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Discussion of "Is there a close spatial relationship between faults and plutons?" by S.R. Paterson and K.L. Schmidt

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Paterson and Schmidt (1999) and Schmidt and Paterson (2000) presented statistical analyses of spatial relationships between faults and plutons from which they "see no evidence that magma is channeled along faults" (Paterson and Schmidt, 1999, p. 1140). If anything, they conclude, there is an antithetic relationship. As an economic geologist familiar with intrusion-related hydrothermal ore deposits, I was at first surprised by these statements and the bold title of the EOS article: "Analyses fail to find coupling between deformation and magmatism." However, after reading the articles I came to understand that these conclusions applied only to plutons emplaced within *compressional orogenic belts*. Fortunately, most hypabyssal plutons related to magmatic hydrothermal ore deposits are emplaced in tensional or transtensional arc environments, albeit perhaps within a broadly compressional regime. In such settings, structural controls on the localization of ore-forming magmatism are evident, as illustrated by the restriction of several of the world's largest porphyry copper deposits to a single ~30 km × ~ 1000 km fault belt (the West Fissure Zone) in northern Chile and southern Peru (Fig. 1; Baker and Guilbert, 1987; Richards et al., 1999, 2001), and more specifically to lineament intersections along its length (Salfity, 1985; Richards, 2000; Richards et al., 2001). Other examples have been provided by Rehrig and Heidrick (1972), Seraphim and Hollister (1976), Titley (1981), Heidrick and Titley (1982), Sylvester and Linke (1993), Sapiie and Cloos (1995), and Cornejo et al. (1997).

The provocative article titles having, perhaps inappropriately, piqued my curiosity, I read further. Again using an ore deposit analogue, the main conclusion, that in compressional orogenic settings magma penetration of faults is not favored, is consistent with the observations of geologists working on shear zone-related vein deposits, in which ore shoots (and locally dikes) typically occur in second or third order splays and not in the main break (e.g. Wyman and Kerrich, 1988; Robert et al., 1995). Trans-crustal shear zones serve broadly to concentrate fluid (and sometimes magma) flow from depth, but in the mid-crustal environment this flow and subsequent mineral deposition is focused along more discrete paths whose distribution is controlled by local structural features, rheological contrasts, and the prevailing stress field. Moreover, fluid flow can be correlated with the temporal evolution of that stress field, and is thus restricted in both time and space (Robert and Brown, 1986; Sibson et al., 1988).

The main conclusions of the articles by Paterson and Schmidt (1999) and Schmidt and Paterson (2000) are, therefore, broadly in accord with observations from other fields. My concern with these papers stems instead from the methodology and presentation, and I list my main points below:

1. In figure 1 of Paterson and Schmidt (1999), enlargements of part of a geological sketch map of the Southern Appalachians are presented to suggest that broad relationships between plutons and faults oberved on a regional scale fall down at a more local scale. In enlarging these map segments, one would expect to see a concomitant increase in geological detail, such as the inclusion of smaller faults not shown on the low-resolution small-scale sketch map. However, the enlargements in figure 1c and d are simply that — enlargements with no increase in resolution, despite the claim to the contrary in the text and figure caption. In fact, one of the two faults shown in figure 1a is omitted from figures 1c and d, as is a pluton from figure 1d, which is shown intruding a fault in figure 1a. Is there really only one fault within the 40,000 km^2 area shown in figure 1d? This concern leads on to the next point.
2. A statistical analysis of the spatial relationship between plutons and faults must surely require that all faults within the analyzed area are included. Paterson and Schmidt (1999) include only major regional faults in

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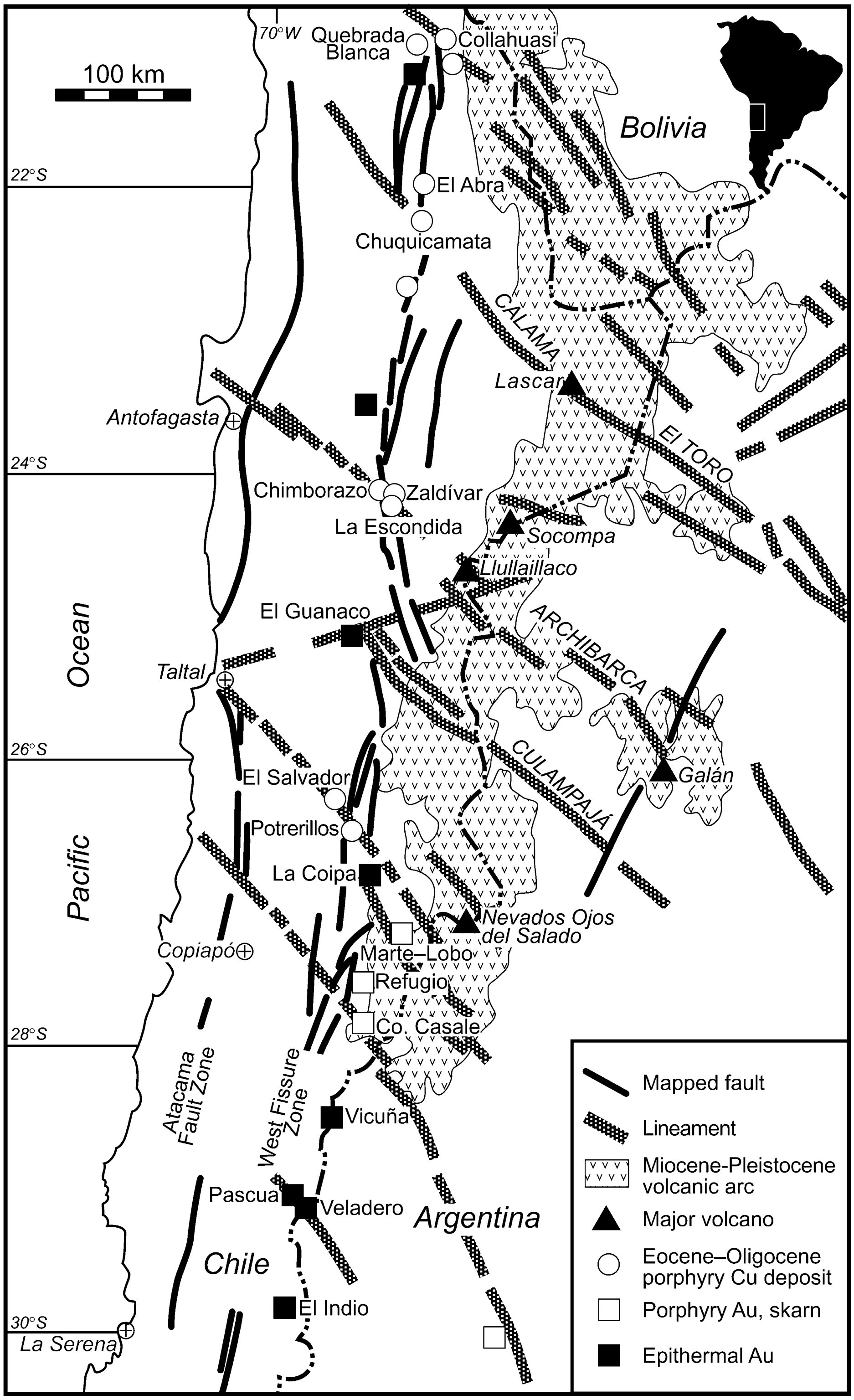

Fig. 1. Geological sketch map of northern Chile, northwestern Argentina, and southwestern Bolivia, showing the locations of major Cu and Au deposits (from Sillitoe, 1992) in relation to the West Fissure Zone and other lineaments (from Salfity, 1985). A discussion of the significance of lineament intersections for localization of porphyry magmatism is given in Richards (2000); Richards et al. (2001).

their analysis, however. What are the criteria used to select these particular faults and to reject others? Perhaps, as observed in the shear-zone vein environment, it is the smaller structures that provide the main controls on emplacement.

3. In the simplest case, magma intruding along a fault might be preserved as a dike (e.g. Petford et al., 1993, 1994; Rubin, 1993, 1995). And yet I did not see the word 'dike'

mentioned once in either of these articles. Are there really no dikes in any of these orogenic belts, or were they not included in the analyses?

4. The ability of magma to penetrate a fault will depend to a large part on the prevailing state of stress. Extensional faults will be much more readily intruded than faults under horizontal compression (Bussell, 1976; Hutton, 1988; Glazner, 1991; Petford and Atherton, 1992; Pitcher, 1997; Ida, 1999). Thus, kinematic considerations are important when evaluating the relationship between faults and plutonism. The analyses reported in these articles do not consider this aspect of structural geology, however, and make no distinction between reverse and normal faults. The faults studied in these compressional orogens are presumably mostly reverse faults, and this distinction should be made clear in the titles and text of the papers.

In summary, for a statistical analysis of fault–pluton relationships to be of real value, many more factors than those included in the examples provided by Paterson and Schmidt (1999) and Schmidt and Paterson (2000) need to be taken into account. The broad approach used here to dismiss a structural control on pluton emplacement only serves to reinforce common prejudices against statistics, and calls into question the validity of the conclusions. This is unfortunate, because the fundamental point that Paterson and Schmidt are trying to make may well be correct, albeit with restricted application to compressional orogenic belts.

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