 30° but this is assigned a weight of only 0.3.
b. The San Luis Bay fault is considered in some models (Figure 7-30 of SSC for DCPP) to dip northeast, but only at steep dip angles of 45~75°. Also, the slip-rates assigned to the whole Southwest Boundary Zone (SWBZ; including the San Luis Bay fault) are low: 90%-confidence limits are assigned as 0.24~0.46 mm/a (p. 8-46 of SSC for DCPP). Finally, the San Luis Bay thrust fault (option) is often modelled as terminating to the southeast of DCPP, with no other thrust fault continuing under the plant. Thus, this FGM is inconsistent with the constraint of neotectonic uplift of the entire Irish Hills at 0.2 mm/a that I discussed on page8, and with the topographic argument on page 9 above.

c. The Local (Areal) Source Region (p. 13-9 to 13-19): according to Fig. 2.2.2-2 of the enclosure summary SSC[2], this is the second most important source of acceleration (after the Hosgri fault) in the critical part of the hazard recurrence curve around (1 g, 1E-4 /year). Also, the spatial disaggregation of spectral acceleration hazard in Figure 14-3 of the SSC for DCPP[1] shows that most of the hazard with annual frequency of 1E-4/year originates with 10 km of the plant. Therefore, the reliability of the Local Source SSC is critical to determining the utility of the whole 2015 SSC. Unfortunately, this part of the source model is based on three errors, all of which combine to underestimate the hazard.

First, PG&E estimated the long-term seismic moment rate of the Local Source Region by using moment rates from the instrumental seismic catalog (p. 13-10 to 13-17), instead of moment rates from a tectonic deformation model. This resulted in very low assigned slip-rates of 0.01~0.14 mm/a for the virtual thrust faults (Table 13-10, p. 13-25). But, because seismicity has a power-law frequency/magnitude distribution and is clustered on all scales in space and time, this method is known [*Geist & Parsons*, 2004; *Zaliapin et al.*, 2005] to have a high probability of yielding a serious underestimate. (If this method were applied to the San Andreas fault, its failure would be obvious. In fact, one could argue that the entire SSHAC PSHA process was invented to prevent this particular kind of error.)

Second, faulting in the Local Source Region was modeled as 70% strike-slip and 30% thrusting (p. 13-19 to 13-22, based on a complex algorithm of Hardebeck applied to only a few years of microseismicity), but there is no geologic reason to expect anything but pure horizontally-compressional thrusting and folding within the Irish Hills.

Third, the maximum magnitude in the Local Source Region was arbitrarily set at 6.6~7.1 (p. 13-22 to 13-23, based on the arbitrary lengths of the imaginary virtual faults); however, *Bird*

& Kagan [2004] showed that the corner magnitude (a similar measure) in Continental Convergent Boundaries is 8.46, with a likely range from 8.07 to 8.67.

If all these errors were corrected, the tornado plots of hazard sensibility would look very different, and it is likely that the Hosgri fault would no longer be dominant.

PG&E's systematic under-estimation of earthquakes resulting from horizontal compression is material and serious because:

a. Kinematic F-E models of regional neotectonics [*Shen & Bird*, 2022] prepared for use in the US Geological Survey's National Seismic Hazard Model, and seismicity models based on their kinematics plus global calibrations [*Bird & Kagan*, 2004; *Bird et al.*, 2009; *Bird & Kreemer*, 2015], suggest that seismicity due to distributed compression may be roughly equal (and additive) to that caused by strike-slip on named, mapped faults. Specifically, in my publications I have advocated a seismicity model known as Seismic Hazard Inferred From Tectonics (SHIFT), with two basic principles:

    i. the long-term seismic moment rate of any tectonic fault, or any large volume of permanently deforming lithosphere, is approximately that computed using the coupled seismogenic thickness (*i.e.*, dimensionless seismic coupling coefficient × seismogenic thickness) of the most comparable class of plate boundary; and

    ii. the long-term rate of earthquakes generated along any tectonic fault, or within any large volume of permanently deforming lithosphere, is approximately that computed from its SHIFT moment rate (of method i above) using the frequency–magnitude distribution of the most comparable class of plate boundary.

b. This method, encoded in my program Long_Term_Seismicity_v12, provides maps and statistics on model seismicity above any desired minimum earthquake magnitude. For the preferred model of *Shen & Bird* [2022], we compute that “off-fault” seismicity should be 44% of total m7+ seismicity in the western US, compared to 56% “on-fault” seismicity. That is, a regional SSC prepared for the western US by traditional methods that rely on a list of named active faults would miss about half of the actual long-term earthquake rate.

c. Following the method described above, DCPP must be reevaluated for its vulnerability to thrust faults. Locally, DCPP lies on a transition from a domain to the SW where seismicity is dominated by the strike-slip component on modeled faults, to a domain on the NE (Irish Hills and San Luis Range) where seismicity is dominated by compression in the (model) continuum. This means that cryptic bedding-plane and Franciscan thrust faults and/or a NE-dipping strand of an inferred thrust fault with trace along the Shoreline fault locally become more important to hazard than more-distant mapped faults.

The simplest structural explanation for the folding that produced the Pismo syncline, and for the regional uplift in the Irish Hills, is that both flanking faults (inferred thrust fault on the SW; Los Osos fault on the NE) are active thrust faults which have relatively uplifted their respective flanks of the Irish Hills. The Shoreline fault trace offshore DCPP could host partitioned slip on two active planes: one vertical strike-slip fault, and one thrust fault dipping gently to the northeast. No amount of positive evidence for a vertically-dipping fault plane beneath the Shoreline fault trace can rule out the possibility that there is another gently-dipping thrust plane in this part of the coast. On page 8 above, I estimated the mean slip-rate of this inferred thrust plane as 0.76~1.04 mm/a since ~5 Ma. To the southeast, it may either continue as the San Luis Bay thrust fault, or continue as a distinct (unmapped) fault. Since a succinct working name for this hypothesis may be convenient, it can be called the “Inferred Coastline Thrust” (ICT) fault, to maintain a necessary distinction from the Shoreline fault (which is vertical in all PG&E models), and a possibly-useful distinction from the mapped San Luis Bay thrust fault to the southeast. Similar proposals have a long history. This proposal has similarities to the Inferred Offshore Fault (IOF) model of *Nitchman* [1988] and *Nitchman & Slemmons* [1994]. It also has some similarities to two proposals of *Hamilton* [2012a, b]: the “IOF/San Luis Range thrust fault” model, and the “Diablo Cove thrust fault” model. ICT differs from the “Diablo Cove fault” model in advocating a NW-SE strike and NE dip, rather than an E-W strike and a N dip. ICT is closer to Hamilton’s “IOF/San Luis Range thrust fault” model, but differs in that the ICT would be less than ~1 km deep under DCPP, instead of ~3 km deep. Both possibilities seem worthy of modeling as potential seismic sources.

Inadequacy of PG&E’s rebuttal of hypotheses proposing a nearby thrust fault:

PG&E’s responses (required by the SSHAC process) to the *Nitchman* and the *Hamilton* models are to be found on p. 5-22 to 5-23 and 7-20 of the SSC for DCPP[1]. To summarize, they did not respond directly the *Nitchman* proposals, but assumed that they were subsumed into the later *Hamilton* proposals. They found that the “Diablo Cove fault” model *“does not have a reasonable technical basis.”* However, they could not dismiss the “IOF/San Luis Range thrust fault” model, and instead argued that essentially the same concept is captured in their proposed SW and OV FGMs. This is misleading because the IOF thrust fault proposed by *Hamilton* had a shallower dip (para. 16b), came closer to the plant, and would have been modeled with a higher slip-rate to achieve the same throw-rate. Also, it was unreasonable for PG&E to assume in their OV and NE FGMs (with total logic-tree weight of 0.6) that the San Luis Bay thrust fault terminates at the Shoreline fault (p. 7-16; 7-22), because: (a) the two traces do not form a right-angle, and therefore the Shoreline fault cannot be considered as a vertical tear-fault terminating a thrust; and (b) the Shoreline slip-rate is much slower than that of the IOF or ICT. This is one of the motivations for my ICT model; others were presented above on pages 8~9 above. Extending either thrust NW past the initial intersection with the Shoreline fault trace will increase modeled hazard at DCPP by locating it closer to the middle of potential thrust ruptures.

The onshore portion of the 2012 CCCSIP seismic surveys, reported in *Fugro Consultants* [2012], had the potential to test hypotheses about shallow thrust faults under DCPP. If NE-dipping structures had been imaged below the sub-Obispo unconformity (~1000', or 300 m), it would have been evidence for such a fault. Conversely, if flat or SW-dipping structures had been imaged, it would have shown that any thrust fault(s) could only be deeper. Unfortunately, no structures were imaged at such depths. Partially, this is due to the technical difficulty of imaging anything below the complex folds and diabase intrusions near the surface. It may also be due to the character of the Franciscan Complex, which has a high volume-fraction of monotonous massively-bedded sandstones and meta-sandstones. Regrettably, this worthy effort did not help to resolve the issue.

V. CONCLUSION

In summary, the ALJ requested comment on the Fact-Finding Report of the DCISC regarding seismic hazard. I strongly disagree with their assumption that only newly-published information (since 2015) is relevant, because I find that the 2015 study was biased toward artificially low hazard in 3 ways: (1) Fault slip-rates were selected subjectively and in isolation, without modern deformation-modeling (as used by USGS) to guarantee that all fault slip-rates and rates of distributed permanent deformation are self-consistent, and also consistent with geodetic-velocity and stress-direction data; (2) Seismicity from unexpected, undetected, and/or subterranean ruptures between the known faults was modeled based on projection of a few decades of microseismicity, ignoring globally-calibrated relationships between long-term tectonic strain-rate and (typically higher) long-term-mean seismicity which includes seismic crises; and (3) Despite several arguments and proposals for a thrust fault at shallow depths under DCPP with slip-rate of ~1 mm/a, no such seismic source was included. Second, in response the ALJ's request for comment on what actions the NRC might reasonably require, I propose that the 2015 SSHAC SSC study must either be redone, or substantially altered, to correct these biases. Finally, in response the ALJ's request for comment on potential new costs, I foresee that the new (or revised) SSC study will find higher seismic hazard, potentially requiring complex and expensive reinforcements to the plant.

This concludes my testimony.

==/==

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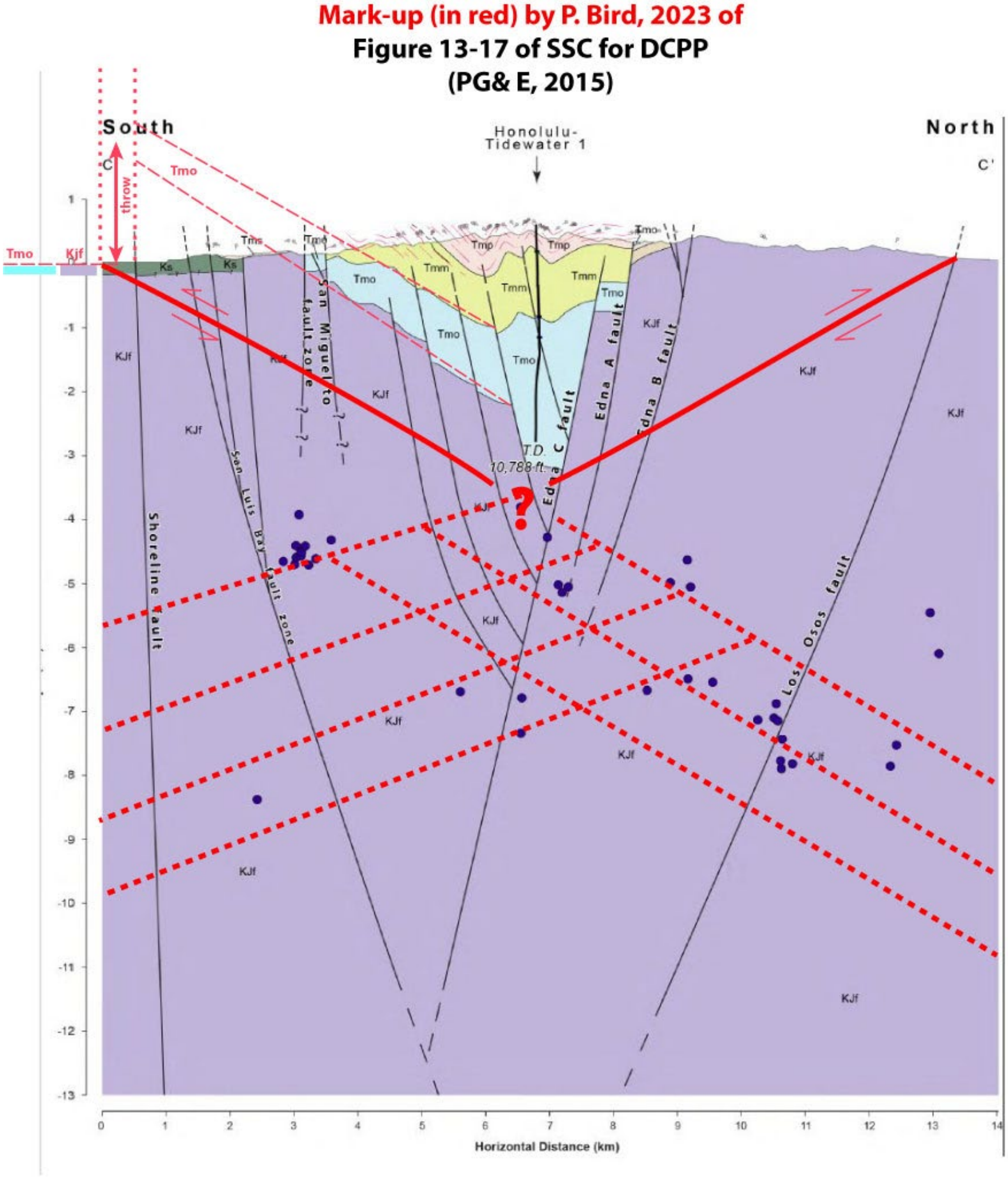
FIGURE 1 OF TESTIMONY:



Mark-up (in red) by P. Bird, 2023 of
Figure 13-17 of SSC for DCPP
(PG& E, 2015)

Attachment A

CURRICULUM VITAE OF PETER BIRD

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EDUCATION

Massachusetts Institute of Technology: Ph.D. in Earth and Planetary Sciences, 1976
Harvard College: B.A. in Geological Sciences, 1972

EMPLOYMENT

University of California, Los Angeles:
- Professor Emeritus, 2011-
- Professor of Geophysics and Geology, 1985-2011
- Vice-chairman, Dept. of Earth and Space Sciences, 1994-2002
- Associate Professor of Geophysics and Geology, 1981-85
- Assistant Professor of Geophysics and Geology, 1976-81

HONORS

Woollard Award, Geological Society of America, 2013
Fellow, American Geophysical Union, 1990
Fellow, Geological Society of America, 1989

RESEARCH AREAS (CHRONOLOGICAL FROM 1973)

Lateral refraction and attenuation of surface waves	1973-1977
Marine paleomagnetism and seafloor spreading	1974-1975
Thermal modeling with finite differences	1975-1977
Dynamic modeling with finite elements	1975-
Tectonophysics of continental collisions	1975-
Formation of marginal basins	1976-1977
Stress and temperature in subduction zones	1976-2009
Continental delamination	1977-1982
Neotectonic models of California	1978-
Hydration state and friction of montmorillonite clays	1979-1984
Mechanism of Laramide orogeny	1982-
Mechanism of Basin/Range taphrogeny	1986-
Solution transfer experiments on quartz	1986-1993
Lateral extrusion of lower crust	1987-1991
Regional neotectonic models: Africa, Alaska, Asia, Europe, ...	1989-
Global dynamic lithosphere models with plates & driving forces	1992-
Inverse or kinematic tectonic models from geologic & paleomag data	1994-
Global long-term seismicity forecasts from geodesy & plate tectonics	2000-
Long-term seismicity forecasts for Europe, especially Italy	2009-

CONSULTING EXPERIENCE ON SEISMIC HAZARD (FROM 2009 TO PRESENT)

GeoPentech, Lettis Consultants International, FM Global, Temblor, San Luis Obispo Mothers for Peace

UNPAID AFFILIATIONS

Southern California Earthquake Center (2000-present; Board member 2004-2012)
Collaboratory for the Study of Earthquake Predictability (model contributor, 2015)

PUBLICATIONS (CHRONOLOGICAL FROM 1975; OMITTING MOST ABSTRACTS)

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