Polish Botanical Journal 55(2): 315–334, 2010

THE RUSTS OF GERANIACEAE IN AUSTRALIA*

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Abstract. Two native and two introduced rusts are present on hosts in Geraniaceae in Australia. The rare *Puccinia geranii-pilosi* McAlpine occurs on native species of *Geranium*, and *P. morrisonii* McAlpine is found on native *Pelargonium* spp. The introduced *P. pelargonii-zonalis* Doidge is common, widespread and often damaging on cultivated zonal pelargonium (*Pelargonium* × *hortorum* L. H. Bailey). *Uromyces geranii* (DC.) Fr. was first recognised in Australia in 2003 on *Geranium* sp. in New South Wales but herbarium specimens show that it has been present since at least 1911. All species are fully described and illustrated from Australian material, with comments on host ranges and geographic distributions. Lectotypes are selected for *P. geranii-pilosi* and *P. morrisonii*. Differences between species are discussed, an identification key given and comparisons made with exotic rusts of Geraniaceae. Evidence suggests that *P. pelargonii-zonalis* was introduced to Australia between 1906 and 1912; its subsequent early spread is discussed. A smooth wall patch free of spines (a tonsure) is present on urediniospores of the four rusts. Erroneous Australian reports of rusts on *Erodium* are clarified, *Puccinia polygoni-amphibii* is newly recorded from uredinial collections on *Fallopia* and *Persicaria,* and its potential connection with *Geranium* hosts discussed.

Key words: *Aecidium*, *Puccinia*, *Uromyces*, *Erodium*, *Geranium*, *Pelargonium*, *Polygonaceae*, urediniospore wall tonsure

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INTRODUCTION

Four rusts of Geraniaceae are known in Australia. With the exception of the introduced *Puccinia pelargonii-zonalis* Doidge, which is common, widespread and often damaging on the widely grown ornamental *Pelargonium* × *hortorum* L. Bailey (zonal pelargonium), these rusts are not well known. In this paper, the four species are described and illustrated, with details of their history, distribution and host range. They are compared with other exotic rusts of Geraniaceae and an attempt has been made to summarise information on as many taxa as possible from the scattered literature dealing with rusts on this host family. Some discrepancies between published accounts and specimen data for the Australian rusts are discussed and resolved. In Australia, native species of *Geranium* and *Pelargonium* occur in temperate areas of all states, but not in the Northern Territory (Hnatiuk 1990). Native and introduced species of *Erodium* are reported from all states and territories except Tasmania where only four introduced species are known (Curtis & Morris 1975; Hnatiuk 1990). A range of introduced *Pelargonium* species and cultivars are popular as ornamentals but *Geranium* cultivars are more rarely grown. No rusts or other diseases have been recorded on Geraniaceae in the Northern Territory (Barry Condé, pers. comm., 2 March 2010).

MATERIALS AND METHODS

Specimens examined are listed under the species descriptions. As a large number of specimens of *P. morrisonii* and *P. pelargonii-zonalis* were examined, only representative collections are listed. Sections and spores were mounted in clear lactophenol or lactic acid, warmed to expand them and expel air bubbles, and examined immediately. Some older specimens in poor condition had few spores present, many distorted, and 10 normal spores of each type were measured. In other collections, examined at different times, 10 to 30 spores were measured, with

* This paper is dedicated to Professor Tomasz Majewski on the occasion of his 70th birthday.

notes on abnormally large or small spores. Herbarium abbreviations follow Holmgren and Holmgren (1998), and author abbreviations for fungus and plant names are from Brummitt and Powell (1992). Terms and Roman numeral symbols for rust spore states are those used by Laundon (1967b, 1973) and Savile (1968, 1988), based primarily on morphology, in contrast to the 'ontogenic' system of spore state nomenclature used by Cummins and Hiratsuka (2003). Pycnium types are those defined by Hiratsuka and Hiratsuka (1980).

For accurate determination of spore shape and germ pore distribution, spores with the hilum visible at the base were used. Urediniospore wall thickness can vary in a single spore by 1–2 μm in different parts. The side wall is usually thinnest, the apical wall sometimes slightly thicker, and the base thickest. At the sides, there may be slight internal thickening around each germ pore. In this study, urediniospore side wall thickness is compared. Equatorial germ pores are those where the two opposite pores are within the central quarter of the spore's length. Where they are neither equatorial nor opposite, their distribution is described. Following Savile (1972) and Parmelee and Savile (1981), the term 'tonsure' is used for the smooth area of variable size free of echinulations on urediniospores of some taxa.

Names of *Erodium*, *Geranium* and *Pelargonium* species in Australia are those used by Carolin (1958, 1962, 1964, 1965, 1967) and in the *Flora of New South Wales* (Harden 1992). For New Zealand, host names in McKenzie (1998) are followed and, with the exception of the zonal pelargonium, names of extra-Australasian hosts are those given in literature cited or on specimens examined, unless otherwise noted. Several botanical names are used in the literature for the zonal pelargonium. Mabberley (2008) says it is a complex hybrid involving the South African species *Pelargonium inquinans* (L.) L'Hér., *P. zonale* (L.) L'Hér., their hybrid *P.* ×*hybridum* (L.) L'Hér. and back-crosses to the parents. He uses the name *P.* ×*hortorum* L. H. Bailey, and that is followed here. In earlier Australian rust and horticultural literature, it is often referred to simply as *Pelargonium zonale*, or frequently under the common name 'geranium'. To avoid confusion with *Puccinia* (*P.*), *Pelargonium* is abbreviated here as '*Pel.*'. Nomenclature of genera and species formerly included in *Polygonum* L. *s.l.* follows Wilson (1988).

Descriptions of rust species

Accepted taxa

The four rusts present in Australia are described in alphabetical order. With the three *Puccinia* species, this corresponds to the chronological order of their original descriptions.

Puccinia geranii-pilosi McAlpine Fig. 1

The Rusts of Australia: 179–180. 1906.

Uromyces scariosus Berk., Fl. New Zealand **2**: 195. 1855 (based on uredinia).

Uromyces scariosa Berk., Handb. N. Zeal. Fl.: 624. 1867 (based on uredinia).

Uredo scariosus (Berk.) G. H. Cunn., Trans. New Zealand Inst. **58**: 48. 1927.

(Synonymy from Cunningham 1931)

Pycnia and aecia unknown. Sori on leaf blades, petioles, stems and calyx segments, mainly on lower leaf surface, a few on upper surface. Uredinia erumpent, circular to oval, very variable in size, with small circular sori 150–200 μm diam., larger circular to oval sori 500–600 μm diam., a few elongated sori to 1 mm long and 250 μm wide, with a reddish-brown powdery spore mass, surrounded by torn remnants of host tissue, scattered on leaves or 3–4 sori in a compact group 1.0–1.5 mm across, subepidermal, aparaphysate. Urediniospores pedicellate, obovoid to broadly obovoid, a few subgloboid, pale golden-brown, (24–)25–31(–33) × (19–)20–26(–27) μm, occasional larger spore to 35 × 26 μm, spores slightly flattened in the vertical plane, slightly narrower in side view, side wall 2.0–2.5 μm thick, to 3 μm at base, two opposite germ pores present, one on each flattened face, predominantly (*ca* 75%) equatorial, less commonly slightly to clearly supraequatorial, more rarely subequatorial or pores at different levels, pores with a shallow, hyaline cap 6–7 μm wide and 1 μm high, wall finely and

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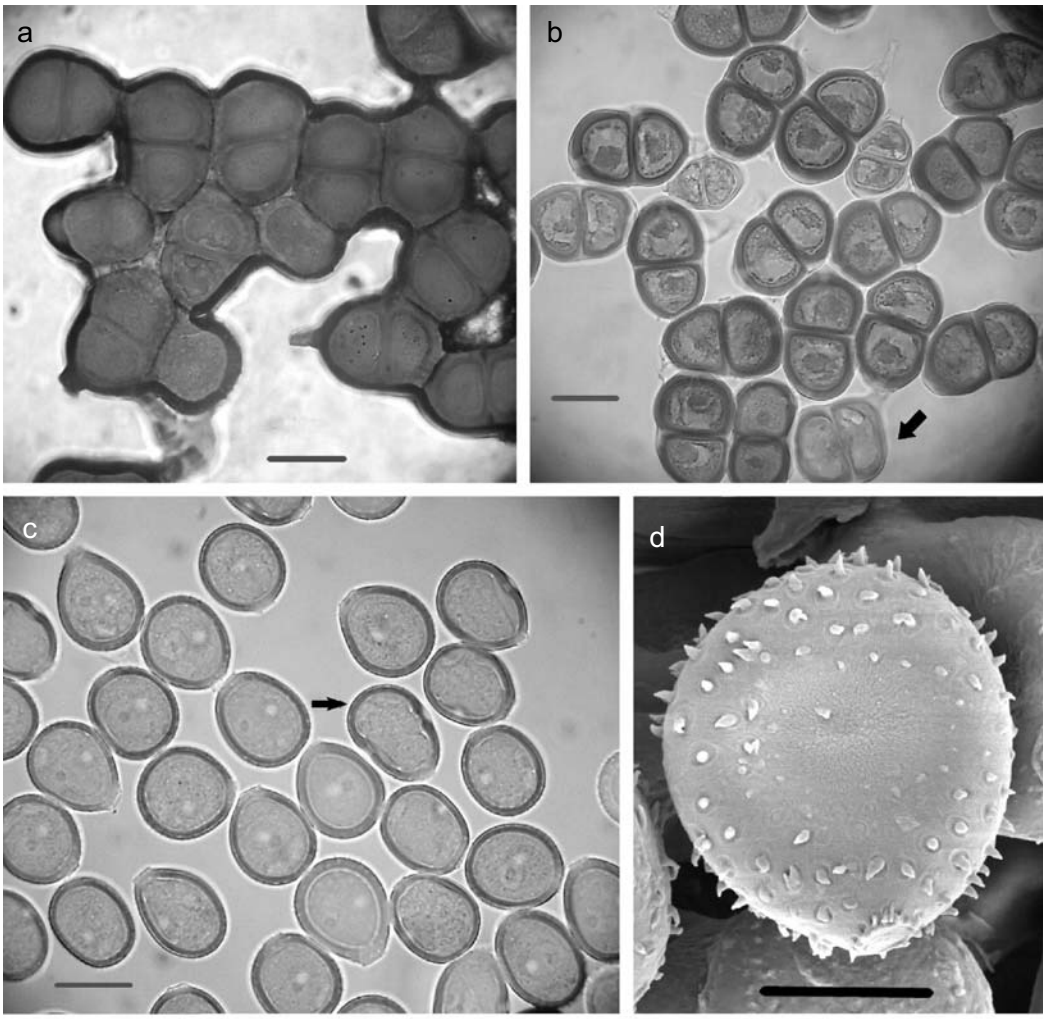
Fig. 1. *Puccinia geranii-pilosi* McAlpine. a – teliospores from dried lectotype slide VPRI 41730a; b – teliospores, with one spore (arrowed) approaching diorchidioid in shape, from DAR 75666; c – urediniospores showing two mainly equatorial germ pores, spore in side view (arrowed) showing flattening, from DAR 75666; d – SEM of urediniospore showing tonsure, from DAR 75666 (sent by R. G. Shivas and D. Tree); e – two original slides (VPRI 41730) examined by McAlpine, the lower slide VPRI 41730a chosen as lectotype of the name *P. geranii-pilosi* McAlpine. Scale bars: a–c = 20 μm, d = 10 μm, e = ruler in mm.


a
b
c
d
e
Dept. of Agriculture, Victoria.
Puccinia geranii-pilosi
Geranium pilosum
Dept. of Agriculture, Victoria.
Puccinia geranii-pilosi
Geranium pilosum
Pathologist & Botanist
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sparsely echinulate except for tonsure 12–15 µm wide below each pore, hilum 4.5–6.0(–6.5) µm wide, slightly protruding, usually with no pedicel fragment attached in mature spores. Pedicel deciduous, hyaline, 45–50 µm long. Telia mainly on stems and petioles, elongated, 0.5–1.5 mm long on petioles, to 6 mm long and 0.5–1.0 mm wide on stems, a few small circular telia on leaves amongst uredinia, erumpent, aparaphysate, with a dark reddish-brown to black spore mass. Teliospores pedicellate, golden-brown to reddish-brown, ellipsoidal, slightly constricted at the septum, (32–)35–44(–48) × (22–)23–29(–31) µm, wall apparently smooth, uniformly 2.5–3.0 µm thick in upper cell, slightly thinner in lower, germ pore apical or slightly depressed to one side in upper cell, in lower cell just below septum or up to ¼ depressed, pores with a large hyaline to faintly yellow pore cap to 11 µm wide and 1.5–2.0 µm high, hilum 6.5–9.0 µm wide, often with pedicel 30–45 µm long attached, hilum usually basal, occasionally closer to septum and spore approaching diorchidioid in shape (Fig. 1b). Mesospores rare, similar in colour to teliospores, subglobose to oval, to 26 × 24 µm, apical wall thickened to 4 µm, pierced by a pore.

SPECIMENS EXAMINED. AUSTRALIA. NEW SOUTH WALES: on *Geranium* sp., Kurrajong Heights, in or before 1905 (see text), *C. T. Musson* (VPRI 3605; formerly 120/05), II. On *Geranium retrorsum* L'Hér. *ex* DC., in paddock, Barcoo Close, Clifton Grove, near Orange, Oct. 1999, *M. J. Priest* (DAR 75666, EPITYPE), II, III. VICTORIA: on *Geranium* sp. (as *Geranium pilosum* Forst.), Killara, 2 Oct. 1902, *G. H. Robinson* (VPRI 3606; formerly 467/02, duplicate as MEL 1054143), II; Killara, March 1903, *G. H. Robinson* (VPRI 41730; formerly 209/03), II, III, two microscope slides only, the one labelled 'Tel. Killara March/03 GHR' filed as VPRI 41730a is LECTOTYPE (see text). NEW ZEALAND: on *Geranium homeanum* Turcz. (formerly as *G. dissectum* L. var. *glabratum* Hook.f.), Day's Bay, Wellington, April 1925, *E. H. Atkinson* (DAR 62519; duplicate *ex* PDD 1848), II.

In his original description, McAlpine (1906) listed three collections: two from Killara, Victoria, collected by Robinson in October 1902 and March 1903, and one said to be from Richmond, NSW collected by Musson with no date given. The Musson collection is filed as VPRI 3605, with McAlpine's accession number 120/05, the locality 'Kurrajong Heights' written on the original packet, and 'old' written under 'Date'. The locality discrepancy can be explained as, at the time, C. T. Musson was science master at Hawkesbury Agricultural College at Richmond, and made many collections in the surrounding country, including Kurrajong Heights, about 14 km NW of Richmond. McAlpine's note 'old' with his 120/05 accession number shows that he received the collection in 1905, but it had been collected earlier.

McAlpine (1906) did not nominate a type for *P. geranii-pilosi*. The October collection from Killara, VPRI 3606, its duplicate MEL 1054143, and VPRI 3605 from Kurrajong Heights, had only uredinia present. On the packet of VPRI 3606, McAlpine wrote 'See 209/03 for teleutospores'. This specimen is no longer present in VPRI (J. Cunnington, pers. comm., 7 Dec. 2009) and there is no duplicate of it in MEL (T. May, pers. comm., 27 Jan. 2010). However, two microscope slides in VPRI, prepared from 209/03 by G. H. Robinson, the original collector and McAlpine's assistant, and now accessioned as VPRI 41730, have been examined (Fig. 1e). Both are badly dried out. One showed a few distorted urediniospores and one teliospore was found. In the other, labelled 'Tel. Killara March/03 GHR', many teliospores are present (Fig. 1a), agreeing with the original description and illustration, and with spores from the 1999 collection (Fig. 1b). As this is the only portion remaining of the original telial material, collected in March 1903 and examined by McAlpine, the slide VPRI 41730a bearing this label is selected as LECTOTYPE of the name *Puccinia geranii-pilosi* McAlpine (Fig. 1e). The only other known collection with teliospores, the 1999 collection DAR 75666 with abundant uredinia and telia, is nominated as EPITYPE.

Urediniospores have two, mainly equatorial, germ pores, and are flattened in the vertical plane (Fig. 1c). A very rare spore with three scattered germ pores was seen. A urediniospore wall tonsure has not been described previously for *P. geranii-pilosi*. One is present on each flattened face (Fig. 1d), with a germ pore just above or just inside its upper edge.

In Australia, *P. geranii-pilosi* is known only in New South Wales (McAlpine 1906; Noble *et al*. 1935) and Victoria (McAlpine 1906; Chambers 1982). Wade *et al*. (1959) listed a 1951 report on *Geranium* sp. from Tasmania, with the comment 'General'. No specimen exists to support this (D. Metcalf, pers. comm., 8 April 2010), and the comment 'General' may indicate that the entry refers to the widespread *P. pelargonii-zonalis* on zonal pelargonium, commonly called 'geranium' in Australia. Sampson and Walker (1982) mistakenly listed *P. geranii-pilosi* from Tasmania on *G. solanderi*, listing a Rodway collection RH 656, the host determined originally as *G. molle* L. This collection has been examined and the rust is not *P. geranii-pilosi* but *Uromyces geranii* (DC.) Fr. *s.l*. Full details are given under that name and, at present, there is no authentic record of *P. geranii-pilosi* from Tasmania. It is rarely found, the only collections located are listed above and, apart from the 1999 specimen, it has not been seen in recent years. It has been known on native *Geranium* species in New Zealand since at least 1855 (Cunningham 1931; McKenzie 1998). Lindquist (1982) recorded it on *G. berteroanum* Colla in Argentina and mentioned that it occurs also in Chile.

Puccinia geranii-pilosi has only uredinia and telia but, with so few specimens known, it may be a long-cycled rust whose pycnia and aecia have not yet been found. Its relationship to several other *Puccinia* species on *Geranium* is unknown. It resembles the hemicyclic *P. geraniphila* Lindquist in Argentina (Lindquist 1982), with urediniospores of similar size, and longer (to 61 µm), similarly shaped teliospores, with the lower cell germ pore not depressed, and the wall described as smooth. Lindquist made no mention of a urediniospore tonsure. The hemicyclic *P. distenta* Jackson & Holway, in Jackson (1931) on *Geranium* spp. in Bolivia and Chile (Lindquist 1982) appears distinct. It has similar urediniospores (tonsure not mentioned) but its teliospores, of similar size, were described with smooth walls, thicker (3–5 µm) at the sides and to 9 µm at the apex (Jackson 1931). Urediniospores and teliospore of *P. geranii-pilosi* are similar in size and shape to those of the macrocyclic *P. callaquensis* Neger (Lindquist 1982) in Argentina, except that its teliospore wall is finely verrucose and the germ pore in the lower cell is not depressed. Lindquist's (1982) description of *P. geranii-pilosi* in Argentina is similar to that given above, except that he gave the teliospore apical wall as 4–6 µm thick. Australian collections show the apical wall not, or only slightly, thickened, but the wide apical pore cap gives an impression of thickness.

The ellipsoidal teliospores of *P. geranii-pilosi* are generally similar in size and shape to those of several microcyclic rusts of *Geranium*. The best known is *P. leveillei* Mont. *in* Gay (in some earlier works as *P. geranii-silvatici* P. Karst.), present in parts of Africa, Asia, Europe, and North and South America on several *Geranium* spp. (Gäumann 1959; Sivanesan 1970b; Majewski 1979; Zhuang 2003; Farr & Rossman 2010). Teliospores have the germ pore in the lower cell depressed, with the wall strongly warted in the upper cell, more finely in the lower. Four other microcyclic taxa are the African *P. escharoides* Syd. & P. Syd. on *Geranium* sp. and *P. geranii-aculeolati* Petrak (1955) on *G. aculeolatum* Oliv., and the Middle Eastern *P. saniniensis* P. Magn. on *G. crenophilum* Boiss. in Syria (Sydow & Sydow 1903) and *P. geranii-tuberosi* Petrak on *G. tuberosum* L. in Iran (Petrak 1953), all with teliospores showing varying degrees of wall roughening.

In China, teliospores of the microcyclic *P. geranii-doniani* J. Y. Zhuang & S. X. Wei (Zhuang 2003) on *Geranium donianum* Sweet are 35–55(–60) × (18–)20–25(–32) µm, slightly longer than those of *P. geranii-pilosi* but of similar width, and with a more prominent conical apical pore cap. The wall is described as smooth and uniformly thickened, with the germ pore in the lower cell just below the septum. *P. geranii-polyanthis* J. Y. Zhuang on *G. polyanthes* Edgew. is quite distinct, with much longer, thinner urediniospores 30–50 × 12–20 µm, thickened at the apex and with 2(–3) equatorial germ pores, and long thin teliospores 28–63 × 13–23(–25) µm (Zhuang 2003).

The name *Geranium pilosum* Sol. was used in the original description by McAlpine (1906) for the host of *P. geranii-pilosi*. On his specimens, it is given as *G. pilosum* Forst. The nomenclature of Australian species of *Geranium* has been thoroughly

examined by Carolin (1965, 1967). He introduced the new name *G. solanderi* Carolin (1965) for the Australian taxon erroneously named *G. pilosum* Sol. *in* Forst., a later homonym of *G. pilosum* Cav.; a full discussion of the synonymy is given in Carolin (1965). McAlpine's material may be *G. solanderi*, or perhaps the related *G. homeanum* or *G. retrorsum* L'Hér. *ex* DC (Carolin 1965, 1967). All are widely distributed in Australia and New Zealand. In MEL 1054143, a duplicate of the Killara 1902 collection, a few young flower pedicels were found, showing long, stiff, not appressed hairs, similar to those figured by Carolin (1965) for *G. solanderi*. However, precise identification of the host in McAlpine's specimens is not possible due to lack of diagnostic features. In New Zealand, hosts of *P. geranii-pilosi* are *G. homeanum*, *G. potentilloides* L'Hér. *ex* DC., and *G. solanderi* (McKenzie 1981, 1998). Cunningham (1931) listed the first two as *G. dissectum* L. var *glabratum* Hook.f. and *G. microphyllum* Hook.f. respectively. Many further collections are needed to clarify the life cycle, host range and geographic distribution of this rust in Australia.

Puccinia morrisonii McAlpine Fig. 2

The Rusts of Australia: 180–181. 1906 (as '*morrisoni*').

Persooniella morrisonii (McAlpine) Syd., Ann. Mycol. **20**(3): 118. 1922 (as '*morrisoni*').

Sori mainly on leaf blades and petioles, also on stems, almost entirely on lower leaf surface except for pycnia, and occasional aecia, uredinia and telia on upper surface. Pycnia type 4, on upper leaf surface on yellowed areas 3–4 mm across, to 5 mm long on petioles, up to 40 pycnia on a spot, pale amber to brown, globose body (80–)120–150(–175) μm diam., embedded in leaf tissue with a protruding bundle to 45 μm wide of parallel amber paraphyses, of variable length and many broken in dried specimens. Pycniospores hyaline, subglobose to oval, 2–3 μm. Aecia almost entirely on lower surface below pycnia, closely clustered in groups to 5 × 3 mm containing up to 40 aecia, sometimes extending along leaf vein, on yellow, later brown necrotic, areas, individual aecia subepidermal, later erumpent, pale yellow, peridium short, revolute, often broken in dried specimens, 200–250(–300) μm across. Peridial cells elongated oval, 18–25 μm long, 15–25 μm wide in face view, 13–15 μm thick in side view, outer wall 4–5 μm thick, faintly striated, prolonged at base into a spur 10–12 μm long interlocking with cell below, inner wall of similar thickness, coarsely and densely verrucose. Aeciospores catenulate, with pale yellow contents, subglobose to oval, 18–22(–25) × (13–)15–20(–22) μm, wall less than 1 μm thick, closely and finely verruculose with scattered, slightly larger, more refringent, warts (see text). Uredinia subepidermal then erumpent, exposing the reddish-brown spore powder, scattered singly or more commonly in groups, or with a central sorus surrounded by 1–2 concentric rings of sori, individual sori from less than 100 to 500 μm diam., surrounded by a torn rim of host tissue, aparaphysate. Urediniospores pedicellate, golden yellow to pale golden brown, slightly flattened in the vertical plane, subgloboid to obovoid in face view, oval to narrowly obovoid in side view, (22–)23–28(–30) μm long, (18–)20–25 μm wide in face view, (15–)18–20 μm thick in side view, side wall (1.5–)2.0–2.5 μm thick, often thicker to 3–4 μm at base around the hilum, echinulate with spines 1.0(–1.5) μm high and (1.5–)2.0(–2.5) μm apart, except for a tonsure 9–12 μm across on each flattened face, germ pores two, very rarely three, mainly opposite, one on each flattened face usually near upper margin of tonsure, mainly equatorial, sometimes supraequatorial or at different levels (see text), each pore with a shallow hyaline pore cap 6–8 μm wide, 1 μm high in the centre. Hilum not or slightly protruding, 4(–8) μm wide. Pedicel hyaline, (15–)20–50 μm long, deciduous, no fragment remaining attached to spore. Telia subepidermal, long covered by host tissue but eventually erumpent, dark reddish-brown to almost black, individually 100–500 μm across, scattered or more commonly in loose groups along leaf veins, or in 1–2 concentric circles 3–5 mm across surrounding a single central uredinium or telium, larger and more obvious on petioles and stems in elliptical groups or fusiform patches 5–10 mm long and 1–2 mm wide, these sometimes joining to give

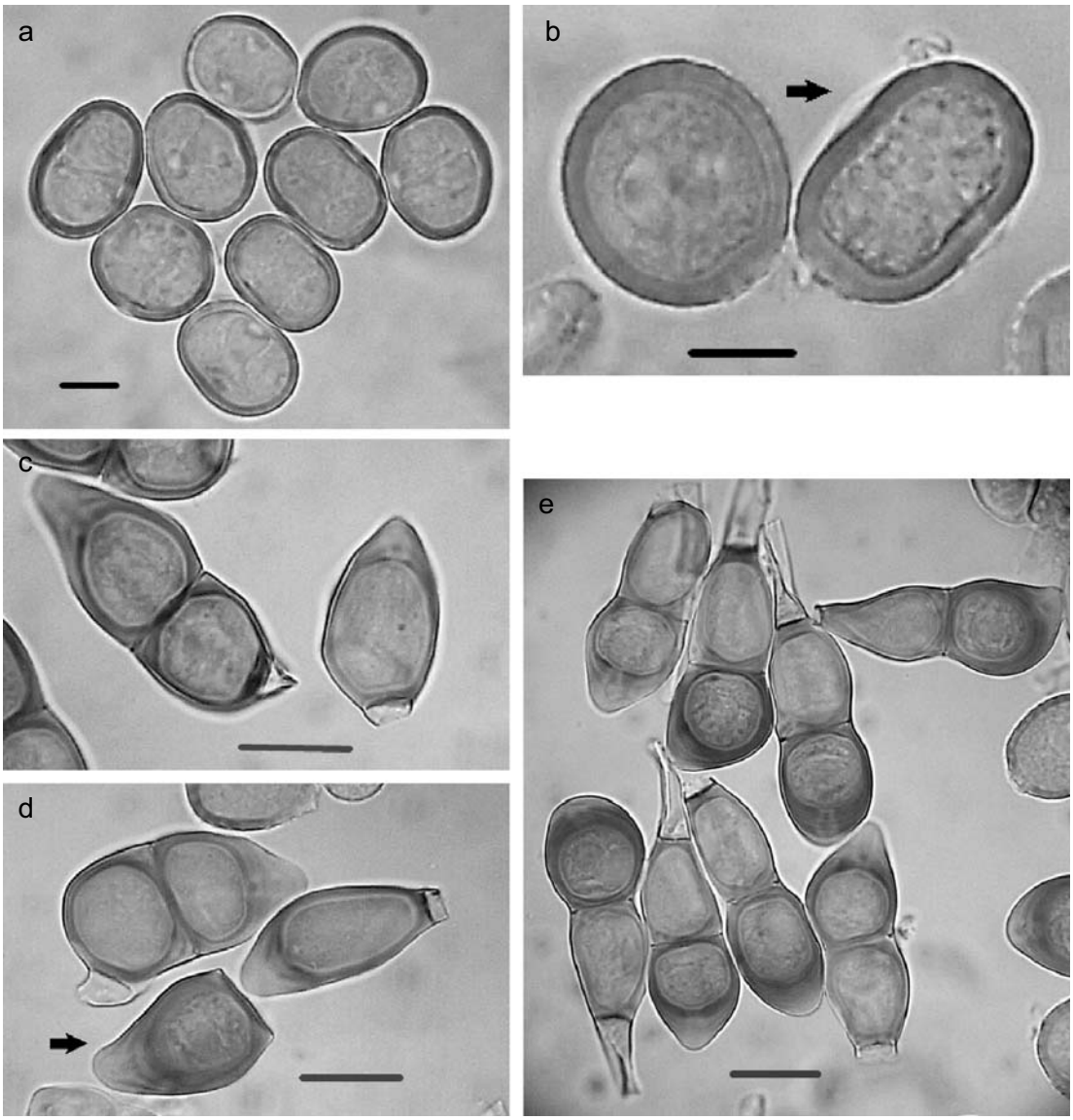

Fig. 2. *Puccinia morrisonii* McAlpine. a – urediniospores, some in side view, two opposite germ pores present, from DAR 77036; b – two urediniospores showing wall thickness and one spore (arrowed) in side view with two opposite germ pores, each with a shallow hyaline pore cap, from HO 554434; c – beaked teliospore with mesospore, from DAR 25463; d – short, wide teliospore with eccentric hilum and pedicel fragment, one mesospore, and a single upper cell (arrowed) from a teliospore that broke in the middle, from DAR 25463; e – several typical teliospores from DAR 25463. Scale bars: a & b = 10 μm, c–e = 20 μm.

blackened areas 5–6 cm long. Teliospores pale yellow brown to pale reddish-brown, upper cell usually slightly darker than lower, mainly narrowly to broadly clavate, occasionally widest in the middle and almost fusiform or wider in the basal cell and obclavate, slightly constricted at central septum, upper cell generally wider than lower, (40–)46–64(–68) μm long, (16–)17–24(–26) μm wide, lower cell usually 2–3 μm narrower than upper, wall apparently smooth, side

wall in upper cell 1.5–3.5(–4.0) μm thick, in lower cell 1.5–2.0(–2.5) μm thick, apically thickened to (5–)7–13(–14) μm, apex bluntly conical, more rarely rostrate, wall thicker to 3–5 μm in corners of cells at central septum and at the hilum, germ pore in upper cell apical through the thickened wall, in lower cell just below the septum. Hilum 4.5–9.0 μm wide, with a pale yellow pedicel fragment to 25 μm long remaining attached, pedicel in sori 35–40 μm long. Teliospores when mature often break at the central septum into two separate cells. Mesospores present in telia, same colour as teliospores, very variable in shape from narrowly clavate to cylindrical, pyriform or obpyriform, (34–)35–53(–59) × (13–)15–20 μm, wall smooth, 1.5–2.0 μm thick at sides, slightly thicker at hilum, 7–11 μm at the bluntly obconical to rostrate apex, a single germ pore through the thickened apex.

SPECIMENS EXAMINED. AUSTRALIA. NEW SOUTH WALES: on *Pelargonium australe* Willd., in sand dunes, 1 km S of lake, Lake Conjola, 1 Sept. 1975, *J. Walker* (DAR 25463; duplicates as BRIP 14726, HO 133163), II, III; dunes behind Ocean Beach, Umina, 20 July 1988, *J. Walker 88/44* (DAR 75626), 0, I, II, III; Avalon, 30 Oct. 1960, *L. R. Fraser* (DAR 5978), II; Newport, Oct. 1930, *R. J. Noble* (DAR 1661), II. SOUTH AUSTRALIA: on *Pel. australe*, Port Noarlunga, May 1924, *I. Davies* (VPRI 3883), 0, I, II. On *Pel. inodorum* Willd., Meningie, Aug. 1955, *L. Williams* (ADW 6272), 0, I. TASMANIA: on *Pel. australe*, Devonport, 18 Jan. 1906, *G. H. Robinson* (VPRI 3873), II, III (issued as Sydow Uredineen No. 2069); shore near heads, Port Arthur, April 1918, *L. Rodway* (R.H. 655 p.p., HO 554434), II, III. VICTORIA: on *Pel. australe*, Kiewa Valley, 10 Dec. 1903, *G. H. Robinson* (VPRI 3881, LECTOTYPE; duplicate as MEL 1055088, ISOLECTOTYPE, see note in text), 0 I, II, III; Phillip Island, 30 Jan. 1900, *D. McAlpine* (VPRI 3880), II, III; Lerderderg Gorge near Bacchus Marsh, 30 Oct. 1920, *C. C. Brittlebank* (VPRI 3885), 0, I, II, III; Eurobin Falls, Mount Buffalo, 7 Jan. 2005, *J. J. Burdon* (DAR 77036), II, III. WESTERN AUSTRALIA: on *Pel. littorale* Hügel, 97.4 km from Armidale on Albany Highway, 24 June 1992, *J. K. Scott* (PERTH 02175517; duplicate as DAR 75619), II, III.

In the original description, McAlpine (1906) listed three collections from Victoria and one from Tasmania. None was chosen as type, so a lectotype is selected from them. A collection on *Pel. australe* from the Murramurrangbong Ranges made in December 1903 has pycnia (not noted by McAlpine), aecia, uredinia and telia present. This collection was given the number 1041/03 and its entry in McAlpine's specimen accession book reads '1041. *Pelargonium australe* Kiewa Valley GHR 10.12.03 *Puccinia pelargonii* I, II, III Aecidia new. Substit. for *P. geranii*'. On the packet of 1041/03 (now VPRI 3881) in McAlpine's herbarium, the date is given as '5–10/12/03', and the name '*Puccinia pelargonii*' is crossed out and replaced by '*Puccinia morrisoni* McAlp. I, II, III'. A duplicate of this collection is filed as MEL 1055088 with the original number 1041/03 and handwritten label as '*Puccinia morrisoni* McAlp.', the locality given as 'Murramurrangbong Ranges, Vic.' and the date as '10.12.03'. The Kiewa Valley is in the Murramurrangbong Ranges. Whether the original 1041/03 is one gathering, or more than one lumped together and collected between 5th and 12th December 1903, is not known. The identical rust and spore stages are present in both VPRI 3881 and MEL 1055088. The specimen in McAlpine's herbarium, VPRI 3881, is chosen as LECTOTYPE for the name *Puccinia morrisonii* McAlpine, with MEL 1055088 as ISOLECTOTYPE. The correct spelling of the specific epithet is '*morrisonii*' [*International Code of Botanical Nomenclature* (*Vienna Code*) 2006, Art. 60, Rec. 60C].

Cooke (1892) was the first to record a rust on *Pel. australe* in Australia from a collection made by Morrison in Victoria. He briefly mentioned uredinia and telia and named the rust '*Puccinia geranii* Corda' (this name is probably based on the rust of *Artemisia* (Asteraceae) currently known as *P. tanaceti* DC., see Hylander *et al*. 1953; Sydow & Sydow 1903). McAlpine (1906) described aecia, uredinia and telia, but made no mention of pycnia, which were first noted by Samuel (1924) from a South Australian collection, or of urediniospore germ pores, first mentioned by Cunningham (1931), as 'germ pores 2, equatorial'. In the present study, the number of spores with equatorial germ pores varied between collections. Over all collections seen, 40–70% of spores had equatorial pores, with the remainder mainly supraequatorial but 10–20% of spores had pores at different levels

in some specimens (compare with *P. pelargonii-zonalis* below).

Aeciospores are similar in size, shape and verrucosity in all collections examined, but some variation has been seen. In the lectotype VPRI 3881 and its duplicate MEL 1055088 from Victoria, and in VPRI 3883 from South Australia, all on *Pel. australe*, from 2–5 indistinct scattered pores were seen, often in the rounded angles of the spore wall. These collections also had typical uredinia and telia present. By contrast, on ADW 6272 on *Pel. inodorum* from South Australia, with only pycnia and aecia present, no germ pores could be seen in the aeciospores. Further study of specimens on different host species, including study of aeciospore germination from fresh collections, is needed to see if more than one taxon is present. The minute warts on the aeciospore wall are partly deciduous, leaving irregular smooth areas in older spores.

Doidge (1927) thought that *P. morrisonii* may be the same as the earlier described, long cycled, South African *P. granularis* Kalchbr. & Cooke on several native *Pelargonium* spp. there (Sivanesan 1970a). Material of *P. granularis* has not been examined during this work, but minor differences are described in the literature. Several publications describe urediniospores of *P. granularis* with walls over 3 µm thick (Doidge 1927; Cunningham 1931, both as 3.0–3.5 µm; Mennicken & Oberwinkler 2004, as 2.5–3.5 µm), whereas those of *P. morrisonii* are mainly 2.0–2.5 µm, rarely 3.0 µm thick, and none thicker than 3.0 µm have been seen (Fig. 2a, b). Teliospores of the two species are similar in shape and apical thickening, but those of *P. granularis* are said to be up to 80 µm long (Doidge 1927) whereas those of *P. morrisonii* rarely exceed 68 µm. The longest seen in all collections examined was a single teliospore 74 µm long in one of the specimens listed by McAlpine (1906), VPRI 3879 collected in 1900 from Phillip Island. Care should be taken not to confuse the single cells from teliospores that have broken in the middle with mesospores (Fig. 2d).

In Australia, seven native *Pelargonium* spp. occur in the southern half of the continent, with *Pel. australe* and *Pel. inodorum* Willd. just reaching the far south-eastern corner of Queensland (Carolin 1962; Hnatiuk 1990). Specimens of *P. morrisonii* on *Pel. australe* (mainly), *Pel. inodorum* and *Pel. littorale* have been seen. The rust is not recorded for Queensland, northern Western Australia or the Northern Territory, but is relatively common in the other states. Its precise host range requires clarification. In most collections, the host is given as *Pel. australe* but the distribution of this species overlaps with that of the six other native taxa, especially *Pel. inodorum* in New South Wales and *Pel. rodneyanum* Mitch. *ex* Lindl. *in* Mitch. in New South Wales, Victoria and South Australia (Carolin 1962). Future rust collections should ensure that specimens are suitable for accurate host species identification.

Puccinia morrisonii is at present confined to Australia and New Zealand (McAlpine 1906; Cunningham 1931; McKenzie 1998) but there are two dubious reports from outside the Australasian region. In their book on the rusts of Madagascar, Bouriquet and Bassino (1965) recorded *P. morrisonii* (as '*morrisoni*') on *Pel. zonale* from the Tananarive district. In French, they describe sori on leaves, and aeciospores, urediniospores, teliospores and mesospores. Only urediniospores and teliospores were illustrated. No specimen details were given and they made no definite statement about the spore stages they observed in Madagascar. Comparison of Bouriquet and Bassino's French description of *P. morrisonii* with McAlpine's (1906) original English description shows that theirs is an almost literal translation from McAlpine, using his terms and measurements for all spore stages (they do not include teliospore measurements). It does not appear to be a description based on specimens from Madagascar. Three obovoid urediniospores illustrated have relatively thin walls, and three teliospores are not markedly thickened at the apex. Both are more similar to spores of *P. pelargonii-zonalis* than to those of *P. morrisonii*. World-wide, the only confirmed rust on zonal pelargonium is *P. pelargonii-zonalis.* The record of *P. morrisonii* on zonal pelargonium in Madagascar is highly dubious, and is most probably a record of the widespread *P. pelargonii-zonalis* on this host. Farr and Rossman (2010) listed the Bouriquet and Bassino record and, citing these authors,

included *Pel. australe* as a host for *P. morrisonii* in Madagascar. This is incorrect, as Bouriquet and Bassino's comment refers to the occurrence of *P. morrisonii* on *Pel. australe* in Australia.

Farr and Rossman (2010) list a specimen, BPI 032484, determined as '*P. morrisoni*' on *Pelargonium* sp. from Mexico, intercepted in quarantine in 1977. Two other quarantine collections, BPI 086948 and BPI 086949, as '*P. morrisoni*' on *Pel. zonale* from Australia in 1971 and 1966 respectively, are included. As noted already, the only rust known on *Pel. zonale* in Australia and elsewhere is *P. pelargonii-zonalis*, and the 1977 Mexican specimen is probably this species.

Puccinia pelargonii-zonalis Doidge Fig. 3

Bothalia **2**: 98. 1927.

Pycnia and aecia unknown. Sori mainly on lower leaf surface, very few on upper surface, in heavy infections often on petioles and flower peduncles, individually 0.25–1.00 mm across, either sparsely or densely scattered, commonly arranged in 1–3(–5) concentric circles, with a large central sorus to 1 mm across surrounded by rings of smaller 0.25–0.50 mm sori, these circles 3–10 mm diam., surrounded by a paler green halo of host tissue, on old yellowed leaves the green colour persisting around groups of sori. Uredinia subepidermal, erumpent with a reddish-brown powdery spore mass, aparaphysate. Urediniospores golden-brown, broadly oval, ovoid to obovoid or approaching subgloboid, slightly flattened in the vertical plane, (22–)24–33(–34) μm long, 20–24 μm wide in face view, and (16–)18–20(–21) μm deep in side view, wall 1.5–2.0(–2.5) μm thick at sides, sometimes to 3(–4) μm thick at base around the hilum, echinulate, spines 1.0–1.5 μm long and 1.5–2.5 μm apart, except for a tonsure 10–12(–14) μm wide on each flattened face, germ pores two (very rarely three), mainly opposite with one on each flattened face, 60–80% supraequatorial, with up to 20% equatorial and 20% at different levels in some collections, each pore with a shallow hyaline pore cap 4–6 μm wide and 0.5–1.0 μm high, hilum 4–6(–7) μm wide, sometimes slightly protruding, pedicel deciduous. Telia dark reddish-brown to greyish-black, long covered by host cuticle and epidermis, eventually erumpent with a compact dark spore mass, individually often small, 50–100 μm across, or several fusing to form a compound sorus, often arranged in 1–2 concentric circles around a central uredinium, aparaphysate. Teliospores golden-brown to reddish-brown, upper cell often slightly darker than lower, variable in shape from almost rectangular, to elongated oval, commonly narrowly to broadly clavate, straight or slightly curved, (35–)36–50(–54) × (17–)18–24(–26) μm, wall apparently smooth, side wall (1.0–)1.5–2.0(–2.5) μm thick in both cells, thickened to 3–5(–7) μm at the apex, which is flattened or narrowly obconical, apical thickening central or slightly to one side, germ pore through apical thickening in upper cell, below the septum in lower cell. Hilum (4.5–)5–10(–11) μm wide, usually with a fragment of hyaline pedicel 20–25 μm long remaining attached. Mesospores common in some collections, similar in colour to teliospores, very variable in size and shape, 25–42 × 15–20 μm, with apex unthickened or commonly with a conical thickening 2.5–6.0(–8.0) μm. Mature teliospores sometimes separate into two cells at the septum.

SPECIMENS EXAMINED. All on *Pelargonium* × *hortorum* L. H. Bailey: AUSTRALIA. NEW SOUTH WALES: Sydney, Oct. 1914, collector not given (DAR 345), II; Port Hacking, 7 Aug. 1915, *E. Cheel* (VPRI 3875), II, III; Toongabbie, 27 Dec. 1965, *J. Walker* (HO 133227), II; Baulkham Hills, 4 Aug. 1995, *J. Walker 95/61* (DAR 75583), III, X; same, *J. Walker 95/62* (DAR 75584), II; garden, Australian National University, Canberra, 25 Feb. 2005, *M. M. van der Merwe* (DAR 77063), II; Port Macquarie, 18 June 1992, *J. Walker 92/88* (DAR 68456), II, III, X. QUEENSLAND: Norman Park, Brisbane, Oct. 1915, *J. Keys* (DAR 30361), II; Toowong, 17 Sept. 1916, *M. A. Wooller* (DAR 69629 *ex* BRIP 3606), II, III, X; Taringa, 3 Dec. 1926, *J. H. Simmonds* (BRIP 3604; originally as '*P. morrisoni*'), II. SOUTH AUSTRALIA: Victor Harbour, Jan. 1920, *T. G .B. Osborn* (ADW 886), II, III; Urrbrae, April 1924, *G. Samuel* (ADW 883), II, III. TASMANIA: Hobart, Dec. 1918, *L. Rodway* (HO 554435), II. VICTORIA: Burnley Gardens, 4 April 1917, *C. French* (VPRI 3876; originally as '*P. morrisoni*'), II; Kew, Nov. 1934, *A. T. Pugsley* (VPRI 3877; originally as '*P. morrisoni*'), II; Portland, 16 Dec. 1961, *A. C. Beauglehole 5240* (MEL 1054720), II; Metung, 20 Mar. 1992, *J. Walker 92/24* (DAR 68228), II, III. LORD HOWE

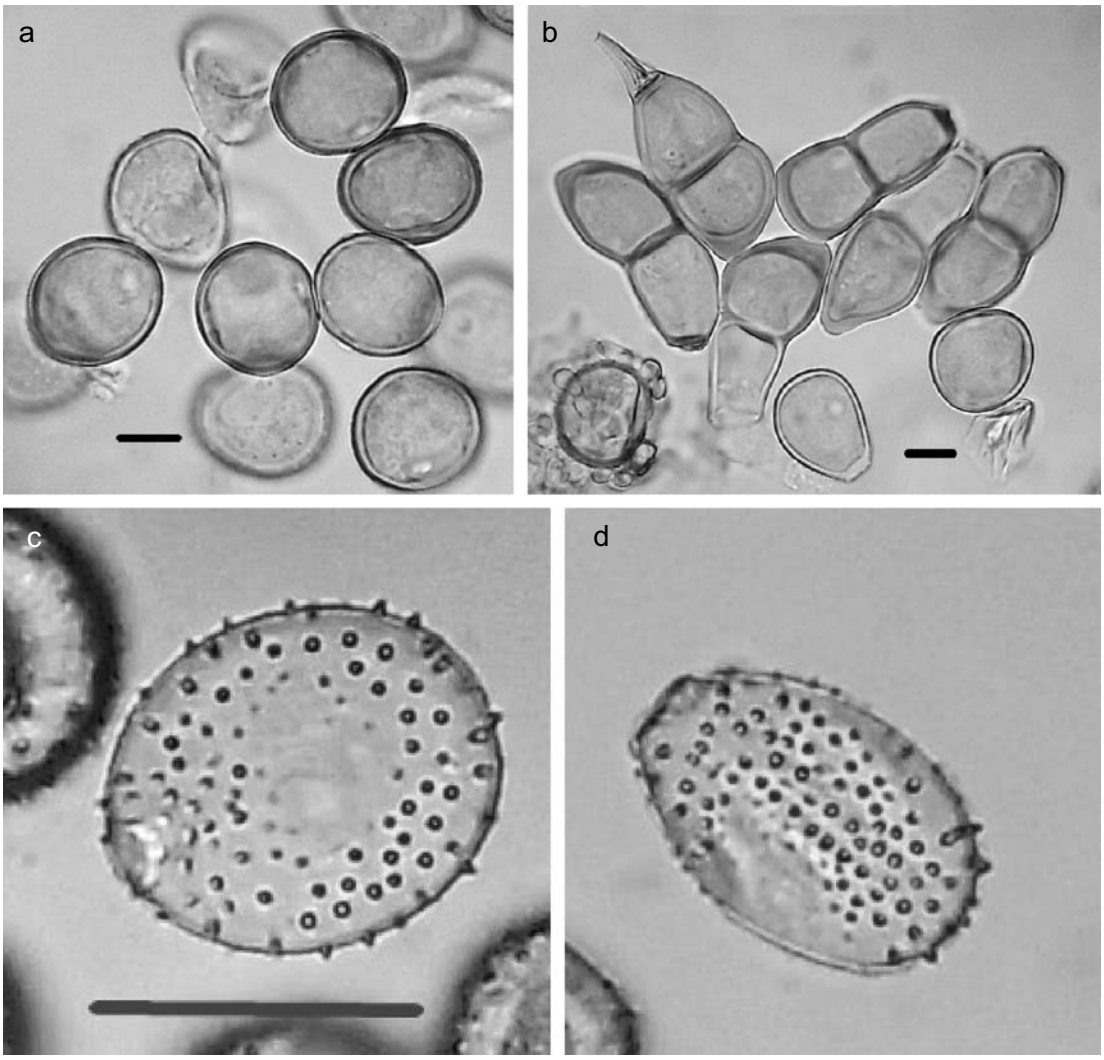

Fig. 3. *Puccinia pelargonii-zonalis* Doidge. a – urediniospores with two opposite germ pores and thin wall, from DAR 68228; b – teliospores showing variation in shape and apical thickness, and two urediniospores, from DAR 75583; c & d – two urediniospores in water showing tonsure, one face view, the other side view, from DAR 75584. Scale bars: a & b = 10 μm, c & d = 20 μm.

ISLAND: Old Government House, 11 Dec. 1991, *M. J. Priest & J. Bates* (DAR 69244), II. NORFOLK ISLAND: garden of J. Powell, Headstone, 11 Oct. 1960, *J. Walker* (DAR 8389), II.

Doidge (1927) described urediniospore germ pores as 'equatorial', as did several later authors (e.g., Cunningham 1931; Sivanesan 1970c; Gjaerum 1974; Henderson & Bennell 1979). Majewski (1979) said they were 'slightly above the equator', and Lindquist (1970) and Zambettakis (1965) described them as 'supraequatorial'. In the present study, collections varied but all had at least 60% of urediniospores with supraequatorial germ pores, with some up to 80%. The remainder were equatorial or at different levels (compare with *P. morrisonii* above). Although not mentioned in his text, Majewski (1979, Fig. 20) drew a smooth patch on the urediniospore wall just below the germ pores, the first report of a urediniospore tonsure in this rust (Fig. 3c, d).

Puccinia pelargonii-zonalis is native to South Africa on *Pel. zonale*. It had spread to Australia and New Zealand prior to its original description in 1927 and several names were used for it. The precise date and method of its introduction are not known. McAlpine (1895, 1906) made no mention of a rust on zonal pelargonium in his list of Australian fungi, and rust monograph, respectively. The earliest published report seen is that of Tryon (1915) who said that geranium rust [as *Puccinia pelargonii* (Thuem.) Syd.] was prevalent in South Brisbane, having become established three years earlier (1912). At about the same time, specimens of rust on zonal pelargonium (as '*Pel. zonale*') from several Sydney (NSW) suburbs were exhibited at the July and August 1915 meetings of the Linnean Society of New South Wales (Anonymous 1915) by E. Cheel, who identified the rust first as '*Uromyces* sp. (?)' and then, from a specimen with telia, as '*Puccinia morrisoni*'. Noble *et al*. (1935), in an entry for '*P. morrisoni'* on *Pelargonium* sp., gave the date 1908, but with no clear indication of the host involved. In New Zealand, it was present on zonal pelargonium prior to 1923 when it was determined as *P. granularis* (see Cunningham 1927).

The earliest Australian specimen of *P. pelargonii-zonalis* seen is DAR 345, Sydney, NSW, October 1914, determined originally as '*Puccinia* (?) *morrisoni*'. In DAR, several collections from Sydney suburbs in 1915, including those exhibited by Cheel (Anonymous 1915), are present. The earliest Queensland collection is DAR 30361 from Brisbane in October 1915, and that from Victoria is VPRI 3876, from Burnley, April 1917, both as '*P. morrisoni*'. Soon it was reported over a wider range, with collections from country New South Wales in May 1917 (Forbes, DAR 347), and from Tasmania in 1918 (Sampson & Walker 1982). The earliest South Australian collection seen is ADW 886 from Victor Harbour made in January 1920; ADW 2963, cited by Cook and Dubé (1989), is a 1953 collection from Meningie. In Western Australia, the first record is in November, 1921 (Goss 1964; Shivas 1989), and by 1925, Carne (1925) reported it as common and damaging in Perth and nearby coastal areas. All earlier collections on *Pel.* ×*hortorum* examined, identified originally as '*P. morrisoni*', or in a few cases as *P. granularis*, are *P. pelargonii-zonalis*. As these collections predate the original description of the rust (Doidge 1927), their identification as the native *P. morrisonii*, thought to be infecting the introduced cultivated pelargonium, is understandable. Available evidence suggests that *P. pelargonii-zonalis* was introduced to Australia between 1906, when McAlpine's rust monograph was published, and 1912, when Tryon (1915) reported it from Brisbane, Queensland. From first record dates, introduction was in either Queensland or New South Wales, with later spread south to Victoria and west to South Australia and Western Australia. It is now widespread in temperate Australia, occurring in all states but not the Northern Territory, and it is present on Lord Howe and Norfolk Islands.

Puccinia pelargonii-zonalis spread widely during the 20th century. It was introduced to countries in Australasia, Oceania, Britain and Europe (Zambettakis 1965; Sivanesan 1970c; Henderson & Bennell 1979; Shaw 1984; Dennis 1993; Farr & Rossman 2010), and was recorded from Canada (Hutchison 1996), the United States (Farr *et al*. 1989), and several Central and South American countries, including Mexico, Costa Rica, Brazil, Colombia and Venezuela (Hennen *et al*. 2005; Farr & Rossman 2010). Lindquist (1970) reported an outbreak in Argentina; only urediniospores were seen, which he described and illustrated. He made no mention of it in his later monograph (Lindquist 1982) but Farr and Rossman (2010) note its occurrence there, citing Hernandez and Hennen (2002). There are few Asian reports. In India, Singh and Raghavendra Rao (1990) reported an outbreak in 1984, saying the disease recurred each year. Zhuang (2003) did not treat it in his account of the genus *Puccina* in China, but it was reported there two years later (Zhou & Zhuang 2005). Several authors have said that telia and teliospores are rare (Doidge 1927; Zambettakis 1965; Sivanesan 1970c; Henderson & Bennell 1979; Majewski 1979). They are common in many Australian collections and sometimes abundant, especially along petioles and, on leaf blades, coalescent telia often form a ring around a central uredinium.

World-wide, *P. pelargonii-zonalis* occurs only on the widely grown, cultivated zonal pelargonium, *Pel.* × *hortorum*. In Australia, leaf infection is often heavy and, especially in hot weather, causes varying degrees of yellowing, scorching and leaf drop. Drought conditions severely restrict rust development; plants heavily rusted in normal seasons may show little or no rust during long droughts.

Uromyces geranii (DC.) Fr. Fig. 4

Summa Veg. Scand. (Fries): 514. 1849.

Uredo geranii DC. *in* Lam. & DC., Syn. Pl. Fl. Gall.: 47. 1806, based on telia (synonymy from Laundon 1967a).

Pycnia and aecia seen in one collection (HO 554429), sparse, in group 3.0 × 1.5 mm on lower leaf surface, with 6–8 central, amber, protruding type 4 pycnia surrounded by oval ring of 12 erumpent aecia opening widely at apex to expose pale yellow mass of aeciospores, surrounded by and embedded in a raised, shiny, dark brown margin of host tissue. Aeciospores faintly yellow, subglobose, oval or obovoid, 22–27(–29) × (18–)20–24 µm, a few spores to 33 µm long, wall 2.0–2.5 µm thick, finely and closely verruculose, verrucae partly deciduous in older spores leaving a few small smooth areas, no germ pores seen. Peridial cells few, loose, 30–40 µm long, 24–25 µm wide, wall smooth on one surface, coarsely verruculose on the other, uniformly 2–3 µm thick. Sori on lower leaf surface, a corresponding pale yellow to yellowish-red area on upper surface. Uredinia erumpent, 0.25–1.50 mm diam., scattered or in loose groups to 2 mm across, surrounded by torn margin of host tissue, spore powder reddish-brown, aparaphysate. Urediniospores pedicellate, broadly obovoid to subgloboid, a minority slightly depressed subgloboid (wider than high), golden yellow to golden brown, (20–)21–26(–27) × (21–)22–25(–26) µm, a few larger spores to 31 × 30 µm present, wall 1.5–2.0 µm thick, often slightly thicker at base, with one equatorial or often depressed germ pore, rarely supraequatorial, finely and sparsely echinulate with spines 2–4 µm apart, except for a tonsure 10–12 µm across on the lower third of the spore below the pore, hilum 5–6 µm wide, often slightly protruding and with a pedicel fragment to 12 µm long attached. Pedicel hyaline, 30–60(–70) µm long in sori. Telia dark brown to black, mixed with uredinia on lower leaf surface, 0.25–1.50 mm diam. Teliospores unicellular, in DAR 75671 broadly to narrowly obovoid, a few almost clavate, golden-brown, (30–)31–37(–39) × (18–)20–24 µm, a few rare long thin spores 39 × 15 µm seen; in HO 554429, teliospores elongated oval, clavate to narrowly pyriform, (32–)33–42 × (16–)18–23(–24) µm; wall uniformly 2 µm thick, apparently smooth, apex umbonate with an apical or slightly laterally depressed germ pore covered by a thick, almost hemispherical hyaline pore cap 6 µm wide at the base and 4 µm high (to 6 µm in HO 554429), spore wall around pore cap base torn, hilum 4–6 µm wide, usually with short pedicel fragment 4–7 µm long attached.

SPECIMENS EXAMINED. AUSTRALIA. AUSTRALIAN CAPITAL TERRITORY: On *Geranium solanderi* Carolin aff., S side of car park, Bulls Head, Namadgi National Park, 26 Feb. 2004, *J. Walker 04/33* (DAR 79394), II. NEW SOUTH WALES. On *Geranium solanderi* (formerly as *G. dissectum* L.), Clifton Gardens, Sydney, 10 June 1911, *E. Cheel* (DAR 8520), II (duplicates as DAR 58027, DAR 75673a). On *Geranium* sp., bushy area near toilet block, E side of car park, Piper's Lookout, Snowy Mountains Highway, Brown Mountain, 6 Sept. 2003, *J. Walker 03/72* (DAR 75671), II, III (another collection, DAR 79393, made at the same time, had only II). TASMANIA: On *Geranium molle* L., Dee River, Dec. 1917, *L. Rodway* (HO 554429; R.H. 656 p.p. originally as *Puccinia geranii-pilosi* McAlpine, see text), II, III. AUSTRIA. On *G. pyrenaicum* Burm.f., in valley of Wurzbachtal, near Weidlingau, no date given, *F. von Höhnel*, Kryptogamae exsiccatae Wien No. 1403, as *Uromyces kabatianus* Bubak, II (duplicate as BRIP 6970). CHINA. On *G. sibiricum* L., Heilongjiang, 8 Aug. 1980, *Li Bin* (DAR 44973), II (duplicate *ex* HMAS 41897). ENGLAND. On *Geranium pratense* L., Camber, Kent, 8 Oct. 1963, *B. C. Sutton & K. A. Pirozynski* (BRIP 18850), II, III (duplicate *ex* IMI 102673). On *Geranium* sp. cult., Buckland Abbey, Devon, 12 Sept. 1971, *J. Walker* (DAR 22912), II, III (duplicate as IMI 164389). ITALY. On *G. nodosum* L., Valon de Pâla, Stura Valley, 1877, *C. Bagnis*, Erb. Critt. Ital., Ser. II, No. 738, as *Uromyces puccinioides* Rabenh., III (duplicate as BRIP 1631). THE NETHERLANDS. On *Geranium* sp. cult., Leiden, 25 Sept. 1956, *R. A. Maas Geesteranus*, Fungi neerlandici No. 11776, II, III (duplicate as DAR 14805).

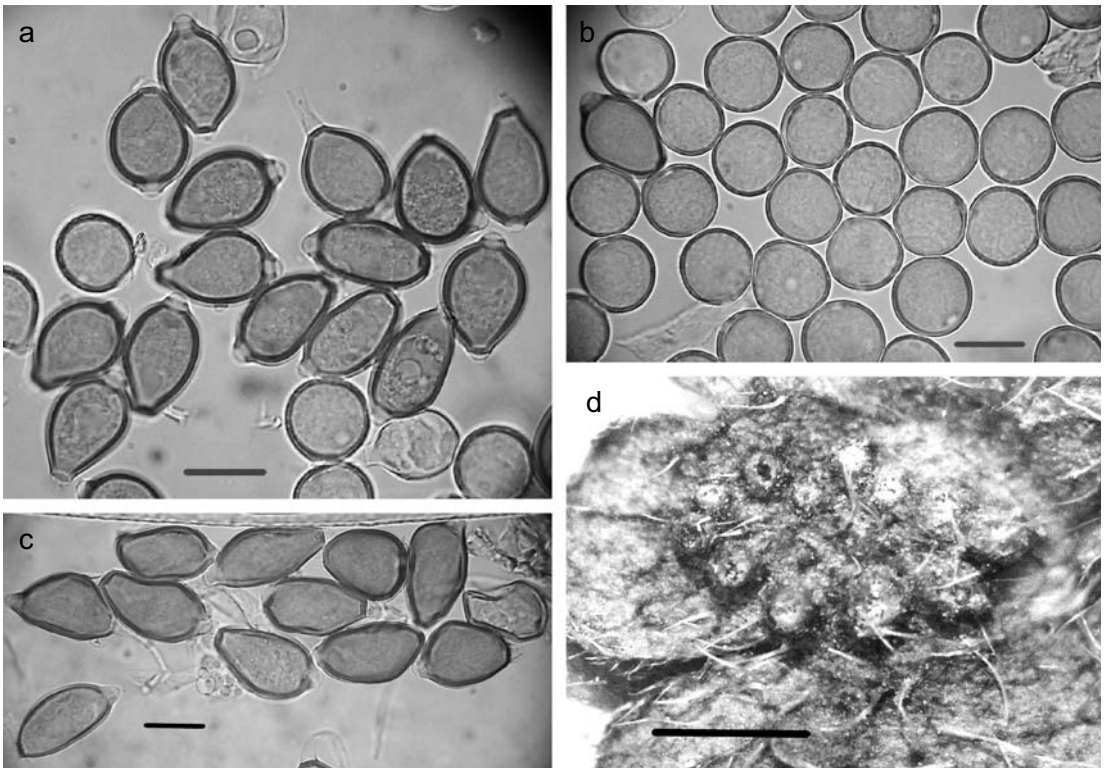

Fig. 4. *Uromyces geranii* (DC.) Fr. a – teliospores showing variation in size and shape, with prominent apical cap, and a few urediniospores, from DAR 75671; b – urediniospores with one germ pore from DAR 75671; c – teliospores from HO 554429; d – cluster of aecia on lower leaf surface from HO 554429. Scale bars: a–c = 20 μm, d = 1 mm.

Teliospores were found in only two Australian specimens, DAR 75671 from New South Wales collected in 2003, and HO 554429 on *G. molle* from Tasmania, collected in 1917, identified originally as *Puccinia geranii-pilosi* (Sampson & Walker 1982). In both collections, some teliospores are longer and thinner than those of *U. geranii* described and illustrated by Fischer (1904), Sivanesan (1970d) and Wilson and Henderson (1966), resembling more closely those of *U. kabatianus* Bubak described from Prague, Czech Republic, on *G. pyrenaicum* L. (see Fischer 1904). *Uromyces kabatianus* was separated from *U. geranii* by having telia circinately arranged, and larger, more elongated teliospores 33–44 × 15.5–26.5 μm (Fischer 1904) with a more prominent apical papilla. *G. pyrenaicum* was then regarded as the only host of *U. kabatianus* but Lind (1913) found it in the field on three other *Geranium* spp. including *G. molle*, and obtained infection on *G. molle* with spores from *G. pyrenaicum*. Gäumann (1959) listed similar results of cross-inoculation tests. *Uromyces kabatianus* has been kept as a separate species by Gäumann (1959) in Switzerland, by Petrak (1959) in Austria [but with short teliospores only 26–33 (–38) × 16–24 μm] and by Ershad (1995) in Iran (all on *G. pyrenaicum*) but in recent years it has been considered either as a variety, *U. geranii* var. *kabatianus* (Bubak) U. Braun (*Index of Fungi* **5**: 217. 1983; Urban & Marková 2009), or reduced to synonymy under *U. geranii* [e.g., Wilson & Henderson 1966; Gjaerum 1974; Majewski 1977; *Index Fungorum*, http://www.indexfungorum.org (consulted March 2010)].

Dennis and Pegler (1975) made SEM studies of teliospores of *U. geranii* on *G. pratense* L. from Northumberland, and *U. truncatulus* Trotter on

G. striatum L. from Italy (Trotter 1904, 1908). *U. geranii* had smooth-walled spores but in *U. truncatulus* '… the surface appears foveate, bearing a uniform pattern of more or less circular depressions which are irregular in size' (Dennis & Pegler 1975). They mentioned, but did not study, *U. numidicus* Maire (1931), described on *G. atlanticus* Boiss. in northern Africa, with thick (to 5 µm), densely foveolate teliospore walls, a thick reticulum and very small areolae. Guyot (1951) repeated Maire's data, but his drawing of three teliospores, showing thickened longitudinal and oblique anastomosing ridges, with large irregular areolae, does not agree with Maire's description. Precise data on ornamentation in *U. numidicus* is needed. A fourth *Uromyces* species, *U. carpathicus* Namysłowski, described on *G. phaeum* L. in southern Poland, with uniformly tuberculate teliospores, has been shown by Majewski (1977) to be based on a specimen of *U. punctatus* Schroet. on *Astragalus* (Fabaceae).

Majewski (1977) was the first to report a urediniospore tonsure in *U. geranii.* He noted that wall spines are not present on the lower part of the spore wall, especially under the germ pores; his Fig. 79C shows the smooth patch. It was also noted later in Canadian collections by Parmelee and Savile (1990). In the Australian collections, the urediniospore tonsure in HO 554429 is less prominent than in DAR 75671.

This is the first Australian record of this predominantly Northern Hemisphere rust. The earliest specimen is the uredinial DAR 8520 collected in 1911. The 1917 Tasmanian collection had uredinia and telia and, after this, this rust was not seen for 86 years and is still known in Australia from only five specimens. It may well be more common in temperate Australia than these few collections indicate. Elsewhere in the Southern Hemisphere, it is not recorded for New Zealand by McKenzie (1998) or Argentina by Lindquist (1982). Hennen *et al*. (2005) mentioned one specimen from Brazil without further comment. In Africa, where the main host is *G. arabicum* Forsk., it is recorded from Ethiopia, Kenya, Tanzania, Zimbabwe (Gjaerum 1995) and Uganda (Wakefield & Hansford 1949) but not from South Africa (A. Wood, pers. comm., 18 April 2010). Its presence in Australia for nearly 100 years before it was recognised illustrates how a plant pathogen can enter and remain undetected for long periods, especially on plants of little economic importance.

Potential rust on *Geranium* in Australia

Overseas, aecia of the varieties of *Puccinia polygoni-amphibii* Pers.: Pers. occur on species of *Geranium* (Fischer 1904; Arthur 1934; Wilson & Henderson 1966). Two Australian uredinial collections of this rust have been seen, one from New South Wales on the introduced *Fallopia convolvulus* (L.) A. Löve (Walker & McLeod 1969), the other from Victoria on the native *Persicaria decipiens* (R. Br.) K. L. Wilson (1988). Urediniospores are subgloboid to obovoid, a few narrowly clavate, pale yellow-brown, (21–)23–31 × (16–)17–21(–22) µm, with wall 1.0–1.5(–2.0) µm thick, finely echinulate except for a tonsure of variable size under each pore, germ pores 2 opposite, equatorial to mainly supraequatorial, a fragment of hyaline pedicel usually attached. From the description, this closely resembles uredinial *P. polygoni-amphibii* as described by various authors (Arthur 1934; McNabb 1966; Wilson & Henderson 1966; Majewski 1979). These are the only Australian records but it may be more common than the two collections indicate. Its presence will need to be considered with any future Australian collections of aecial rusts on *Geranium*. *P. polygoni-amphibii* has been recorded as uredinia on *Persicaria hydropiper* (L.) Spach in New Zealand but the aecial stage has not been found there (McNabb 1966; McKenzie 1998). While the urediniospore tonsure has not been mentioned by most authors, McNabb (1966) noted it in the New Zealand collection, and Majewski (1979) illustrated it in his drawings.

Specimens examined: AUSTRALIA. New South Wales: On *Fallopia convolvulus*, Bent's Basin, Nepean River near Silverdale, 9 July 1967, *O. M. Williams 67/174* (DAR 16976), II. Victoria: On *Persicaria decipiens*, Edwards Lake, Resevoir (suburb of Melbourne), 18 Mar. 1992, *J. Walker 92/22* (DAR 68226b), II.

Unconfirmed record

Macnish (1963) listed 'Unidentified Rust (Aecidial stage)' on *Erodium botrys* (Cav.) Bertol. collected at Merredin, Western Australia in September 1929. In his comprehensive list of Western Australian plant diseases caused by fungi and bacteria, Shivas (1989) gave the record as '*Aecidium* sp. rust (aecidial stage)' citing Macnish (1963). Shivas (pers. comm., 29 March 2010) was unable to find a specimen in PERTH to support this report.

There are few records of rusts on *Erodium*. Gäumann (1959) gave *E. cicutarium* (L.) Aiton as a host of *Uromyces geranii*. Sydow and Sydow (1923) listed *Aecidium erodii-cicutariae* Const. on *E. cicutarium* from Romania, commenting that it was probably not distinct from *A. tranzschelianum* Lindr. on *Geranium sanguineum* L. in Europe. These aecia were thought to be part of the life cycle of grass rusts (Sydow & Sydow 1923; Gäumann 1959).

This is the only published report seen of a rust on *Erodium* in Australia. In the absence of a specimen, its identity and authenticity remain unknown (see comments under Excluded record).

Excluded record

One specimen labelled '*Uredinales* indet.' on *Erodium crinitum* Carolin has been seen. Examination showed leaves and branches heavily infected with the chytrid *Synchytrium papillatum* Farl., causing abundant clustered small reddish galls. *S. papillatum* has been known in Australia since at least 1907 (VPRI 261) and is reported from New South Wales (Noble *et al*. 1935), South Australia (Cook & Dubé 1989) and Victoria (Chambers 1982). There is no authentic record of a rust on *Erodium* in Australia.

Specimen examined: *Synchytrium papillatum* Farl. AUSTRALIA. Victoria: On *Erodium crinitum* Carolin, Wyperfeld National Park, 2 Oct. 1968, *A. C. Beauglehole 28856* (MEL 1055024 as '*Uredinales* indet.').

DNA comparisons

Specimens of three of the four rusts studied in this paper were included in DNA work reported by van der Merwe *et al.* (2008). They were *P. geranii-pilosi* (DAR 75666), *P. morrisonii* (DAR 77036) and *U. geranii* (DAR 75671). In that study, two major clades, I and II, were found, based on rusts that diverged on Cyperaceae/Asteraceae and on Poaceae/Ranunculaceae respectively. In clade I, the Australian isolate of *U. geranii* grouped closely with two European isolates, with the Australian *P. geranii-pilosi* sister to them. *P. morrisonii* was also placed in clade I, but in a different subclade, together with other Australian and overseas rusts on Asteraceae, Goodeniaceae, Stylidiaceae, Scrophulariaceae, Cyperaceae and Juncaceae. The microcyclic European *P. morthieri* on *Geranium* spp., with teliospore morphology similar to that of *P. morrisonii*, was quite distinct, placed in clade II with several other microcyclic rusts on Brassicaceae, Caryophyllaceae, Grossulariaceae, Plantaginaceae and Saxifragaceae.

Discussion

The two native rusts of Geraniaceae in Australia, *P. geranii-pilosi* on *Geranium*, and *P. morrisonii* on *Pelargonium*, are not closely related. Apart from some similarity in urediniospore morphology, they differ in teliospore size and shape, in life cycle and in host genus. Molecular studies placed them in different subclades (van der Merwe *et al.* 2008). *P. morrisonii* shows similarity with the South African *P. granularis* on *Pelargonium*, with small differences in urediniospore wall thickness and teliospore size. *P. geranii-pilosi* occurs on native *Geranium* spp. in New Zealand, Argentina and Chile, and shows some resemblances to both the hemicyclic *P. geraniphila* and the macrocyclic *P. callaquensis* on *Geranium* in South America. While *P. morrisonii* and the Australian species of *Pelargonium* (Carolin 1962) point to a relationship with the flora of southern Africa, *P. geranii-pilosi* and Australian *Geranium* species indicate a relationship with the floras of New Zealand and South America (Berndt 2002).

From the literature, *U. geranii s.l.* is seen to vary over its many host species and throughout its geographic range, particularly in teliospore size and shape. Wilson and Henderson (1966) regarded it as a 'polymorphic species', of which *U. kaba-*

tianus is one component. It is also of interest that the two *Geranium* rusts in Australia, *P. geranii-pilosi* and *U. geranii* (both Australian and European isolates) grouped closely in molecular studies (van der Merwe *et al.* 2008). Further investigations of variability in *U. geranii s.l.* are needed before the relationship between Australian and Northern Hemisphere specimens of *U. geranii*, and between Australian *U. geranii* and *P. geranii-pilosi*, can be determined.

With the exception of Majewski (1977, 1979) and Parmelee and Savile (1990), no previous mention of a urediniospore wall tonsure in the four rusts discussed here has been found. Their urediniospores are also flattened to varying degrees in the vertical plane and, with the exception of *U. geranii* with a single germ pore, have two opposite germ pores. This association of tonsure, two opposite germ pores and varying degrees of spore flattening was pointed out by Savile (1972) in some rusts of *Scirpus* (Cyperaceae) and by Parmelee and Savile (1981) in several asteraceous rusts of the *Puccinia hieracii* type. The significance of this combination of morphological characters in helping determine relationships and lineages in molecular studies on rusts has been discussed elsewhere (van der Merwe *et al.* 2008).

Teliospores of *P. morrisonii* are similar in size, shape and apical thickening to those of the microcyclic *P. morthieri* of Europe, whose main host is *G. sylvaticum* L. (Gäumann 1959; Majewski 1979). However, in molecular studies (van der Merwe *et al.* 2008), with one specimen of each, they were placed in different major clades and are not closely related. Following Tranzschel's law, the microcyclic *P. morthieri* on *Geranium* may be correlated with the macrocyclic *P. polygoni-amphibii* with uredinia and telia on *Polygonum s.l.*, and pycnia and aecia on *Geranium* (Arthur 1934). *P. polygoni-amphibii* is recorded here for the first time in Australia from two uredinial specimens, but the aecial stage on *Geranium* has not been found.

More detailed searching in Australia is needed to determine the host range and distribution of the two rarely seen *Geranium* rusts, the native *P. geranii-pilosi* and the introduced *U. geranii*. Similar study of *P. morrisonii* across the range of the seven native *Pelargonium* spp. is also required to clarify the identity of its hosts. In all cases, rust specimens should be accompanied by good botanical specimens of infected plants for accurate host identification. These studies have shown that further morphological and molecular comparisons of all the rusts on this host family are needed to help clarify species limits and relationships, especially in the *U. geranii* complex.

Key to the Australian rusts on Geraniaceae

On *Geranium*

1. Urediniospores with two supraequatorial germ pores; teliospores two-celled . . . . . ***Puccinia geranii-pilosi***
1*. Urediniospores with one, usually depressed, germ pore; teliospores unicellular . . . . ***Uromyces geranii***

On *Pelargonium*

1. Pycnia and aecia not known. Urediniospore side wall mostly < 2 μm thick, germ pores mainly supraequatorial; most teliospores not longer than 55 μm, apex often flattened, rarely thicker than 7 μm. Known only on zonal *Pelargonium* . . . . . ***Puccinia pelargonii-zonalis***
1*. Pycnia and aecia often present. Urediniospore side wall mostly > 2 μm thick, germ pores mainly equatorial; some teliospores over 60 μm long, apex often conical, 7–13 μm thick. Known only on Australian native species of *Pelargonium* . . . . . ***Puccinia morrisonii***

Acknowledgements. I am most grateful to Professor Zbigniew Mirek and Dr Marcin Piątek for the invitation to contribute a paper to this issue of the *Polish Botanical Journal* celebrating the 70th anniversary of Professor Tomasz Majewski. I thank Roger Shivas and Desley Tree (BRIP), Michael Priest and Karren Cowan (DAR, including ADW), Gintaras Kantvilas (HO), Josephine Milne and Tom May (MEL), and James Cunnington and Sharon Morley (VPRI) for lending specimens and commenting on older records. Barry Condé and Lois Ulyatt, Plant Pathology, Berrimah Farm, Department of Primary Industries, Northern Territory, provided information on diseases in the Territory, and Dean Metcalf, Diagnostic Services, Department of Primary Industries, Water and Environment, Tasmania sent details of the 1951 report of *P. geranii-pilosi* there. I am grateful to Roger Shivas and

Desley Tree (BRIP) for sending the SEM photograph of a urediniospore of *P. geranii-pilosi* showing the tonsure (Fig. 1d). Lizbeth Gale and Tracy Wells (Library, Royal Botanic Gardens, Kew, England), Leonie Samuelsson (Western Australian Museum Library), Michael Priest (DAR) and Roger Shivas (BRIP) willingly sent copies of papers and other references. I thank sincerely Marcin Piątek who, in 2005, made me a gift of the two volumes on Polish rusts by Prof. Majewski; these have been an invaluable reference. Recently, he has kindly translated into English fungal descriptions from these texts for me. I thank Halvor Gjaerum, Oslo and Reinhard Berndt, Zurich, for sending reprints of their many papers over the years. Cyberliber, an Electronic Library for Mycology (http://www.cybertruffle.org.uk/cyberliber/) and the British Mycological Society library abstracts (http://www.britmycolsoc.org.uk/files/BMS-ABS20.pdf) gave access to important references. The United States Department of Agriculture fungal data bases (http://nt.ars-grin.gov/fungaldatabases/) were helpful in assessing host range and distribution data, and were a useful guide to literature references. Alan Wood, ARC-Plant Protection Research Institute, Stellenbosch, South Africa, kindly commented on African records of *U. geranii*. The assistance of an unnamed referee whose comments have considerably improved the paper is gratefully acknowledged. I thank ACT Land Management and Planning, Forests NSW, and the NSW National Parks and Wildlife Service for granting scientific collection permits. I am grateful to the Agricultural Scientific Collections Trust, Department of Industry and Investment NSW for the loan of equipment and access to the collections of DAR, and to the Forest Biosecurity and Resource Assessment Group, Forest Science Centre, Department of Industry and Investment NSW, West Pennant Hills for provision of laboratory and library space, and facilities.

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Received 1 May 2010