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Collecting and Processing Cacti into Herbarium Specimens, Using Ethanol and Other Methods

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Abstract—Many collectors avoid collecting cacti (Cactaceae) and other succulent plants because they are unsure of how to preserve cacti as herbarium specimens. However, preserved specimens of cacti are valuable and crucial for research and conservation. This paper addresses techniques for collection and processing of cacti to make herbarium specimens, with particular reference to the use of ethanol to aid drying.

Keywords—Borax, cactus, ethanol, herbarium specimen, salt.

Many herbaria, it seems, have comparatively fewer collections of cactus than of less succulent or spiny plants (see Griffiths 1907; Clover 1952), often to the detriment of research and conservation. R. H. Peebles lamented, "…the research worker is severely handicapped by the inadequacy of preserved material" (Peebles 1942: 3). Often, a number of these collections were made by a researcher whose focus was cacti (e.g. Lyman Benson, at POM), along with a handful of other brave individuals. However, although collecting cactus for herbarium specimens is sometimes more difficult or tedious than it is for most other plants, it is certainly not impossible to produce good specimens in a fairly straightforward manner, and it is important. As Lyman Benson wrote, "…the contribution of herbarium specimens to research on the cacti has been enormous, because, despite the handicap of scattered information, the study of these specimens in many herbaria provided the opportunity to put together fragments of information about the ramifications of taxa and their distribution" (Benson 1982: 101).

There have been several articles dealing with cactus specimen preparation, and various methods have been suggested: (1) leaving a whole cactus or section of stem in the shade for several months until it shrivels up and dries out, then storing it in a box in the herbarium (Engelmann et al. 1886); (2) slicing a cactus stem lengthwise, removing parenchyma tissue, packing with table salt or borax, and drying between metal screens or in an ordinary press (Peebles 1942; Clover 1952; Benson 1982); (3) slicing a stem lengthwise, removing parenchyma, and placing directly into a drying press (Griffiths 1907; Reyes-Agüero et al. 2007); (4) dipping stems in boiling water for a few minutes prior to placing in a drying press (Fosberg 1932; Clover 1952; but see Griffiths 1907); (5) drying in a microwave oven (Baker et al. 1985); or (6) immersing in ethanol (Baker et al. 1985 and references therein). Freezing also will speed up drying, because it will both kill and rupture cells, allowing water to escape.

However, not all of these methods are to be recommended. To be useful, herbarium specimens need to preserve important taxonomic characters, such as the size and shape of areoles, diameter of stems, number and position of spines in each cluster, and flower shape and color, without too much distortion. If specimens do not preserve key features, they will be useful only for label data, and then only dubiously so if their identity cannot be confirmed with certainty. Method (1) is less satisfactory because it results in bulky specimens (Griffiths 1907), and also introduces much distortion of key features, due to shrinkage during drying. Method (2) can also result in bulky specimens if the cactus slices are not flattened out in some way, although it generally preserves specimens without a great amount of distortion. Method (3) can work well with smaller or thinner species such as prickly-pears (*Opuntia*), but may be problematic with large or thick plants such as *Ferocactus*, and is likely to distort stem and areole shape. Method (4) has had mixed reviews and some authors find it too cumbersome. I have no experience with (5), but have been able to turn out some nice specimens with the ethanol method (6), which produces specimens with minimal distortion that are also fairly flat. Therefore, this method is detailed below, along with some suggestions on collecting, cutting, pressing, and mounting that could be applied to many of the other suggested techniques.

First, though, note that many cacti are rare. Although they are not well collected, documentation by removing whole plants may impact rare species. If only one individual of a species is seen in an area, do not collect the whole plant. Many cacti grow slowly and it will take time to replace that individual. Frequently, a spine cluster or two and a flower or fruit will be enough to identify the species, and can be removed fairly easily without causing much damage to the plant. This might preclude extensive comparative morphological study from the resulting herbarium specimen, but at least the species will still be extant and can be studied in the field.

Second, I would encourage cactus collectors not to be afraid of spines. Handle a cactus gently, and the spines do not do much damage. As you collect and handle cacti, you will get accustomed to working around spines and glochids (little sharp, stiff, hair-like spines found on prickly-pears, chollas, and club-chollas). As David Griffiths wrote,

"All who are familiar with the prickly-pear will question the comfort of the collector in the preparation of specimens. Of course, the spines and spicules are always present and usually some of them find their way into one's hands, which is very aggravating, especially inasmuch as the hands are usually at the same time slippery and slimy with mucilage from the plant. But this is one of the penalties of having anything to do with the plants and must be put up with. However, a few precautions and a little care will enable one to minimize the annoyance" (1907: 280).

Picking Spiny Things—Since most cactus stems are sliced in half, the amount of material collected need be only about half of what might be collected from other non-succulent plants. A collection of two cactus stems will make four nice herbarium specimens. Clover (1952) offered other useful suggestions on selection of material and observations to make in the field (e.g. soil type, exposure, plant habit, height, diameter, stem form (ribbed, angled, flat, etc.), stem color, spine arrangement and color, leaves (persistent or deciduous), flower color, fruit color and taste, seed color; Clover 1952: 110–111). It is advisable to note particular characteristics such as whether the areoles are grooved or not, position of flowers on the plant (tip of the stem, all along the stem, etc.) flower color (including color of each of the various parts), petal margin detail, flower height and width, fruit dimensions, fruit color and fleshiness, spine color, or number of hooked spines prior to pressing. Photographs of the whole plant and the flowers are also useful, often essential, and will make the herbarium specimen much more valuable to researchers.

A sturdy set of tongs, like salad tongs, are invaluable for collecting cactus with minimal injury (but note I do not say no injury, there is always that chance). The tongs should have a handle at least 30 cm (12 in.) long, so that your hands are well clear of spines. The tip should be wide enough to hold large cacti firmly, but narrow enough that flowers or fruits also can be held for slicing. Thick leather gloves can be used with some cacti, particularly species with stiff spines such as *Ferocactus*, but these are not recommended for handling any Opuntioid cacti (prickly-pears, chollas, *Grusonia*, etc.), since glochids work readily into and through leather gloves (Clover 1952; and personal experience). After only a few uses you will find glochids in your fingers, from the gloves, not the cactus. Reyes-Agüero et al. (2007: 77–78) recommend "industrial rubber gloves or metal forceps with rubber tips" for handling prickly-pears. Alternatively, several sheets of paper, a fold of cardboard, a rock, or even a bottle can also be used to hold specimens (Clover 1952; Griffiths 1907). Larger cacti are sometimes wrapped in a piece of carpet for handling. If there are enough plants to collect a whole individual, the individual can usually be carried by the root.

Some cacti, like the jumping cholla (*Cylindropuntia bigelovii*) have stems that are easily broken at the joints and can be collected only with tongs. However, stems on other chollas may not detach as easily, requiring use of a clipper or pruner. Incidentally, I have also had good success using my hiking boots (when I forgot to bring the clipper). If you want to take a rib with some spine clusters off a large columnar (Cereoid) cactus such as saguaro (*Carnegiea gigantea*), you will need

Fig. 1. Freshly collected cacti in a paper bag, awaiting processing.

a sharper implement, like a large knife. If there are enough plants for you to dig up a whole individual, you probably will need a trowel, spade, rock pick, or pickaxe, since the soils in which cacti are found are often hard and rocky. Some cacti have underground tubers, which may be left in the ground unless they are vital for identification.

Generally, you will collect a whole individual if the cactus is smaller than an herbarium sheet, and there are enough plants in the area. For larger cacti, part of a rib with spine clusters and some flowers or fruits will suffice. Clip several branches or cladodes from branching cacti like chollas and prickly pears; if possible include both the tips of the branches and some older growth as these sometimes can be different.

Once you have collected all or a part of a cactus and noted down the locality information and observations about the plant, the rest of the work in the field is easy. Place the cactus into a paper grocery bag (Fig. 1) or a box, label with your collection number, and stash it away in your vehicle where the plants will not be damaged and the spines will not puncture anyone or anything valuable, such as aluminum beverage cans. Being succulents, cacti can live some time in the dark without any water. I had one specimen live about six months in a paper bag, but note that cacti will start to shrivel, lose color, and can etiolate while languishing in a paper bag, so it is best not to leave them too long (see Baker et al. 1985).

As with most plants, it is best to collect flowers or fruits with the cactus stems. However, flowers and colorful, fleshy fruits should be treated differently, since their color will be lost if treated in ethanol. In the field, take a pocket knife or scalpel and slice the flowers or fruits in half lengthwise (or in thirds if they are large), and place them directly onto newspaper in a press (Fig. 2 ; see also Engelmann et al. 1886; Clover 1952). You can also slice them cross-ways near the base and press them face-down (Baker et al. 1985). Slicing them fairly thin helps them to dry before they get moldy or lose color. Beware, though, mucilage from those freshly cut margins will act like glue between your lovely specimen and the newspaper. At least once every day until they are dry, check flowers and fruits and scrape them loose from the newspaper if need be. I tend to use the same pocket knife for this. Dipping or misting the ovary of a flower in ethanol just prior to pressing may alleviate this to some extent (S. Vanderplank, pers. comm.). Other collectors press flowers or fruits between pieces of wax paper or parchment paper, which works well as long as there is still enough airflow that the specimens can dry.

Photographs of the cactus and its flowers should be taken before you collect it, particularly if the specimen you make is not likely to be representative of the whole plant's habit. That also means you should print copies of the photos on archival paper and have them affixed to the sheet along with the specimen.

Fig. 2. Sliced fruits in newspaper, which can go directly into the usual drying press. Most flowers can be treated the same way.

This is more trouble than many collectors are willing to go through, but it will make the specimen more valuable to researchers. Alternatively, you could include a nice text description of the plant's architecture on the label, although it might be rather long if it is to equal a picture. Ideally, a specimen should include both a detailed label and photographs. Often, collectors think of taking photos after the fact, which is why I mention it after the fact, but if you have not collected the whole plant, you probably do not have a good representation of the architecture either, so a picture still will be useful.

Back at the Lab—Begin processing cactus collections back at the lab or at home. Allow adequate time. Some cacti, even when placed in an herbarium specimen dryer following ethanol treatment, could take over a week to dry, and should be checked every day. If you come in from fieldwork but are heading out again soon, just leave the cactus in the paper bags, they will be fine (and more flowers may open).

When you are ready to start processing cacti, you will need the tongs again, a large knife (a vegetable chopper works well), and a cutting board, to keep the counter top intact (Fig. 3). Slice the cacti lengthwise to expose the inner surface to ethanol, salt, borax, or some other drying agent. If the cactus is thick (as in hedgehog cacti, *Echinocereus*), cut them in three or four lengthwise slices (Fig. 4). If cacti have ribs, cut so that the slices follow the ribs as much as possible. Thick specimens (e.g. *Echinocactus*) can also be sliced apart between ribs like pieces of pie, and it is sometimes useful to slice one half of the cactus in this way, while slicing the other half into two longitudinal sections so that the stem diameter can still be determined. However, specimens of this size might be collected only rarely, and it is much easier to take part of a rib with several spine clusters in the field, rather than later trying to wrestle a large cactus into several lengthwise sections. Some collectors cut cross-sections through the stems, which you can do, but longitudinal sections show most of the same information and also are a better representation of the overall stem architecture. Prickly-pear cactus pads (cladodes) should be filleted through the middle. Place a piece of plywood, cardboard, or several sheets of newspaper on top of the cladode to hold it down flat while you slice it (Fig. 5). Be sure to mark which side of the plywood contacted the cactus, so that it does not contact your hand the next time you use it. For branching cacti such as chollas (*Cylindropuntia*), it is nice if you can slice through the joints lengthwise and preserve the branching pattern. This is not particularly easy, but with a little practice it is possible to produce nice specimens this way. Wipe the knife clean between specimens.

Many authors suggest removing parenchyma tissue from the inside of the stems (e.g. Baker et al. 1985; Reyes-Agüero et al. 2007). This may be desirable in thicker specimens, although the succulent tissue usually shrinks considerably during drying, and usually is not overly bulky after the specimen is dried. The method used to dry the cactus is a main factor in the decision of whether parenchyma is removed or not. Collectors who do not have access to large quantities of ethanol may prefer to remove parenchyma, dry the cactus either with salt or borax or by laying cut slices out in the sun. If these methods are used, specimens generally will dry faster

Fig. 3. Equipment for processing cacti: cutting board, knife, tongs, large containers for soaking specimens, and ethanol.

Fig. 4. Making lengthwise (longitudinal) slices.

if some parenchyma is removed. If ethanol is used, cactus specimens dry rapidly enough that removing parenchyma may not be worth the effort. Beware, however, that removing parenchyma can often result in distortion of important morphological features during drying.

The main goal when turning cacti into herbarium specimens is to get the specimens both dry and flat, without losing or distorting too many details of their morphology. Also, once cacti are cut, they tend to develop mold within about a week unless they are dry by then, so they should be dried as fast as possible. I find this is most easily accomplished by soaking sliced specimens in ethanol, but there are other ways to accomplish the same thing (Benson 1982; Clover 1952; Peebles 1942,; Reyes-Agüero et al. 2007; Baker et al. 1985). Freezing cactus specimens after slicing but prior to drying has been suggested to work well (M. Honer, pers. comm.). Some thin specimens (e.g. beavertail, *Opuntia basilaris*) can be placed directly into a drying press, although it might be useful to place the cut sides on wax paper to prevent them from sticking to the newspaper. Parenchyma tissue may be removed from thicker specimens, and the cut sides packed with salt or borax, and/or the slices laid out in the sun to dry. The slices will tend to curl as they dry, but as long as they are placed into a press while they are still pliable, it should be possible to produce nice flat specimens this way.

If you use the ethanol method, you will need to place the cactus slices into a large container where they will soak (Fig. 6). I generally use the largest lidded plastic containers I can find, but also have had success using a small trash can. Just remember, if you need a container that is much larger than a herbarium sheet, your specimen may not fit on the herbarium sheet. Alternatively, if you have a number of specimens, it may be more economical to use a larger container (like a cooler) and soak several collections at once, as long as they can be distinguished. Consider labeling each specimen with a paper tag, written in pencil, particularly if you have more than three different collections. Once the cacti slices are comfortably settled in a suitable plastic container, pour in enough 95% (190 proof) ethanol to cover the fleshy part of the cactus, and especially the cut surfaces (it is fine if a few spines are not covered). You may be able to use lower proof ethanol, even down to 75% (150 proof), although specimens probably will need to soak longer in those cases. Sometimes this can take a large volume of ethanol. Once the ethanol is in, put the lid on, so that the ethanol does not evaporate away overnight, and label with your collection number(s), so you can relate the specimens back to the data on where you found them.

Sometimes it is possible to slice through attached flowers or fruit, and keep them attached to the stem. In this case, you do want to soak the stem in ethanol, but you do *not* want the flowers or fruit in ethanol, because they will lose color. For these specimens, you can tilt a container and put just enough ethanol in the bottom corner to contact the stem, but not the flower or fruit. If the fruit is green like the rest of the stem, I usually slice it longitudinally and soak it in ethanol with the stems, because there is no color to lose and it will dry faster.

So why use ethanol to dry cactus? One obvious reason is because it does just that, begins the process of drying the

Fig. 5. Slicing prickly-pear cladodes.

cactus. Cacti are well adapted to hold onto their water, and do not give it up easily. Also, ethanol is generally fatal for cactus (and cactus seeds), which means that your specimen should not keep growing after it has been glued to a herbarium sheet (however, if you wanted to make a seed collection, it is best to take seeds prior to soaking in ethanol). Another advantage of ethanol is that as it pulls water out of the cactus, the cactus usually becomes less turgid, and some spines become more flexible. This allows the spines to bend and lie flat when you press the cactus. Although this does introduce some distortion, spine clusters usually remain in fairly good shape, and your specimen is much thinner. At the same time, stem tissue is usually preserved with minimal distortion. Baker et al. (1985) suggested that specimens will curl if they are not pressed while soaking in ethanol, and I have noticed this, particularly in prickly pears. However, if the specimens are removed from ethanol while they are still soft, they can be flattened easily in the press.

Some collectors may be concerned about the cost of 95% ethanol, which is a legitimate concern since it is more expensive than salt. However, you do not need to use expensive, high-grade ethanol, I use ACS/BSP grade, but cheaper grades are likely to perform just as well. Also, cacti can be soaked in it multiple times, you do not need fresh ethanol every time. Indeed, the exact amount of time required to soak cactus specimens depends on several factors: the freshness of the ethanol (fresh ethanol will dry specimens faster), the thickness of the specimen (thick specimens will dry slower), and to some extent, the species of cactus. In my experience, thick slices of barrel cactus (*Ferocactus*) or clustered barrel cactus (*Echinocactus*) take much longer (24 hr, in some cases) than small cacti like *Mammillaria* (which may be ready in eight hours). If you have a fairly thin and soft cactus, like beavertail (*Opuntia basilaris*), you may not want to use fresh ethanol because it can make the specimen brittle. You will come to understand the appropriate length of time with experience, but when you see that the parenchyma tissue has shrunk back somewhat from the vasculature, then it is usually fine to remove the cacti from the ethanol.

Pressing Matters—Although ethanol gives cacti a good start in the drying process, cacti do not come out of the ethanol completely dry. After cactus slices have soaked in ethanol for 8–24 hr (and they are becoming less turgid and show shrinkage around the veins), it is time to take them out and put them in a drying press. For this, again, you will want tongs.

To get cactus both dry and flat as fast as possible (see Peebles 1942), I like to use aluminum ventilators (also known as aluminum corrugates). These transmit heat through the press, and are quite effective for getting succulent tissue to dry quickly. At the same time, plywood is effective for making the spines bend and lie flat.

The sequence of material in the press is as follows: start the press with a piece of plywood, then lay on an aluminum ventilator, then a cardboard corrugate, so that the ridges from the aluminum ventilator do not show on the cactus specimens. When I first pull cactus out of ethanol, a blotter on top of the corrugate but under the newspaper serves to wick up inevitable drips of ethanol. However, I usually pull the blotters out after 8–24 hr, because they tend to get wet and drying seems to go faster if moisture can escape quickly through the corrugates or aluminum ventilators. Each cactus slice then goes

Fig. 6. Cactus slices ready for soaking in ethanol.

directly into a single sheet of newspaper or parchment, labeled in multiple places with your collection number and preferably in pencil or ink that is not soluble in ethanol. If parchment paper is used, the cut sides are placed against parchment, then the specimen and parchment are all placed in a sheet of newspaper (W. Hodgson, pers. comm.). On top of the newspaper, place another cardboard corrugate (but no blotter), an aluminum ventilator, and another piece of plywood (Fig. 7). This process can be repeated for the number of specimens that you have. Note that cactus specimens fresh out of ethanol are

Fig. 7. Drying press for cactus specimens. Blotters will be pulled out after 8–12 hr.

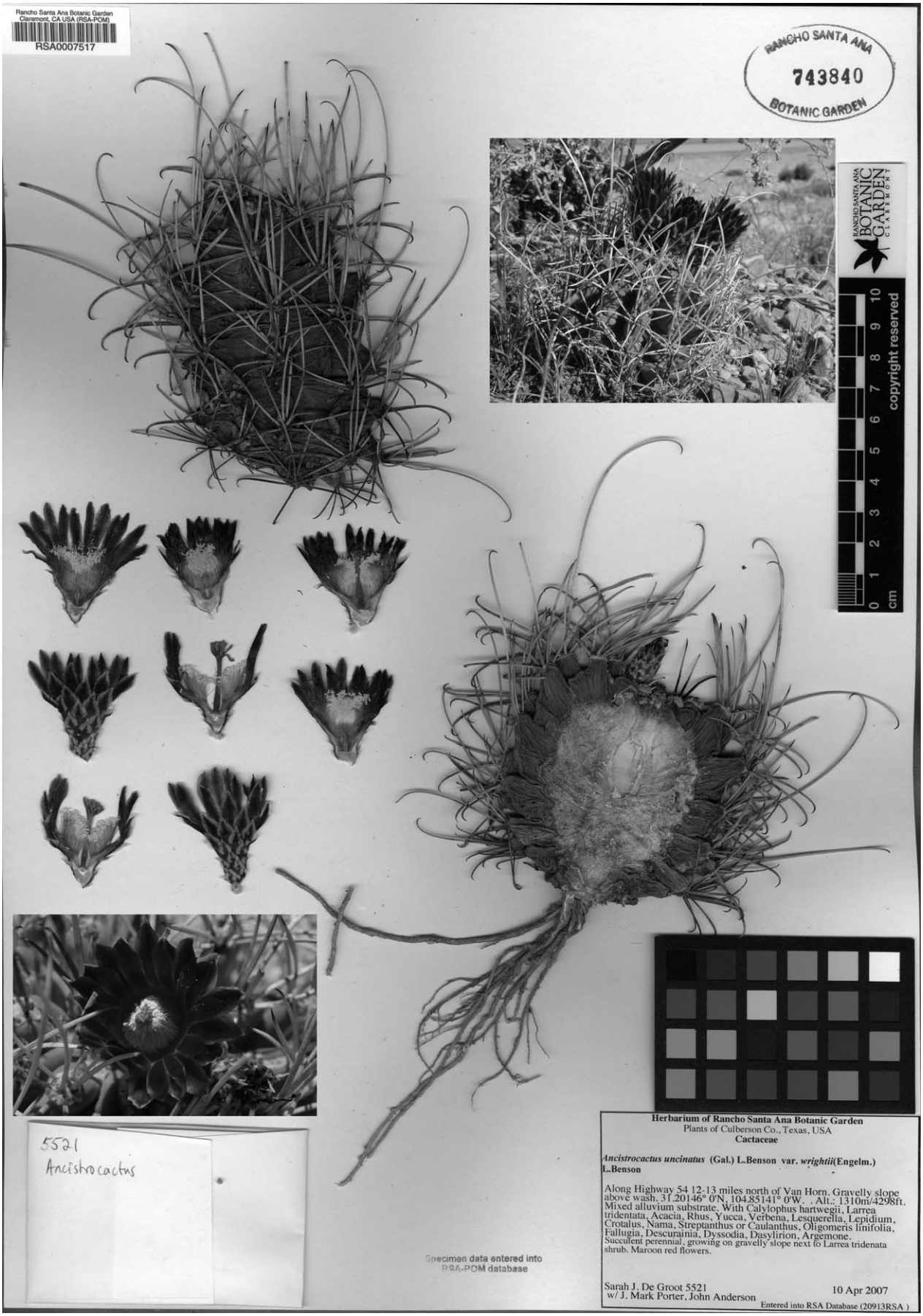

FIG. 8. Nicely prepared herbarium specimen.

usually not flat, so if your press is threatening to tip over it is best to tie it up and start another. More, shorter presses may dry faster than a single large press. When you tie up the press, you want to put some pressure on the specimens, to be sure those spines do lie flat, but not too much pressure or the soft tissue might splay out more than would be natural. The whole press can then be placed in a conventional herbarium specimen dryer, preferably close to the heat source.

It is best to check the cacti every day, peel them off the newspaper (or not, if parchment is used instead), and change the newspaper, corrugates, and ventilators, since all of these usually become wet. I usually use a forceps (or bare hands, but do so at your own risk) to pick up the cactus specimens, and a pocket knife or scalpel to loosen them from the newspaper. Also, as the specimens shrink and the spines lie flat, the resulting slack in the press straps (which can be considerable) will need to be taken out.

Usually, cacti treated like this will be crispy-dry within a few days, or a week at the most. Again, keeping a close watch on them is good, if left too long, beavertail cactus and other prickly-pears become brittle and easily breakable. Thicker specimens may go moldy if they are not soaked in ethanol long enough or if they do not dry fast enough, but usually are fine if they dry in five days. If the specimens do get moldy, you can freeze the whole press overnight or for 24 hr. This seems to slow the growth of the mold (although it does not eliminate it), and after changing the newspaper and cardboard corrugates, you can put the press back in the dryer for a few more days.

I have had good success drying other succulent plants, such as *Orobanche* and *Sarcodes* in a similar manner, slicing lengthwise and using aluminum ventilators. However, I do not soak these taxa in ethanol, since it will remove color. Once dry, all these specimens can be treated just like other herbarium collections, labeled and mounted on paper.

***Additional Notes*—**There are a few key features that should be visible after the cactus specimen is mounted: spine clusters, aerioles or ribs (if present), fruit and seeds, and flowers (both inner and outer parts). Cactus researchers usually do not need to see the interior of the stem, so it is better to mount stems with the exterior surface showing. In the case of central slices from a thick cactus, where the exterior surface is only around the edges, the stele side should be visible in the mounted specimen. Some mounted flowers should display the outside (tepals), while others should display the inside (stamens and pistil). Likewise, mounted fruits should show both the outside morphology and also the seeds.

Sometimes during the course of fieldwork, cacti are encountered that lack flowers or fruits. Unless it is easy to return to the site later to search for flowering of fruiting specimens, it may be worthwhile to collect whole cacti and grow them in cultivation until they produce flowers (see Peebles 1942). Additionally, cultivated cacti could be useful for obtaining chromosome counts. This may not be a good option for large, slow-growing cacti such as *Stenocereus*, but it has worked well for smaller plants such as *Mammillaria*, *Coryphantha*, *Sclerocactus*, and members of Opuntioideae. Be sure to note on the herbarium label which parts were collected from cultivated plants, along with their date of collection, as well as the origin of the cultivated material.

So, do not be afraid of the spines. With a bit of patience, anyone can produce good-quality herbarium specimens of cacti (Fig. 8).

Acknowledgments. Thanks to J. Mark Porter for first introducing me to the technique of using ethanol to dry cactus specimens, although I have modified the procedure over time and any problems with the methods detailed above are my own. Wendy Hodgson and an anonymous reviewer provided many invaluable comments which greatly improved the paper. Special thanks also to the enthusiastic volunteers who mount specimens in the RSA-POM herbarium and requested a workshop about cactus specimens, which provided an outline for this article. *S. D. G.*

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