ELEMENTARY METALLURGY

AND

BASIC HEAT TREATING

FOR

CARBON AND ALLOY STEELS

Compiled by

Bert Gaston

ANNUAL PINEY WOODS HAMMER-IN 2002

REPRINTED FEBRUARY 2004

CLASSIFICATION OF STEEL

Classification of carbon and alloy steels by the Unified Numbering System (UNS) is a system of designations that are established in accordance with ASTM E 527 and SAE J 1086, Recommended Practice for Numbering Metals and Alloys. Its purpose is to provide a means of correlating systems in use by such organizations as American Iron and Steel Institute (AIAI), American Society for Testing Materials (ASTM) and Society of Automotive Engineers (SAE) as well as individual users and producers. This system uses a 4 or 5 digit number.

Classification as follows:

First digit denotes the characteristic allowing element or elements.

1 Plain Carbon (not alloy steel)
2 Nickel
3 Chromium and Nickel
4 Molybdenum
5 Chromium
6 Chromium and Vanadium
7 Tungsten
8 Nickel, Chromium and Molybdenum
9 Silicon and Manganese

The last two digits indicate the approximate carbon content in hundredths of one per cent. The intermediate number indicates the approximate content of alloying element. Thus 1084 indicates a plain carbon steel containing 0.84 per cent carbon. 2340 designates a steel containing about 0.40 per cent carbon and approximately 3 per cent nickel. Steels beginning with 50 are low in chromium, such as 50100 and those that begin with 52 are high in chromium, such as 52100 ball-bearing steel.

Tool steels have their own system and are classed into seven (7) major groups for which one or more letter symbols have been assigned. Please refer to the accompanying chart.

7 Major Groups Of Tool Steels

Group	Designation	Description
Group 1	W	Water hardening
Group 2	S	Shock resisting
Group 3 (cold work)	O1, A and D	Oil hardening, air hardening & high carbon/high chromiu
Group 4 (hot work)	H 10-19, H 20-29 and H 40-59	Chromium, tungsten & molybdenum bases
Group 5 (high speed)	T and M	Tungsten & molybdenum types
Group 6 (special purpose)	L and F	Low alloy & carbon tungsten types
Group 7 (mild steels)	P 1-19 and P 20-39	Low carbon & other types

10-SERIES STEELS

The 10-series steels are perhaps the most usable of the available alloys for bladesmithing. They are very stable and quite easy to form under the hammer.

The following alloys contain the following percentages of carbon and manganese:

<u>1050</u>

Carbon: 0.48 to 0.55
Manganese: 0.60 to 0.90

<u>1060</u>

Carbon: 0.55 to 0.65
Manganese: 0.60 to 0.90

<u>1070</u>

Carbon: 0.65 to 0.75
Manganese: 0.60 to 0.90

<u>1080</u>

Carbon: 0.75 to 0.88
Manganese: 0.60 to 0.90

<u>1095</u>

Carbon: 0.90 to 1.03
Manganese: 0.30 to 0.50

Wear resistance: medium
Toughness: high to medium, depending upon carbon content
Red hardness: very low
Distortion in heat-treating: very low
Forging: Start at 1,750 to 1,850 °F.
Austenite forging: yes
Hardening: 1,450 to 1,550 °F
Quench: oil
Tempering: 300 to 500 °F
Rc hardness: 62 to 55, depending upon carbon content

5160

5160 is a medium carbon "spring steel" that has excellent toughness and high durability. It is quite flexible, resists heavy shocks very well, and is well suited for swords, axes, really large bowies and other blades where a larger flexible blade is desired.

5160 has the following characteristics:

Carbon: 0.56 to 0.64%
Chromium: 0.70 to 0.90%
Manganese: 0.75 to 1.00%
Phosphorus: 0.035% maximum
Silicon: 0.15 to 0.35%
Sulphur: 0.04% maximum
Wear resistance: high medium
Toughness: high
Red hardness: low
Distortion in heat-treating: low
Forge: Start at 1,800°F.
Austenite forging: yes
Hardening: 1,450 to 1,550°F
Quench: oil
Tempering: 300 to 450°F
Rc hardness: 62 to 55

Effects of Alloying Elements

Alloying elements are added to steels to effect changes in the properties of the steels. A semantic distinction can be made between alloying elements and residual elements, which are not intentionally added to the steel, but result from the raw materials and steelmaking practices used to produce the steel. Any particular element may be either alloying or residual. For example, some nickel or chromium could come into steel through alloy steel scrap and so be considered residual; however, if either of these elements must be added to a steel to meet the desired composition range, it might be considered an alloying element.

Both alloying and residual elements can profoundly affect steel production, manufacture into end products, and service performance of the end product. The effects of one alloying element on a steel may be affected by the presence of other elements; such interactive effects are complex. In addition, the effects of a particular element may be beneficial to steel in one respect but detrimental in others.

General effects of the various alloying and residual elements commonly found in steels are summarized below.

Carbon is the most important single alloying element in steel. It is essential to the formation of cementite (and other carbides), pearlite, spheroidite, bainite and iron-carbon martensite. Microstructures comprising one or more of these components can provide a wide range of mechanical properties and fabrication characteristics. The relative amounts and distributions of these elements can be manipulated by heat treatment to alter the microstructure, and therefore the properties, of a particular piece of steel. Much of ferrous metallurgy is devoted to the various structures and transformations in iron-carbon alloys; many other alloying elements are considered largely on the basis of their effects on the iron-carbon system.

Assuming that the comparisons are made among steels having comparable microstructures, strength, hardness and ductile-to-brittle transition temperature are raised as the carbon content is increased. Toughness and ductility of pearlitic steels are reduced by increases in carbon content. The hardness of iron-carbon martensite is increased by raising the carbon content of steel, reaching a maximum at about 0.6% carbon. Increasing the carbon content also increases hardenability.

Manganese is normally present in all commercial steels. It is important in the manufacture of steel because it deoxidizes the melt and facilitates hot working of the steel by reducing the susceptibility to hot shortness. Manganese also combines with sulfur to form manganese sulfide stringers, which improve the machinability of steel. Manganese slightly increases the strength of ferrite; it also greatly increases the hardenability of steel. One result of these two effects is that manganese contributes to the effectiveness of normalizing as a heat treatment for strengthening the steel and to the formation of fine pearlite. It lowers the temperatures at which martensite is formed during quenching; thus, it increases the likelihood of retained austenite in quenched steels.

Silicon is one of the principal deoxidizers used in steelmaking. The amount of this element in a steel, which is not always noted in the specifications, depends on the deoxidation practice specified for the product. Rimmed and capped steels contain minimal silicon, usually less than 0.06%. Fully killed steels usually contain 0.15 to 0.30% silicon for deoxidation; if other deoxidants are used, the amount of silicon in the steel may be reduced.

Silicon slightly increases the strength of ferrite, without causing a serious loss of ductility. In larger amounts, it increases the resistance of steel to scaling in air (up to about 260 °C, or 500 °F) and decreases the magnetic hysteresis loss. Such high-silicon steels are generally difficult to process.

Chromium is used in low-alloy steel to increase its (*a*) resistance to corrosion and oxidation, (*b*) high-temperature strength, (*c*) hardenability and (*d*) abrasion resistance in high-carbon compositions. Chromium carbides require high austenitizing temperatures for dissolution. Straight chromium steels can be quite brittle; they are also susceptible to temper embrittlement.

Nickel is used in low-alloy steel to improve low-temperature toughness and to increase hardenability. It appears to reduce the sensitivity of a steel to variations in heat treatment and to distortion and cracking during quench ing. It strengthens the ferrite, thu strengthening the steel. Nickel is part cularly effective when used in combin tion with chromium and molybdenu: in forming an alloy steel that has hig strength, toughness and hardenabilit

Molybdenum increases the harde ability of steel and is particularly usef in maintaining the hardenability be tween specified limits. This elemen especially in amounts between 0.15 an 0.30%, minimizes the susceptibility of steel to temper embrittlement. Harc ened steels containing molybdenur must be tempered at a higher tempera ture to achieve the same amount of sof ening. Molybdenum is unique in th extent to which it increases the high temperature tensile and cree strengths of steel. It retards the trans formation of austenite to pearlite fa more than it does the transformation o austenite to bainite; thus, bainite ca be produced by continuous cooling c molybdenum-containing steels.

Copper is added to steel primarily t improve its resistance to atmospheri corrosion. Amounts added to steels fo this purpose typically range from 0.2 t 0.5%. Copper is detrimental to surfac quality and hot-working behavior be cause it migrates to the grain bound aries of the steel during hot working.

Vanadium is generally added t steel to inhibit grain growth durin heat treatment. In controlling grai growth, it improves both the streng and toughness of hardened and tem pered steels. Additions of vanadium c up to about 0.05% increase the harder ability of steel; larger additions appea to reduce the hardenability, probabl because vanadium forms carbides tha have difficulty dissolving in austenit

Niobium lowers the transition tem perature and raises the strength of low carbon alloy steel. It imparts a fin grain size, retards tempering and ir creases the elevated temperatur strength of steel. Because it forms ver stable carbides, it can decrease th hardenability of steel by reducing th amount of carbon dissolved in the au tenite during heat treatment.

Titanium may be added to boro steels because it combines readily wit any oxygen and nitrogen in the ste thereby increasing the effectiveness c the boron in increasing the hardenabi ity of the steel.

Zirconium and cerium, which ar most frequently used in HSLA steel can be used to control the shape of inclusions (primarily sulfides), thereby increasing steel toughness.

Boron, usually added in amounts of 0.0005 to 0.003%, significantly increases the hardenability of steel. It is particularly effective at lower carbon levels. Because boron does not affect the strength of ferrite, it can be used to increase the hardenability of steel without sacrificing ductility, formability or machinability of that steel in the annealed condition.

Lead is added to steel to improve its machinability; it does not dissolve in the steel, but is retained in the form of microscopic globules. At temperatures near the melting point of lead, it can cause liquid metal embrittlement.

Aluminum is used to control the grain size of steel during hot working and heat treatment. It is also used to deoxidize steel; aluminum-killed steels have excellent toughness because they generally have a very fine grain size. A special use of aluminum is in steels intended for nitriding.

Calcium is sometimes used to deoxidize steels. In HSLA steels, it helps to control the shape of nonmetallic inclusions, thereby improving toughness. Steels deoxidized with calcium generally have better machinability than steels deoxidized with silicon or aluminum.

Effects of Residual Elements

Any of the alloying elements mentioned above may inadvertently appear in steel as a result of their presence in raw materials used to make the steel. As such, they would be known as "residual" elements. Because of possible undesired (though not necessarily undesirable) effects of these elements on the finished products, most steelmakers are careful to minimize the amount of these elements in the steel, primarily through separation of steel scrap by alloy content.

Several other elements, generally considered to be undesirable impurities, may be introduced into steel from pig iron. For certain specific purposes, however, they may be deliberately added; in this case, they would be considered alloying elements. A brief description of each of these follows:

Phosphorus increases strength and hardenability of steel, but severely decreases ductility and toughness. It increases the susceptibility of medium-carbon alloy steels, particularly straight chromium steels, to temper embrittlement. Phosphorus may be deliberately added to steel to improve its machinability or corrosion resistance.

Sulfur is very detrimental to the transverse strength and impact resistance of steel, but it affects the longitudinal properties only slightly. It also impairs surface quality and weldability. Sulfur normally appears as manganese sulfide stringers; one of the functions of manganese is to combine with sulfur and prevent the formation of a low-melting iron/iron sulfide eutectic. These sulfide stringers enhance the machinability of steel; sulfur is deliberately added to some steels solely for the improvement in machinability that results.

Nitrogen increases the strength, hardness and machinability of steel, but it decreases the ductility and toughness. In aluminum-killed steels, nitrogen forms aluminum nitride particles that control the grain size of the steel, thereby improving both toughness and strength. Nitrogen can reduce the effect of boron on the hardenability of steels.

Oxygen, which is most likely to be found in rimmed steels, can slightly increase the strength of steel, but seriously reduces toughness.

Hydrogen dissolved in steel during manufacture can seriously embrittle it. This effect is not the same as the embrittlement that results from electroplating or pickling. Embrittlement resulting from hydrogen dissolved during manufacture can cause flaking during cooling from hot rolling temperatures. Dissolved hydrogen rarely affects finished mill products, for reheating the steel prior to hot forming bakes out nearly all of the hydrogen.

Tin can render steel susceptible to temper embrittlement and hot shortness.

Arsenic and antimony also increase susceptibility of a steel to temper embrittlement.

PROPERTIES OF CARBON STEEL

Metals, like everything else in the world, are made up of atoms. These essential building blocks, in the case of metals, are stacked together in orderly patterns called crystals. By controlling the way crystals form, grow, and organize themselves, metallurgists (and knifemakers) affect the properties of their material.

We all know that various metals have different qualities. Aluminum, for instance, is light and malleable. Lead is malleable, but very heavy. Some metals turn dark with age, others rust, and some stay shiny. These properties and many others are due in part to the chemistry of the metal (what it is made of) and in part to the shape of the crystals that make it up. The first factor, the ingredients of a metal, are controlled by alloying. This refers to the mixing of ingredients in a metal.

By working with the second factor, the shape of the crystals and/or their arrangement within a pattern, we can alter the properties of a material. This is true of most metals, but we'll concern ourselves here with steel.

Steel is an alloy of iron and carbon. The relative amounts of these two ingredients will go a long way to determining the nature of the resulting metal. Pure iron (commercially known as *wrought iron*) is soft and brittle. The addition of carbon makes the steel tougher, up to about 0.65%, when maximum toughness is achieved. The addition of more carbon increases wear resistance, up to about 1.5% carbon. Beyond this amount, increased carbon causes brittleness and loss of malleability. Alloys containing 2 to 6.6% carbon are tough and easily melted and flow into molds nicely. They are called *cast iron*. The steels of interest to knifemakers are generally those that contain between ½ and 1½% carbon. These simple steels are known collectively as *plain carbon steel*. They are further described as low-carbon (under 0.4%), medium-carbon (0.4–0.6%), and high-carbon (0.7–1.5%).

Theory of Heat Treatment

The concept of solid metals as crystalline substances is essential for an elementary understanding of the theory of heat treatment. In the solid state the atoms of the metallic elements in the crystal are so packed into the space lattice in such an orderly way that they form a very dense structure. In the liquid state, however, the atoms move about in a random fashion, so that the liquid is less dense than a solid.

The lattice transformations, or changes in internal structure, that are listed below occur only in iron and make it possible to explain why the alloys of iron respond to heat treatment.

Structure	*Temperature Range*	*Name*
Body-centered cubic (B.C.C.)	2552 to 2795°F	Delta
Face-centered cubic (F.C.C.)	1670 to 2552°F	Gamma
Body-centered cubic (B.C.C.)	Room to 1670°F	Alpha

At 1330°F, the F.C.C. lattice is capable of holding about 0.8 per cent carbon by weight. At 2066°F, the F.C.C. lattice is capable of holding about 2.0 per cent carbon by weight. At 1330°F, the B.C.C. lattice (ferrite) is capable of holding about 0.03 per cent carbon by weight. At room temperature, the B.C.C. lattice (ferrite) is capable of holding about 0.007 per cent carbon by weight.

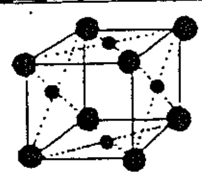
The physical properties of a plain carbon steel of a specified carbon content are dependent upon the form in which the carbon is present; the effect of heat treatment therefore depends upon the manner in which it changes the distribution of carbon.

For a hypoeutectoid or eutectoid steel, the first step in any heat treating operation, whether for the purpose of softening or of hardening, is conversion of the steel to a solid solution consisting of homogeneous austenite. That is accomplished by heating uniformly to a temperature above the critical range, as represented by the line *GS* in Figure 20, and maintaining that temperature until all carbon has dissolved and diffusion has become complete. The length of time during which the steel must be held at that temperature in order that diffusion of carbon may be complete depends upon the structure of the steel before heating, because carbon atoms diffuse more slowly through some structures than through some others. Ordinarily the steel is not held at this temperature for a longer time than that which is required for complete diffusion, because of the tendency of the grains to become coarser.

Crystals

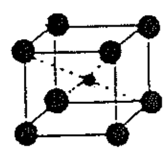
AT ROOM TEMPERATURE METALS EXIST AS CRYSTALS, REGULARLY SHAPED UNITS ARRANGED IN AN ORDERED RECURRING PATTERN CALLED A SPACE LATTICE. THERE ARE 7 CRYSTAL SYSTEMS AND 14 LATTICE CONFIGURATIONS. HERE ARE THOSE ASSOCIATED WITH FAMILIAR METALS.

FACE CENTERED CUBIC

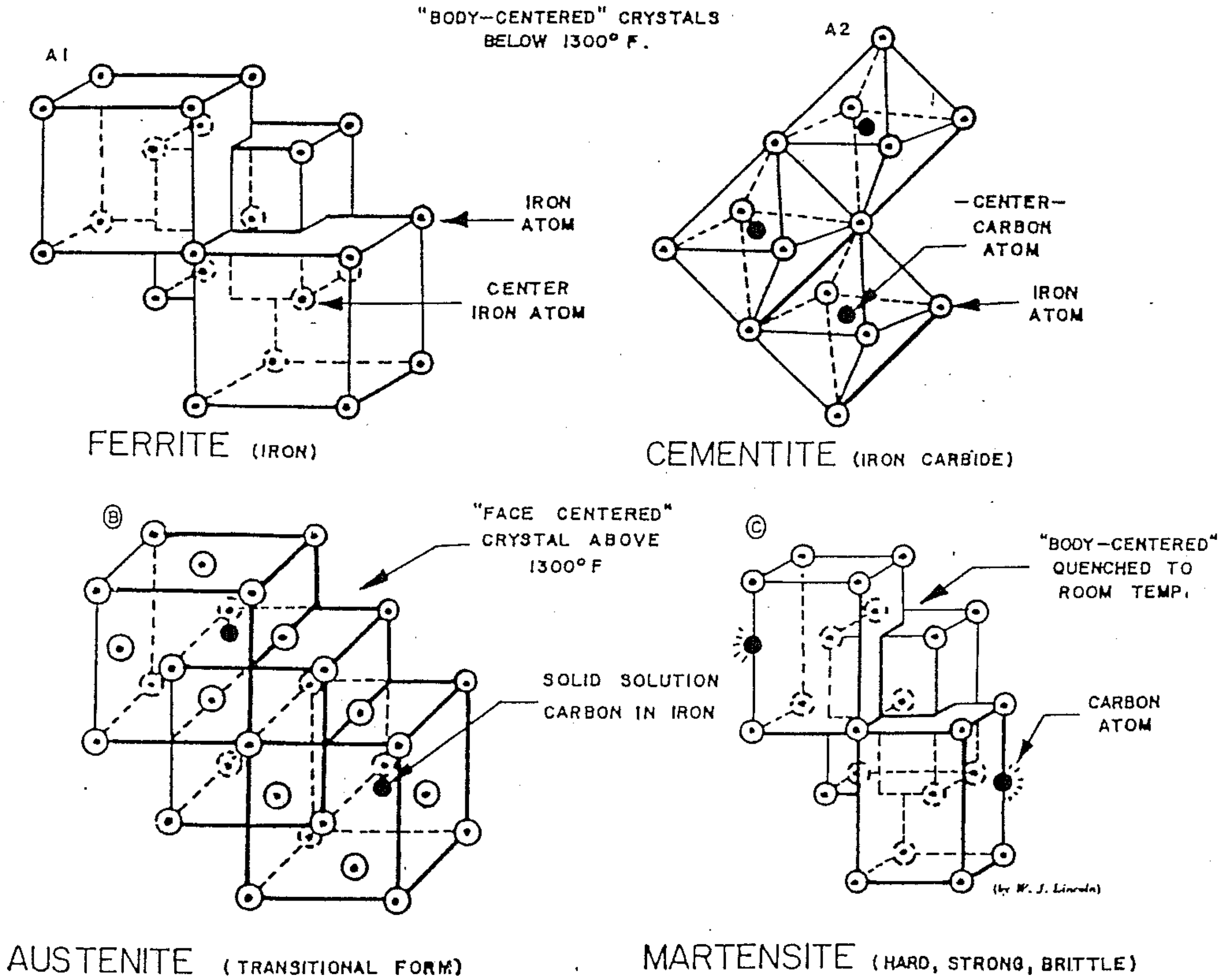


LEAD
COPPER
ALUMINUM
CALCIUM
GOLD
SILVER
NICKEL
IRON (AT HIGH TEMPERATURES)

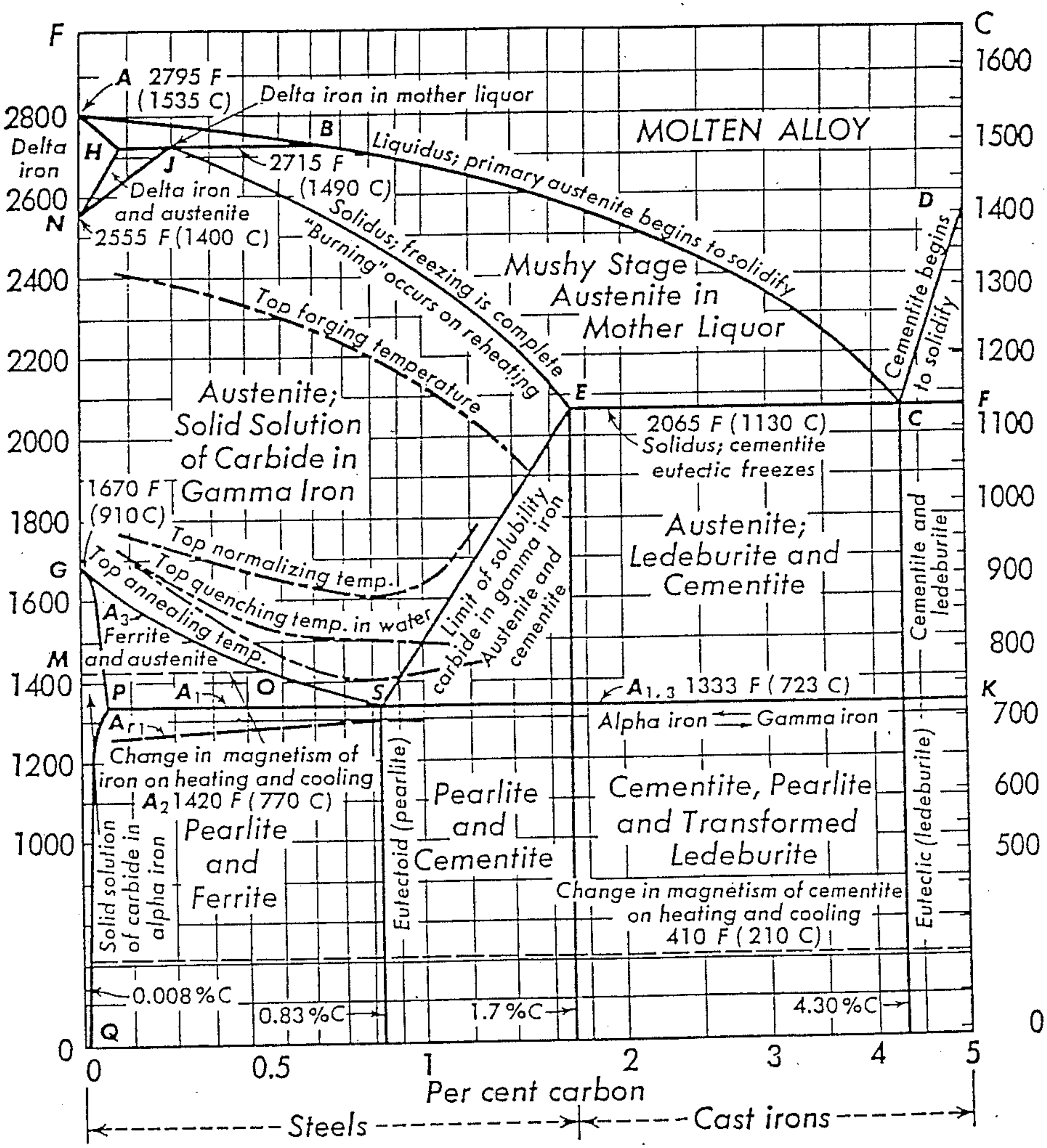
CHROMIUM
LITHIUM
MOLYBDENUM
POTASSIUM
SODIUM
VANADIUM
IRON (AT ROOM TEMPERATURE)



BODY CENTERED CUBIC



Crystal structure of iron and steels.



Iron-carbon constitutional diagram.

MICROSTRUCTURES AND CHARACTERISTIC PROPERTIES FOR APPROXIMATE TRANSFORMATION TEMPERATURE RANGES

Approximate Transformation Temperature Range	*Microstructure*	*Characteristic Properties*
1300–1000°F	Pearlite	Softest of the transformation products Lower ductility than bainite or tempered martensite at same hardness Good machinability
1000–500°F	Bainite	Substantially harder than pearlite and at the lower temperature levels approaches hardness of martensite Excellent ductility at high hardness
Below 500°F	Martensite	Hardest of the transformation products Brittle unless tempered
Reheating martensite in Temp. Range 300—1300°F	Tempered Martensite	Superior strength and toughness

Hardening Steel:

STEEL METALLURGY IS A COMPLEX FIELD AND DESERVES MORE SPACE THAN CAN BE GIVEN HERE. IN A SIMPLIFIED WAY, THOUGH, THIS IS HOW TOOL STEELS MAKE THEIR MAGIC.

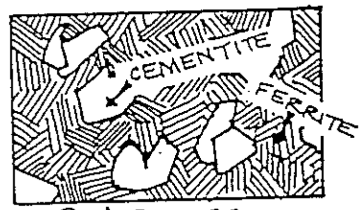
ANNEALED CARBON STEEL CONTAINS FERRITE, WHICH IS MALLEABLE, AND HARD PARTICLES OF CARBIDE CALLED CEMENTITE.

WHEN HEATED TO A GLOWING RED THE CARBIDES DISSOLVE INTO THE IRON; THE RESULT IS CALLED AUSTENITE. THE TEMPERATURE AT WHICH THIS OCCURS IS CALLED THE CRITICAL RANGE.

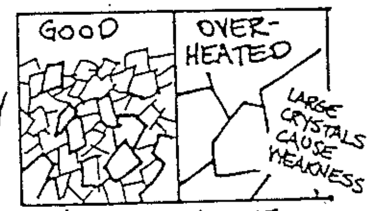
IF THE STEEL IS COOLED QUICKLY THE RESULT IS A HARD NEEDLE-LIKE STRUCTURE CALLED MARTENSITE. THIS IS WHAT GIVES CARBON STEEL ITS TOUGHNESS. UNFORTUNATELY IT ALSO MAKES IT BRITTLE.

BY HEATING THIS TO A PRESCRIBED TEMPERATURE AND COOLING IT AT A CERTAIN RATE THE STRESS MAY BE RELIEVED WITHOUT REMOVING ALL THE HARDNESS. THE RESULT CONTAINS HARD CEMENTITE PARTICLES HELD IN A TOUGH MATRIX OF MARTENSITE. THIS PROCESS IS CALLED TEMPERING OR DRAWING THE TEMPER, AND USUALLY TAKES PLACE BETWEEN 200-350 °C (400-600 °F).

IT IS IMPORTANT TO DISTINGUISH BETWEEN WEAR RESISTANCE AND HARDNESS. THE FIRST DEPENDS ON THE NUMBER AND HARDNESS OF THE PARTICLES; THE LATTER ON THE STRENGTH OF THE MATRIX. FOR INSTANCE, GRAVEL IN MUD WILL NOT MAKE A DURABLE MATERIAL EVEN THOUGH THE GRAVEL (PARTICLES) ARE HARD. IN STEEL THIS PROPERTY IS MOSTLY CONTROLLED BY THE ALLOY AND NOT BY HEAT TREATMENT. INCREASED CARBON - UP TO 1.6 % - MEANS MORE PARTICLES BUT LESS MATRIX OR INCREASED WEAR RESISTANCE BUT DECREASED HARDNESS.



PEARLITE



AUSTENITE


MARTENSITE


TEMPERED MARTENSITE

ANNEALING - consists of heating steels to slightly above A_3 (usually around 1600 degrees F.), holding for Austenite to form, then SLOWLY cooling in order to produce small grain size, softness, good ductility and other desirable properties such as ease of grinding.

Normalizing. The process of normalizing consists of heating to a temperature above A_3 and allowing the part to cool in still air. The actual temperature required for this depends on the composition of the steel, but is usually around 1600 °F (870 °C). Actually, the term normalize does not describe the purpose. The process might be more accurately described as a homogenizing or grain-refining treatment. Within any piece of steel, the composition is usually not uniform throughout. That is, one area may have more carbon than the area adjacent to it. These compositional differences affect the way in which the steel will respond to heat treatment. If it is heated to a high temperature, the carbon can readily diffuse throughout, and the result is a reasonably uniform composition from one area to the next. The steel is then more homogeneous and will respond to the heat treatment in a more uniform way.

Note: On cooling, Austenite transforms giving somewhat higher strength and hardness and slightly less ductility than in annealing.

Spheroidizing

To soften high-carbon steel sufficiently to make it readily machinable, it is *spheroidized*. The cementite is caused to assume a rounded or globular shape, leaving larger areas of ferrite free from cementite; this produces the softest steel possible for the same chemical composition.

Spheroidizing is accomplished by prolonged heating at a temperature slightly below the critical point. It is general practice to heat first to a temperature less than 100°F above the critical range; the closer this temperature is to the transformation temperature, the greater is the tendency to spheroidize. After this heating the temperature is allowed to fall to just below the critical range, and is maintained there for an extended period. Slow cooling is the final step.

Austempering

Austempering is an interrupted quenching process which consists in quenching in a bath of molten salt at a temperature between 450°F and 900°F, depending upon the microstructure desired, and maintaining that temperature until transformation of austenite into bainite is complete. Because the steel is held at the same temperature for the entire period during which transformation is taking place, little internal stress or distortion are developed. The result is a steel which has greater toughness and greater ductility than one that is hardened and tempered in the usual way. Austempering is used for treatment of light articles such as wire, springs, knife blades, needle bearings, and the like. Use of austempering on large sections is limited by the fact that the part must cool with sufficient rapidity to prevent transformation to pearlite in a bath which is at such high temperature that its heat-abstracting power is relatively low.

The advantages of austempering are:

1. Better ductility at high hardness.
2. Greater impact strength.
3. Freedom from distortion.
4. Uniformly heat-treated product.

Martempering

The purpose of martempering is to produce a fully martensitic structure. Work is quenched in molten salt at a temperature only slightly above the point at which formation of martensite begins, and is held at that temperature long enough to permit temperature equalization throughout the work. Because transformation in this temperature range does not start for an appreciable length of time, there is no risk of partial transformation into bainite. After temperature is equalized, the work is removed from the bath and allowed to cool slowly in air. Because the austenitic metal is kept at the same temperature throughout its mass, martensite forms at a uniform rate. Because the metal has contracted to a considerable extent while still austenitic, the additional contraction during transformation is relatively small, and the net result of the small degree of contraction and the uniform rate of formation of martensite is that virtually no strain is set up. Work may be straightened if necessary immediately after removing from the bath, with assurance that no residual strain will be introduced during transformation. A conventional tempering operation may follow cooling if required. Heavier sections can be hardened by martempering than by austempering, and the process is more rapid than austempering. It is used for parts which have been machined and which must be treated to have high hardness without distortion. Springs and knife blades which have been martempered have high resilience.

NOTES: The martempering process stops the temperature drop at 400-600 degrees F. by quenching into either oil or molten salt held at that temperature. The blade should be held at this temperature for a sufficient time for 100 per cent (?) transformation to martensite. A martempered blade may be more flexible but at the expense of edge holding ability.

TERMS AND DEFINITIONS:

AUSTENITE A solid solution of one or more elements in face-centered cubic iron. Unless otherwise designated (such as nickel austenite), the solute is generally assumed to be carbon.

BODY-CENTERED CUBIC SPACE LATTICE (B.C.C.) In crystals, an arrangement of atoms in which the atomic centers are disposed in space in such a way that they may be presumed to be situated at the corners and centers of a set of cubic cells.

BAINITE A structural intermediate between pearlite and martensite, which is formed when steel is cooled rapidly to about 800 degrees F. and is held at any temperature between 800 degrees F. and about 400 degrees F. for a sufficient length of time. the structure depends upon the temperature at which transformation occurs.

CARBIDE A compound of carbon with a more positive element such as iron.

CEMENTITE (Iron Carbide) A chemical compound of iron and carbon also known as iron carbide (Fe_3C), which contains about 6.8 per cent carbon. It occurs as grain envelopes or needles within a grain of hypereutectoid steel. It occurs as lamellae in pearlite. It mat also occur as speroids in annealed steel. It is extremely hard and brittle.

CRITICAL RANGE The range between the recalescence point and the decalescence point.

CRITICAL TEMPERATURE The temperature at which some change occurs in a metal or alloy during heating or cooling.

DECALESCENCE POINT The first critical point, 1333 degrees F., at which a change occurs in steel. The steel absorbs a considerable amount of heat as the structure changes in part to the face-centered cubic form.

DEOXIDIZER A material used to remove oxygen or oxides from metals and alloys.

EUTECTOID STEEL Steel that contains approximately 0.83 per cent carbon.

FACE-CENTERED CUBIC SPACE LATTICE (F.C.C.) An arrangement of atoms in crystals in which the atomic centers are disposed in space in such a way that they may be supposed to be situated at tha corners and the middle of the faces of a set of cubic cells.

FERRITE Nearly pure iron which contains less than 0.05 per cent of carbon. A solid solution of one or more elements in body-centered cubic iron. The solute is generally assumed to be carbon.

Continued next page

FLASH POINT The lowest temperature at which vapors above a volitile combustibe substance will ignite in air when exposed to flame.

HARDNESS This refers to the ability to resist penetration.

HYPEREUTECTOID STEEL A steel containing more carbon than the eutectoid steel which is 0.83 per cent.

HYPOEUTECTOID STEEL A steel containing less carbon than the eutectoid composition which is 0.83 per cent.

MARTENSITE A supersaturated solid solution of carbon in ferrite. In alloys where the solute atoms occupy interstitial positions in the martensitic lattice, such as carbon in iron, the structure is hard and highly strained. (Structure is needle-like.)

OXIDATION The combination of an element with oxygen to form an oxide.

PEARLITE A metastable lamellar aggregate of ferrite and cementite resulting from the transformation of austentite at temperatures above the bainite range.

RECALESCENCE A phenomenon, associated with the transformation of gamma iron (the face-centered cubic of pure iron, stable from 1670 to 2550 degrees F.) to alpha iron (the body-centered cubic form of pure iron, stable below 1670 degrees F.) on the cooling of iron or steel, revealed by the brightening of the metal surface owing to the sudden increase in temperature caused by the fast liberation of the latent heat of transformation.

STEEL An iron based alloy, malleable in some temperature range as initially cast, containing manganese, carbon and often other alloying elements.

TOUGHNESS The ability of a steel to resist breaking. It is a near opposite of brittleness.

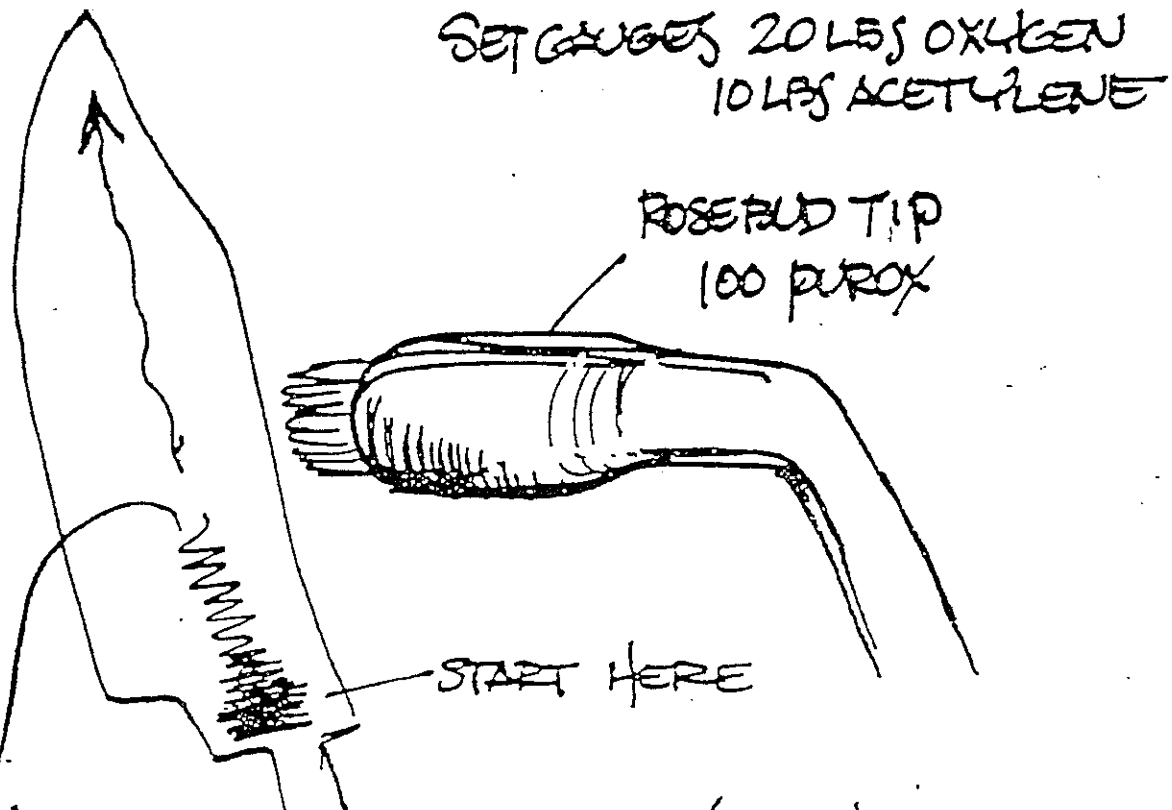
TRANSFORMATION A constitutional change in a solid metal; for example, the change from gamma to alpha iron or the formation of pearlite from austentite.

TRANSFORMATION RANGE The range of temperatures at which changes in phase of iron-carbon alloys occur.

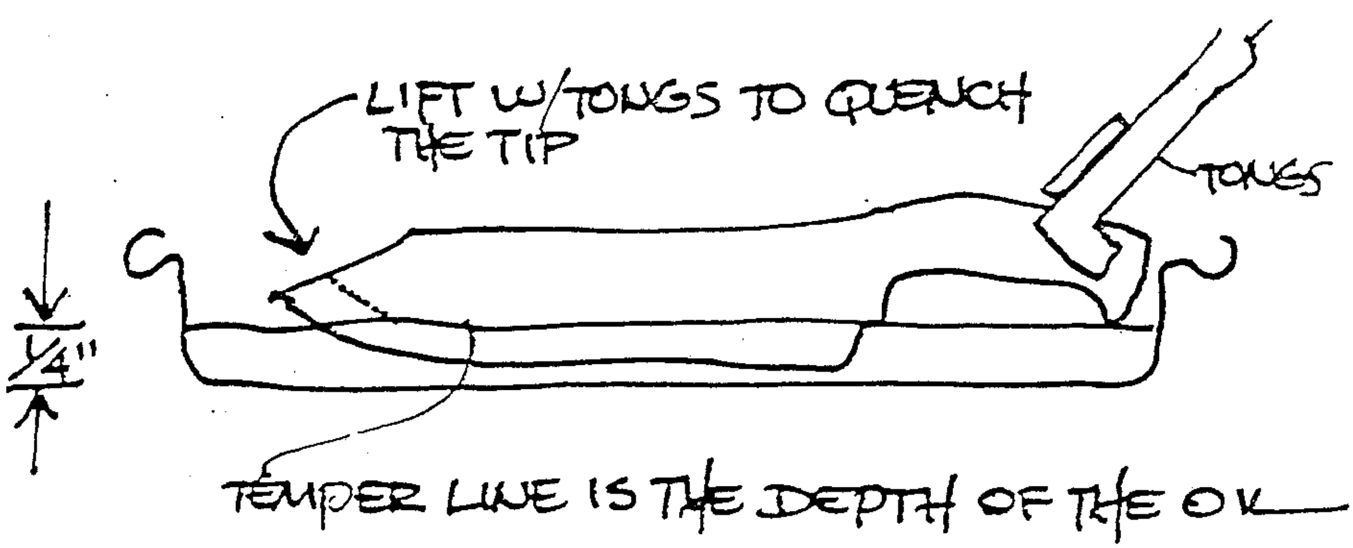
TROOSTITE (Obsolete) Term used for tempered martensite.

WEAR RESISTANCE This property is what gives a blade edge-holding power. It is the ability to stand up to abrasion

HEAT TREATING



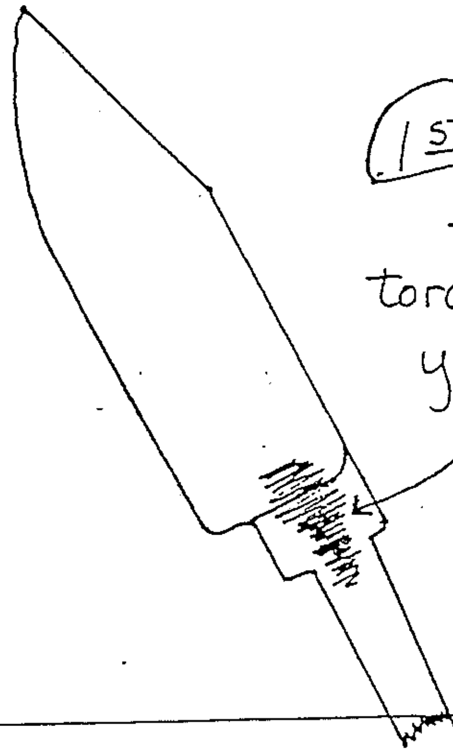
STAY IN CENTER OF BLADE W/TORCH
THE DARKER THE SURROUNDINGS THE EASIER IT IS TO SEE THE COLOR CHANGE.



5168 carbon steel — Heat treat

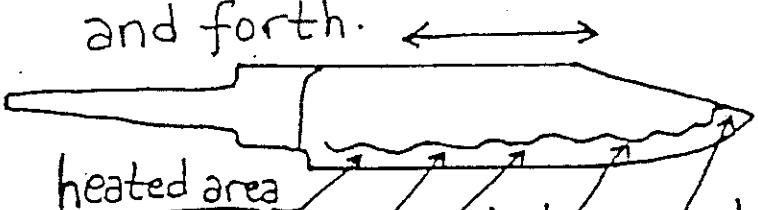
Courtesy of Jerry Fisk

Edge hardening



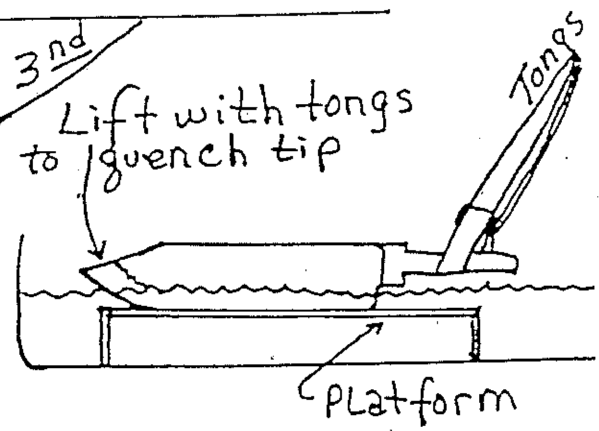
(1st) Heat this area first with acetylene torch or forge fire - your choice. (The thicker ricasso takes Longer to heat up than the cutting edge.)

(2nd) Edge down in the forge fire move blade back and forth.



You may need to provide an air source to forge. The heated area must be brought to a non-magnetic stage. Appox 1450° F

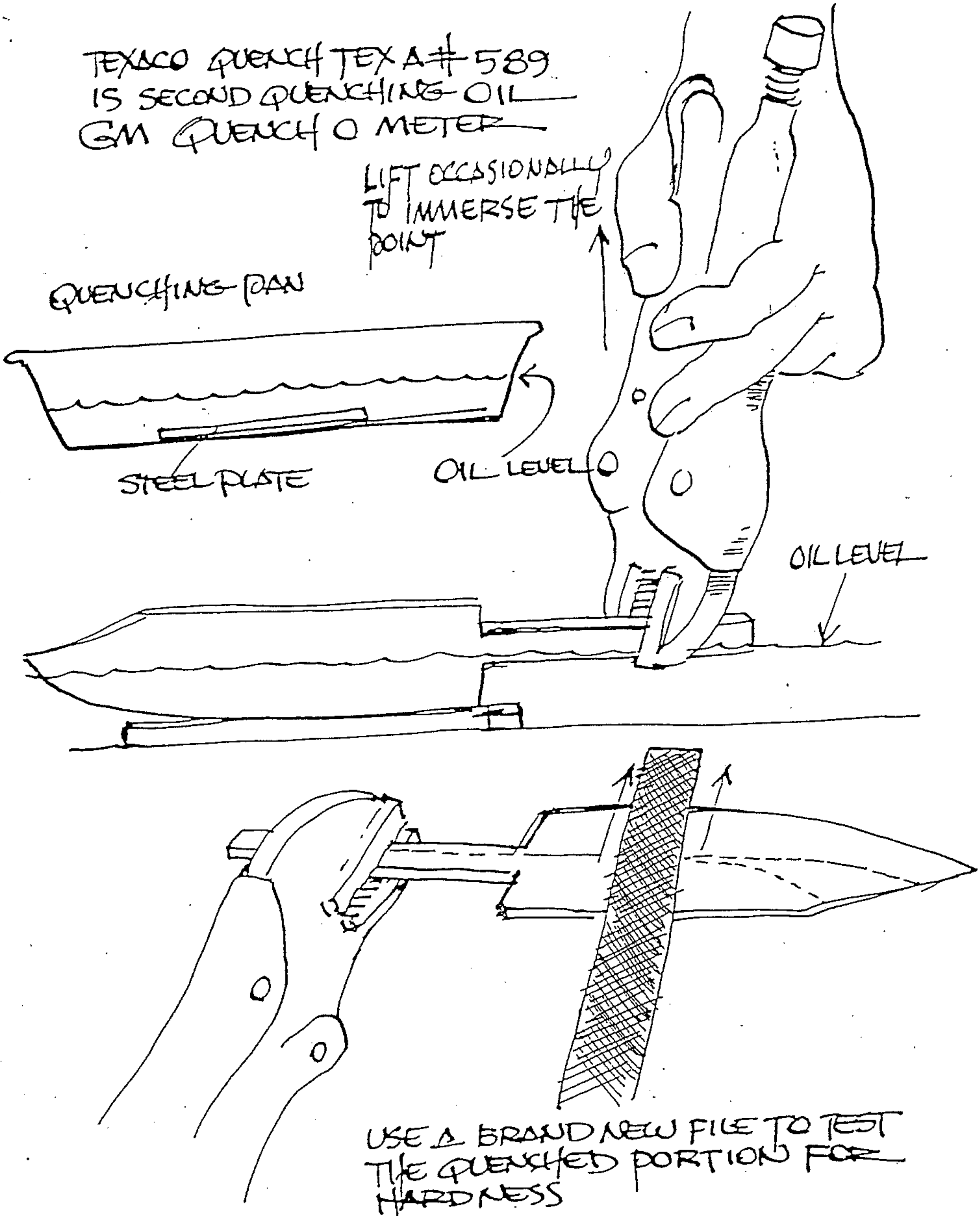
3rd Lift with tongs to quench tip



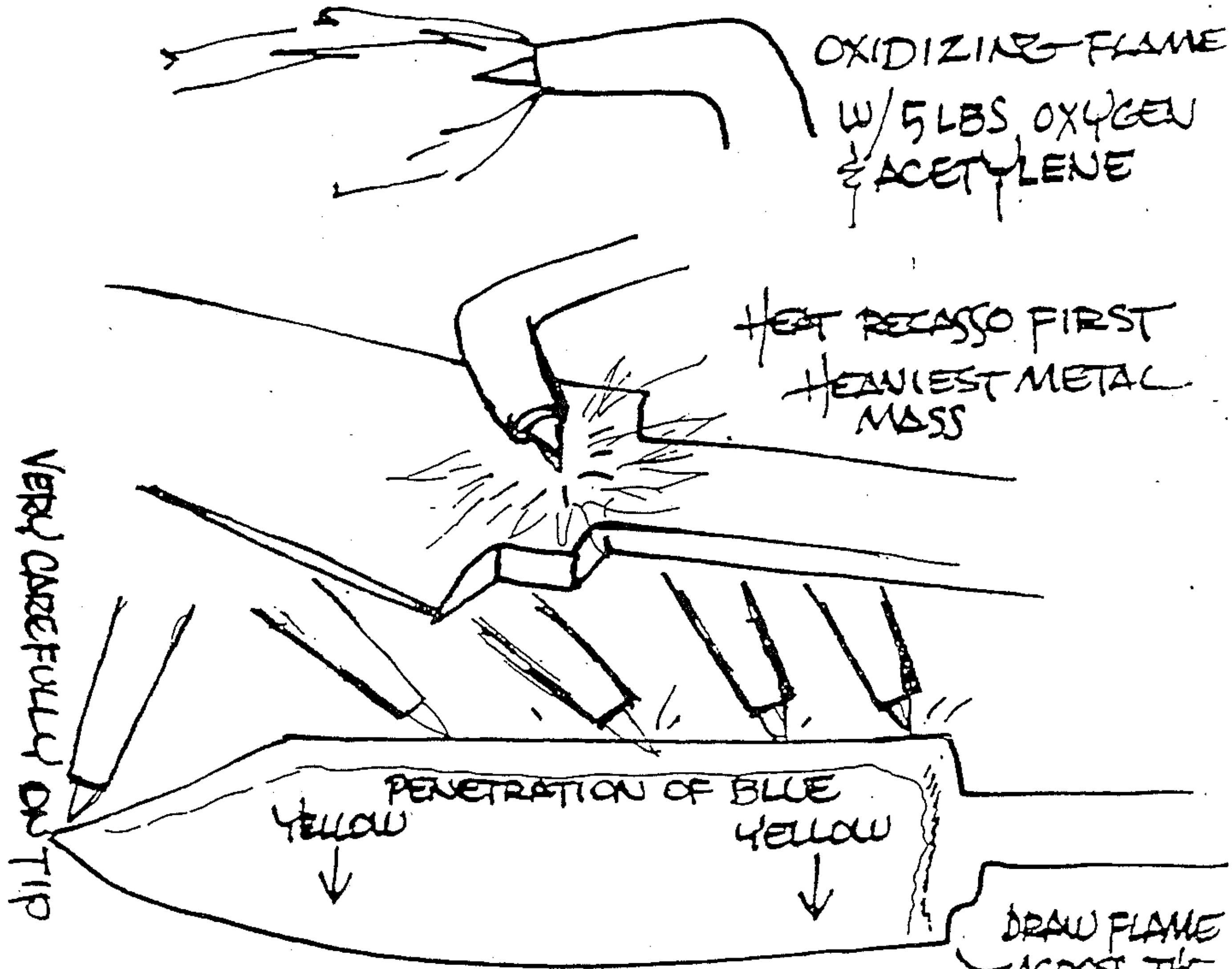
Oil level appox. 1/4" above plat form heigh (appox 2" deep)

Rock back and forth (Tip to Ricasso) until 100°F - 200°F

Courtesy of Bill Moran



DRAWING THE TEMPER



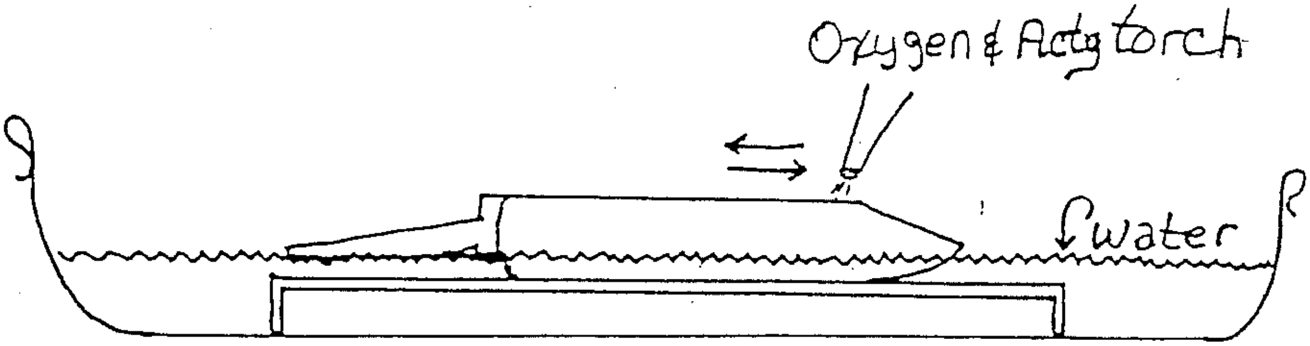
THE DOWN SIDE OF THE BLADE BECOMES DARKER AIR CIRCULATION IS RESPONSIBLE

HOLD BLADE W/VISE GRAPS ON THE TANG & DRAW THE TEMPER WHILE SEATED WITH A LOT OF LIGHT ON THE BACK OF THE BLADE

TRIPLE DRAW (EVERYTHING)

Courtesy of Jerry Fisk

drawing the spine



Water level to be about 1/4" deep on cutting edge. - Bring spine color to dark blue 3 times. Blue color will stop appox 1/4" above water line. Keep an eye on the water level if it starts dropping add a small amount of water to keep the proper level.

Stop torch a couple of inches short of where knife point starts coming out of the water. work toward tip carefully with torch tip pointed toward ricasso. You may need to just "brush" tip when you get close. stop when 1/2" to 1" from tip - depending on knife.

Do not bring spine of chrome steels to red color - this will air harden.

When finished with this you are ready to grind the cutting edge.

MISCELLANEOUS GOOD TO KNOW STUFF:

1. Quenching oil temperature should be between 90 to 140 degrees F. Stop if temperature reaches 160 degrees F.

2. When quenching the edge only, after 15 seconds submerge the whole blade.

3. Carbon steels start to go non-magnetic at 1333 degrees F. This is a dull red color and is the LOWER transformation temperature.

4. Care must be taken so that the blade does not remain at the critical temperature any longer that required to get the temperature even about the cutting edges as the following problems mat result:
   a. Decarburization (loss of carbon)
   b. Grain Growth (the larger the crystal structure, the weaker the steel)

Quench as soon as possible after the heat is even!!

5. #0 Victor tip (or equivalent) good for heat treating oxy/acetylene torch.

6. Viscosity of heat treat oil determines a slow or fast quench. Examples of heat treat oil:
   a. Transmission Fluid - favored by Bert Gaston
   b. Chevron Super Quench 70 - favored by Jerry Fisk
   c. Quench Tex A - favored by Bill Moran
   d. Burnt motot oil with 5 or 6 per cent diesel fuel

7. O-1 steel will air harden.

8. 1060 steel makes a very tough knife and will also produce a good "temper line".

9. Chrome steels will air harden if you bring the spine of the blade to a red color. This will create hard spots and should be avoided.

10. In order for a carbon steel knife blade to achieve full hardness in an oil quench, the temperature must be lowered from the hardening temperature to 400 degrees F. or less in six to eight seconds.

11. There is a rearrangement of atoms within the grain when steel or iron is heated through B.C.C. temperatures where changes to F.C.C. occur. This shifting of atoms is referred to as an ALLOTROPIC change. The science of heat treating is dependent on this allotrophy of iron and the variations of carbon solubility in each crystal form of iron.

Continued next page.

12. Manganese (Mn) is usually present in all steel. It is usually present in quanyities of 0.5 to 2.0 per cent.

13. Normally, carbon is not present in steel as carbon but rather as cementite (iron carbide) a compound of iron and carbon having a formula of Fe_3C.

14. The carbon content of an alloy is expressed as a point of carbon, with each point signifying 0.01 per cent of the alloy.

BIBLIOGRAPHY AND RECOMMENDED BOOKS:

BASIC FORGING by Jerry Fisk

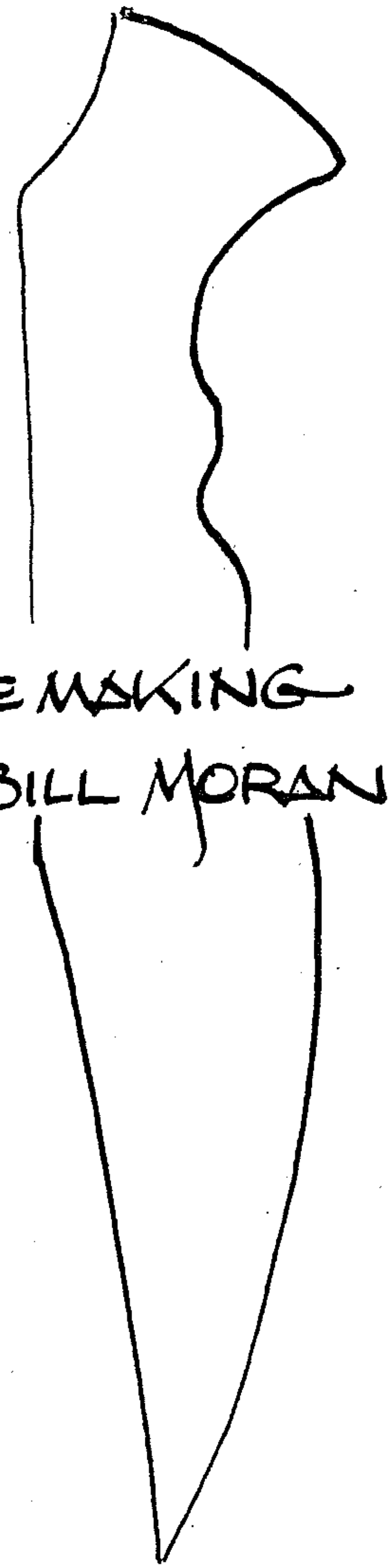
KNIFE MAKING (Illustrated) by Bill Moran

ELEMENTARY METALLURGY AND METALLOGRAPHY by Arthur M. Shrager

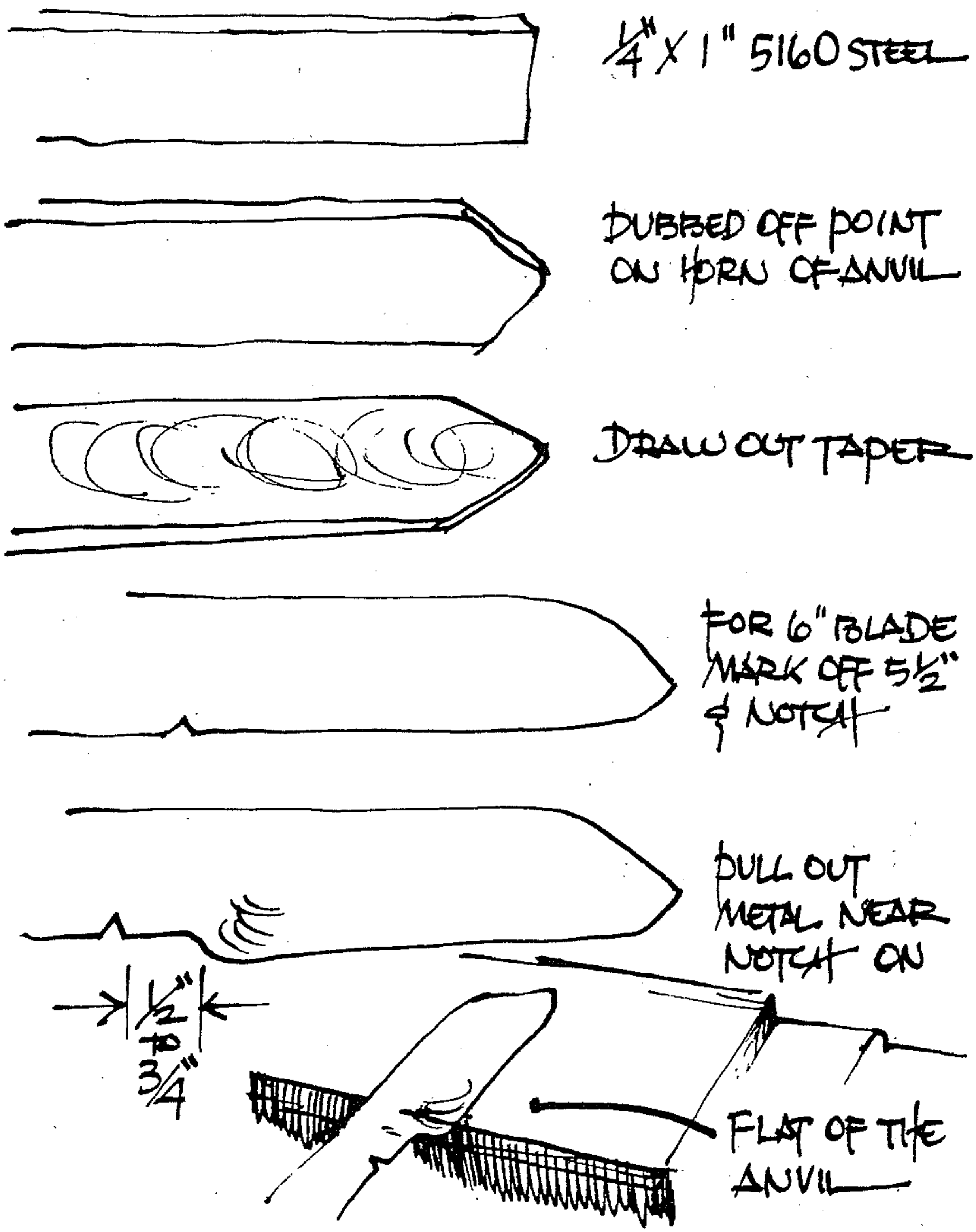
HEAT TREATERS GUIDE produced by the American Society for Metals

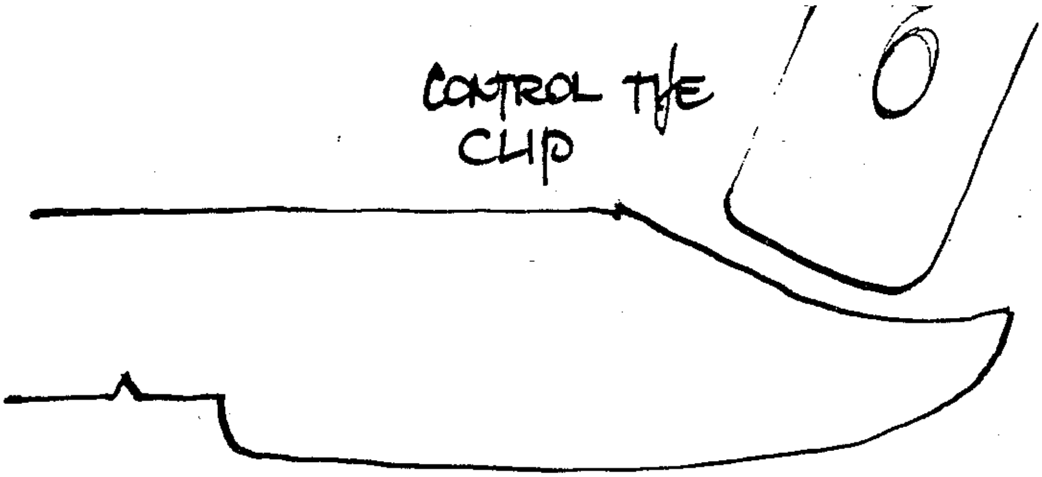
THE COMPLETE METALSMITH by Tim McCreight

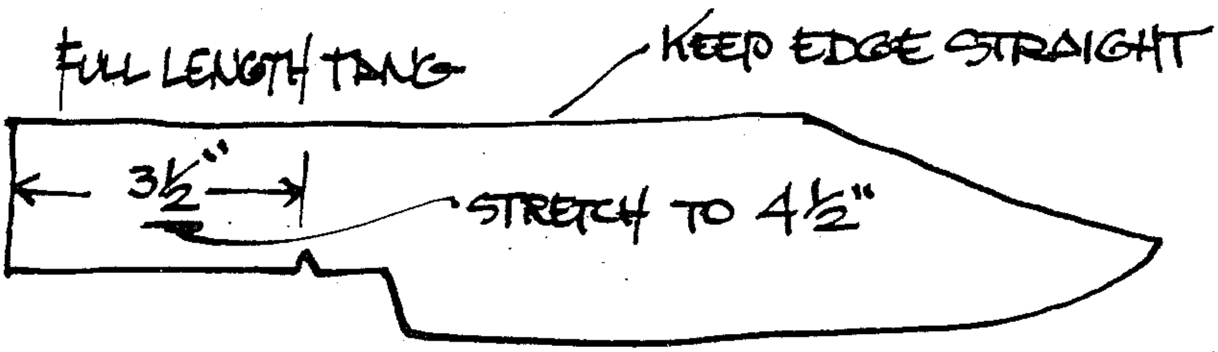
Bill Moran

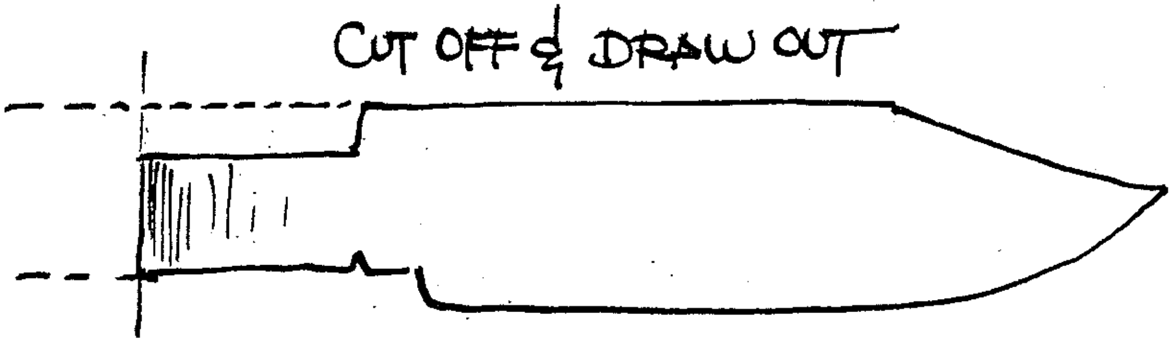


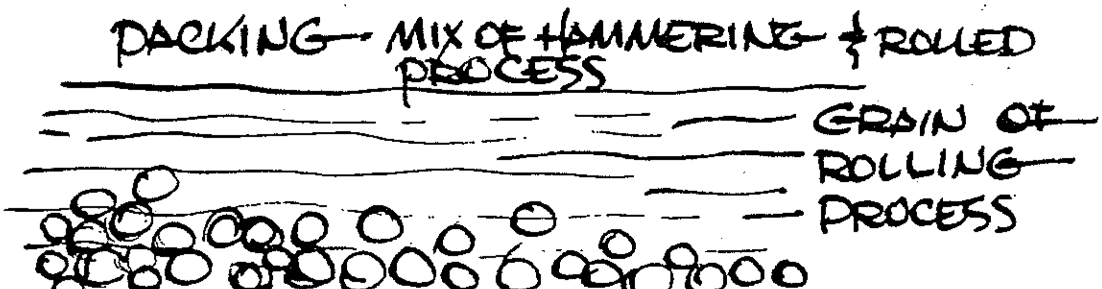
KNIFEMAKING/BILL MORAN.

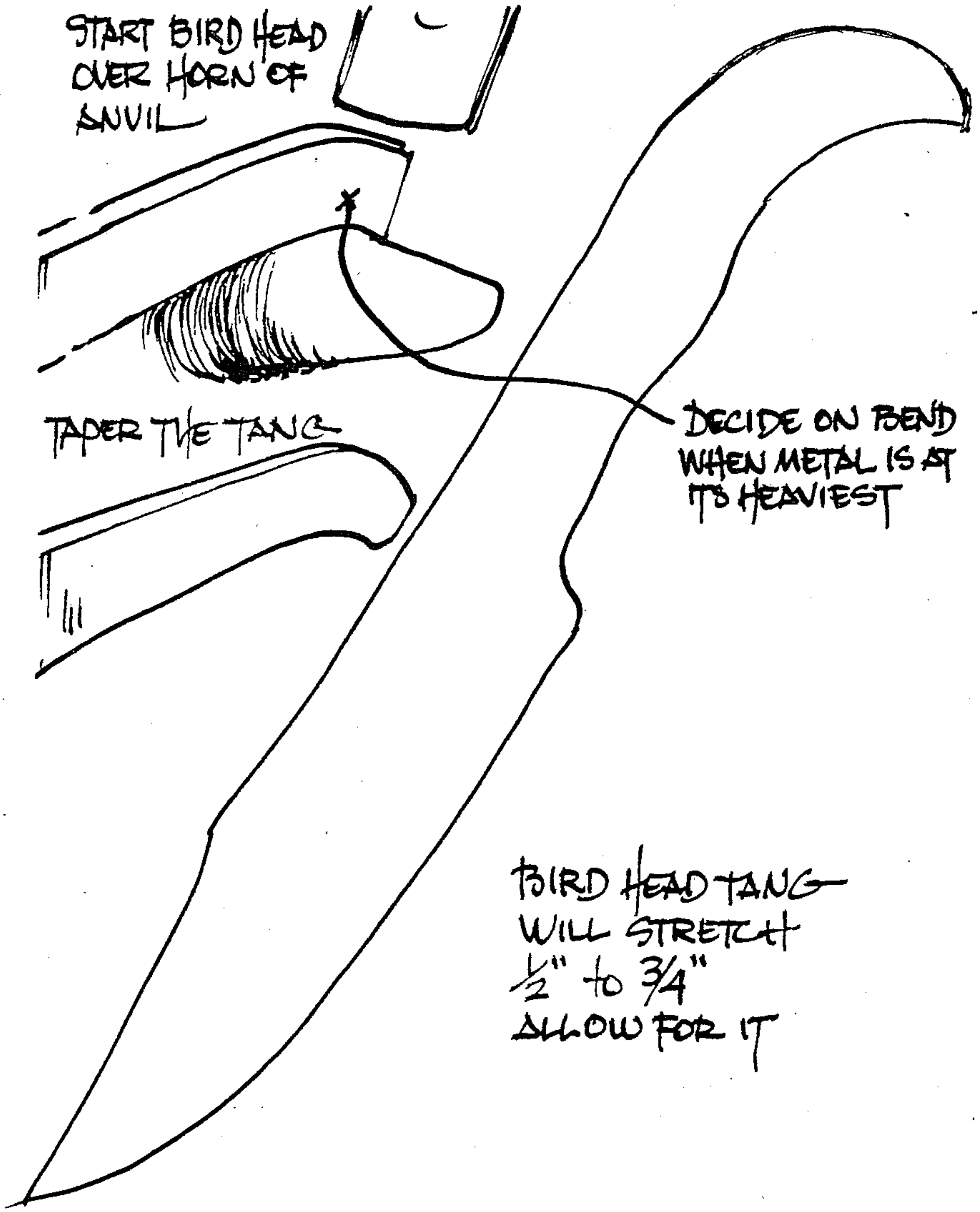


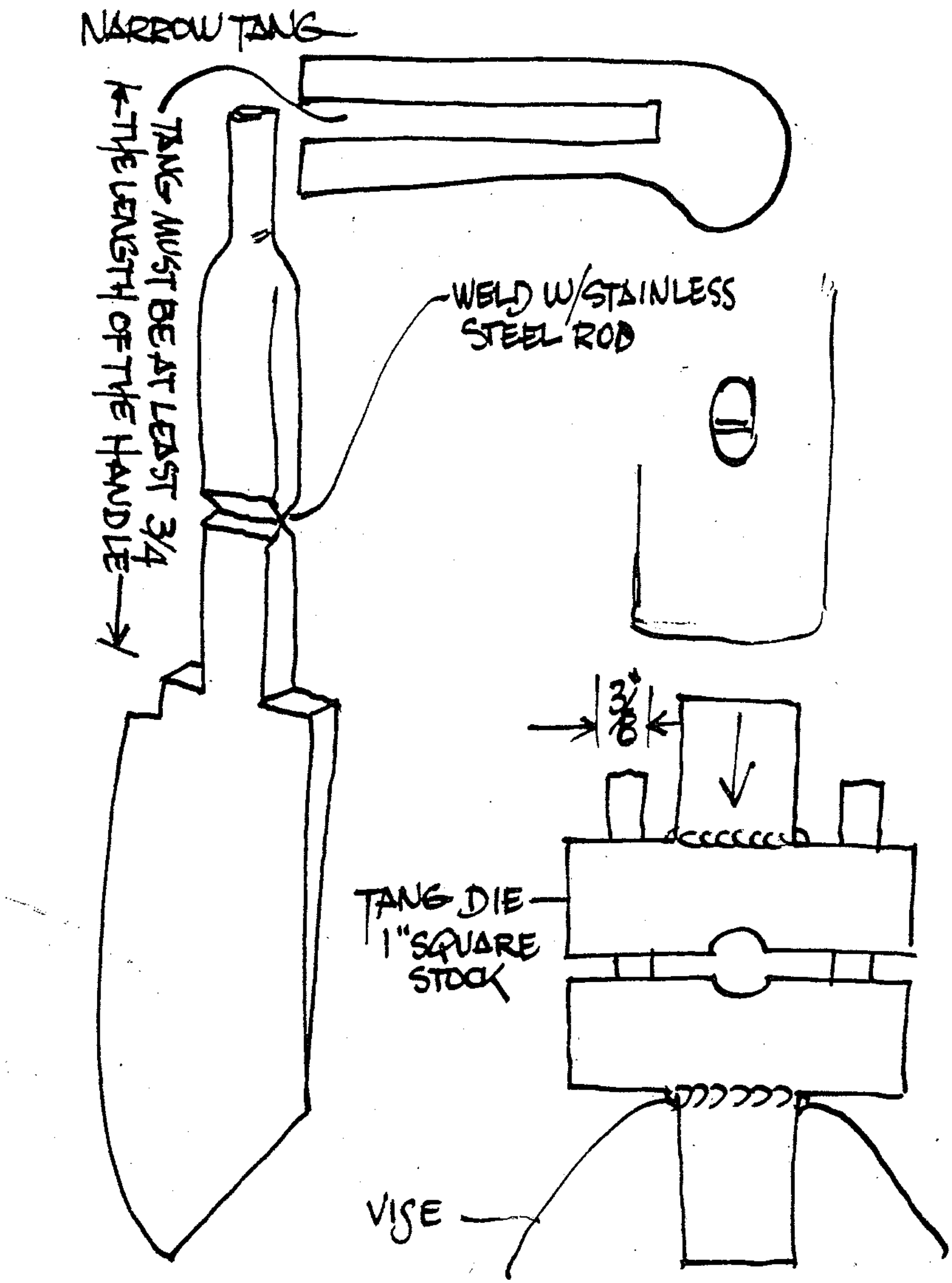

CONTROL THE CLIP


FULL LENGTH TANG
KEEP EDGE STRAIGHT
3½"
STRETCH TO 4½"

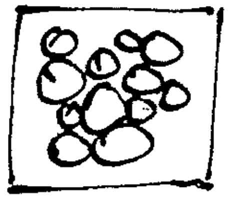

CUT OFF & DRAW OUT


PACKING - MIX OF HAMMERING & ROLLED PROCESS
GRAIN OF ROLLING PROCESS


START BIRD HEAD OVER HORN OF ANVIL
TAPER THE TANG
DECIDE ON BEND WHEN METAL IS AT ITS HEAVIEST
BIRD HEAD TANG WILL STRETCH 1/2" to 3/4" ALLOW FOR IT


NARROW TANG
TANG MUST BE AT LEAST 3/4
THE LENGTH OF THE HANDLE
WELD W/STAINLESS
STEEL ROD
3/8"
TANG DIE
1" SQUARE
STOCK
VISE

GENERAL INFORMATION •

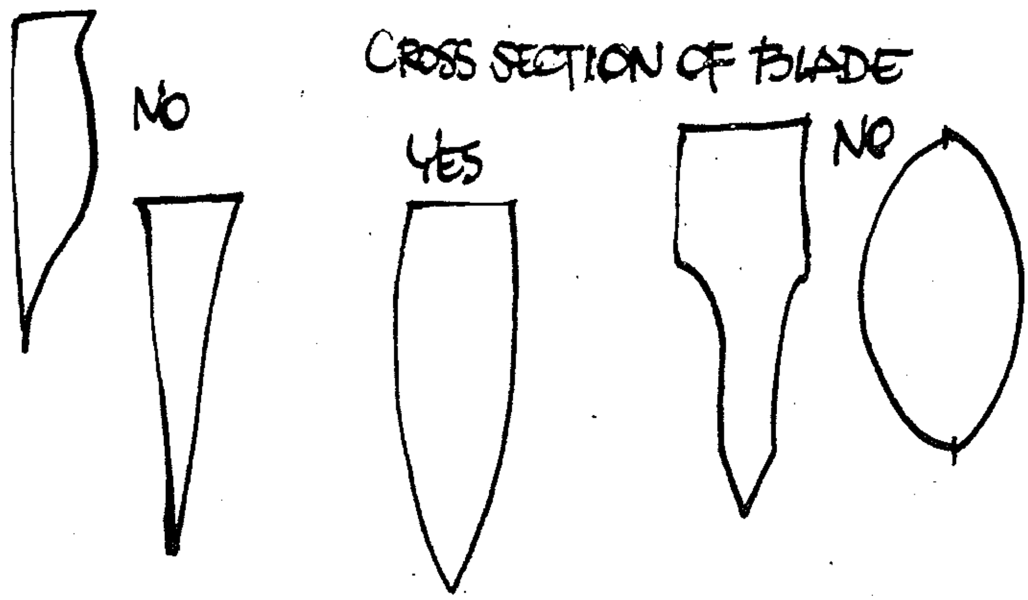


DON'T OVERHEAT STEEL

CORRECT

- GAS FORGE IS DESIRABLE FOR FORGING MORE THAN ONE BLADE AT A TIME
- COAL FORGE IS USED FOR ONE BLADE AT A TIME
- DON'T USE O1 STEELS THEY AIR HARDEN
- 1095 ALMOST THE SAME AS W2
- 1060 TOUGHER BLADE STEEL
- 9260 EXTREMELY TOUGH
  TOUGHER THAN DAMASCUS
- 51 = 1% CHROME IN STEEL EX. 51<u>60</u>
  .60 = CARBON
- 5, 6, 7 % CHROME INDICATES AIR HARDENING STEELS
- ALL STEELS ARE HARDENED IN OIL

GENERAL INFORMATION.



TO TEMPER SMALL OBJECTS

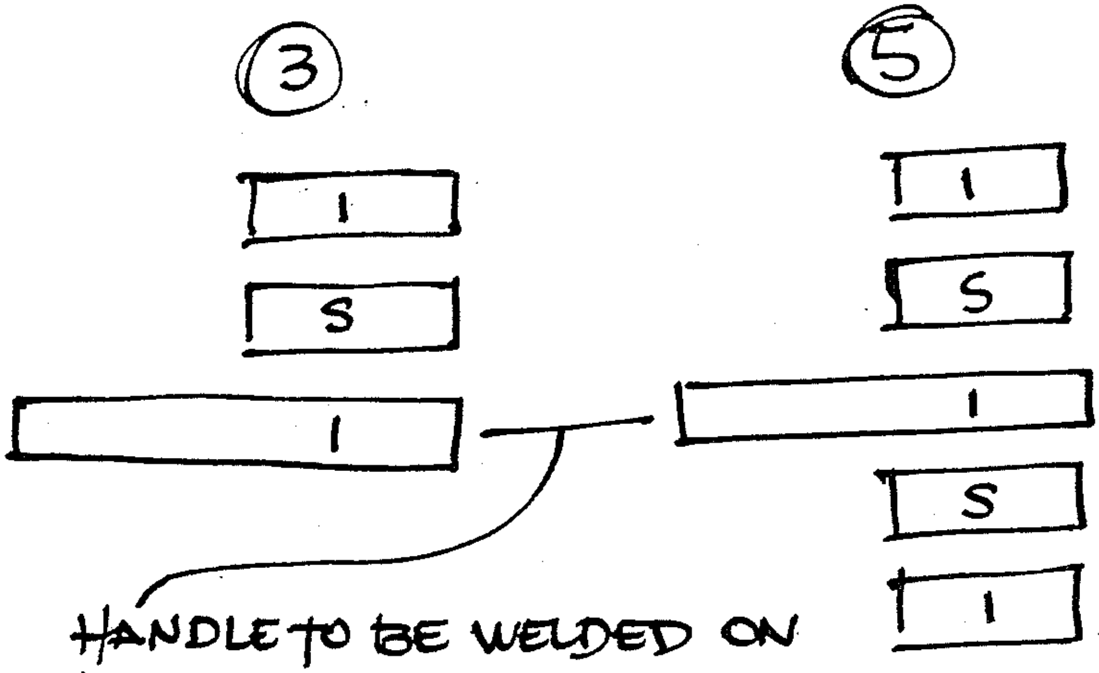
- BRING UP TO RED HOT & OIL QUENCH
- SUBMERGE IN LADLE & HEAT UNTIL OIL CATCHES FIRE
- REMOVE FROM SOURCE OF HEAT & ALLOW LADLE & CONTENTS TO BURN OFF

QUENCH HARDEN STEEL AT LOWEST TEMPERATURE. CHECK W/MAGNET FOR PROPER DULL CHERRY RED.

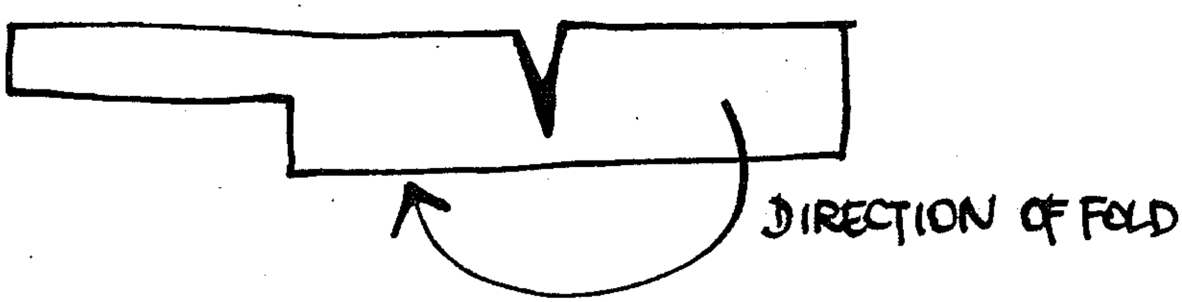
QUENCHING OILS W/ADDITIVES TEND TO LOSE THEIR QUENCHING CAPABILITIES

CHECK QUENCHING OIL(S) FOR SLOW, MEDIUM OR FAST CAPABILITIES

DAMASCUS STEEL

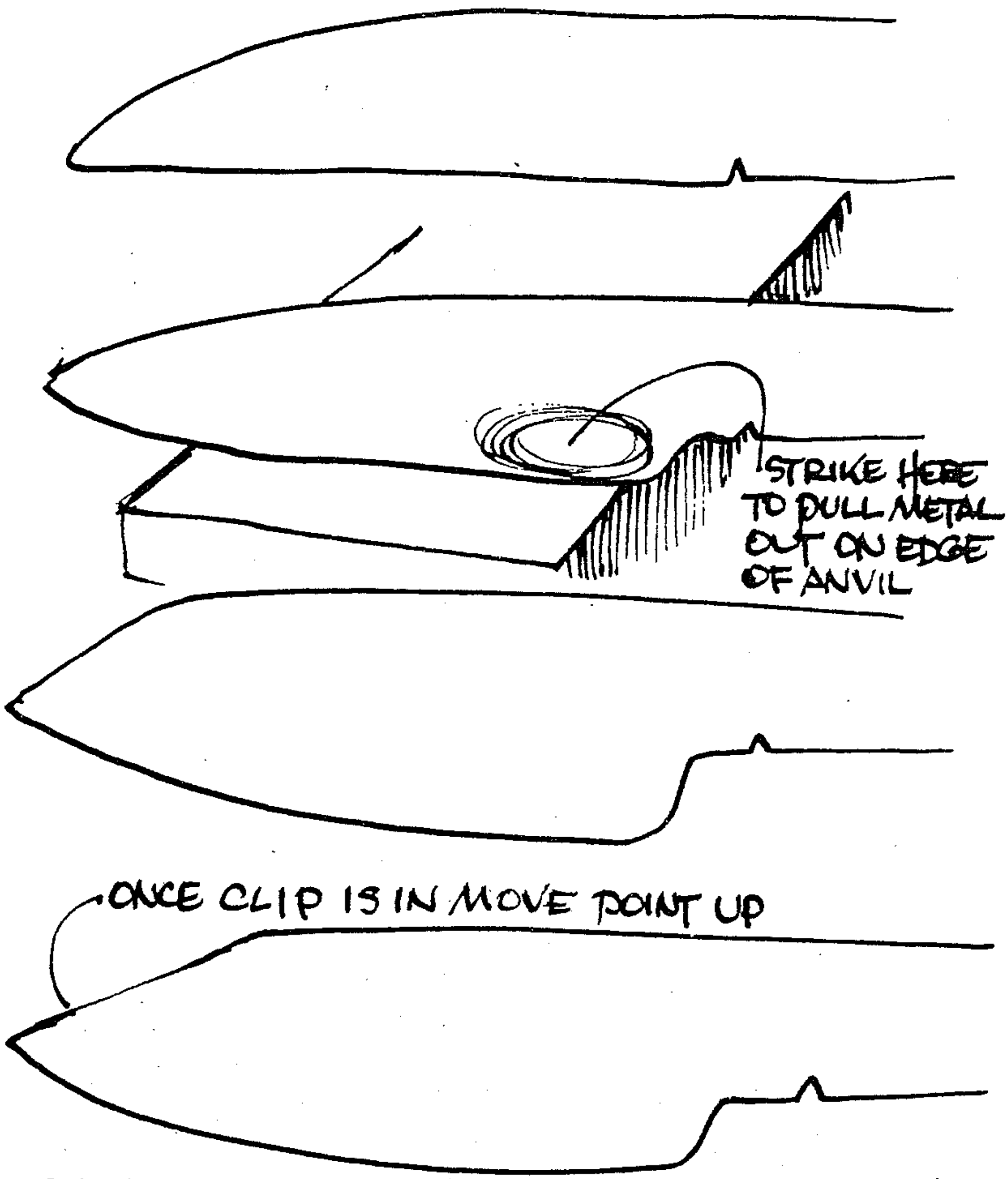


- HOT ROLLED MILD STEEL IS REFERED TO AS IRON
- FIRE IS TWICE AS BIG AS STEEL FOR FORGING



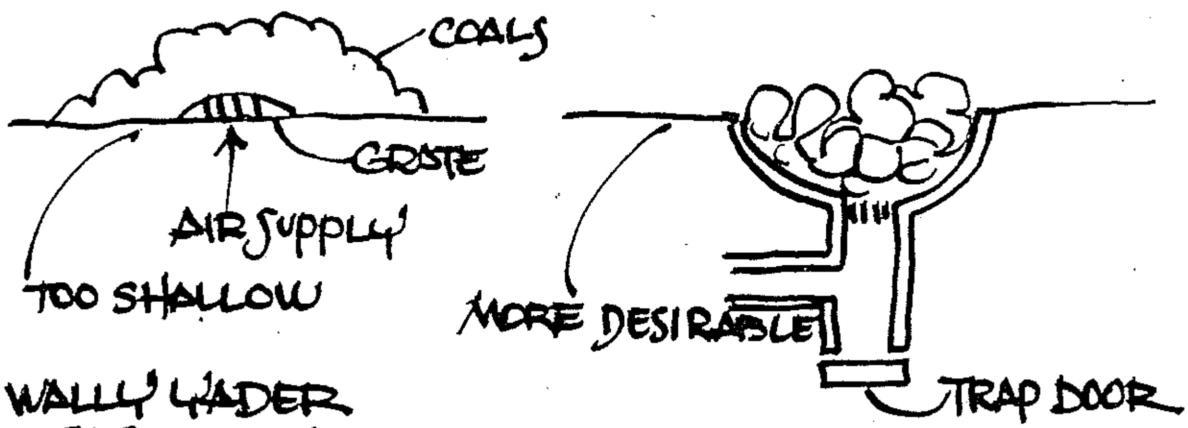
GROUND GROOVES CREATE WAVY PATTERN IN FORGING

FORGING REVIEW

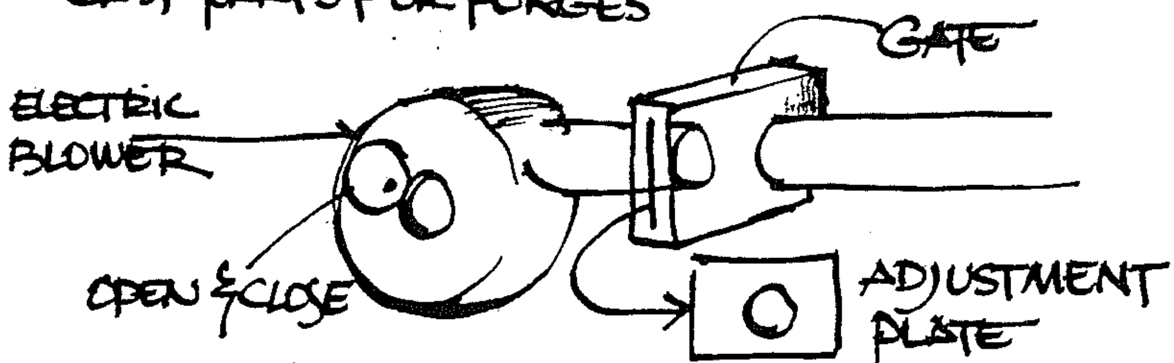


TO REMOVE DENTS REHEAT & HAMMER FROM THE OPPOSITE SIDE

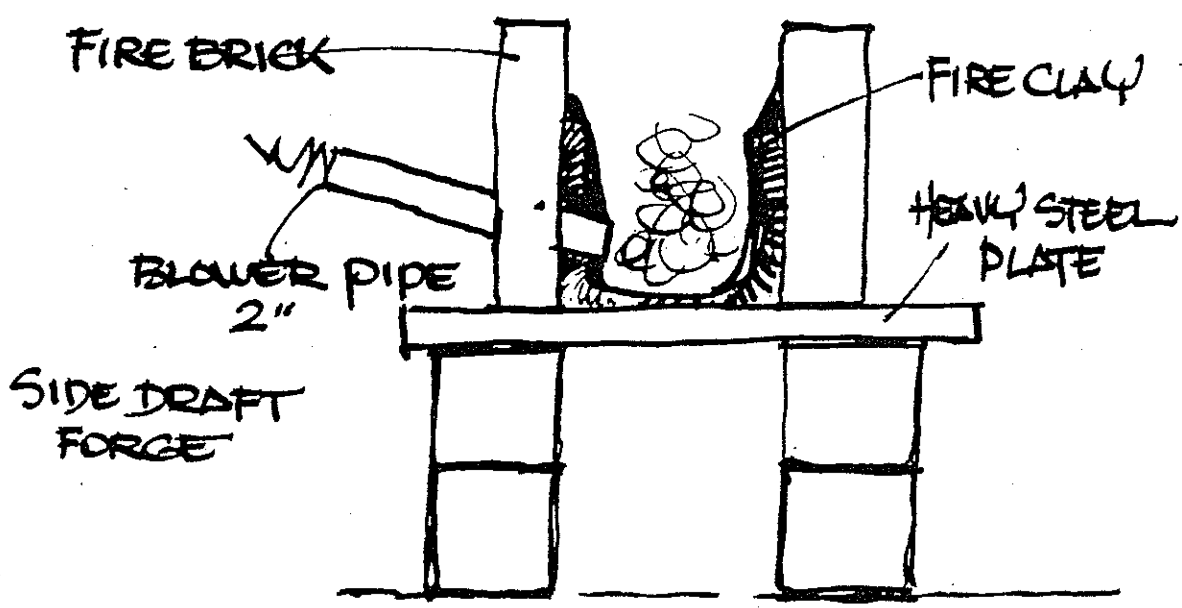
FORGES

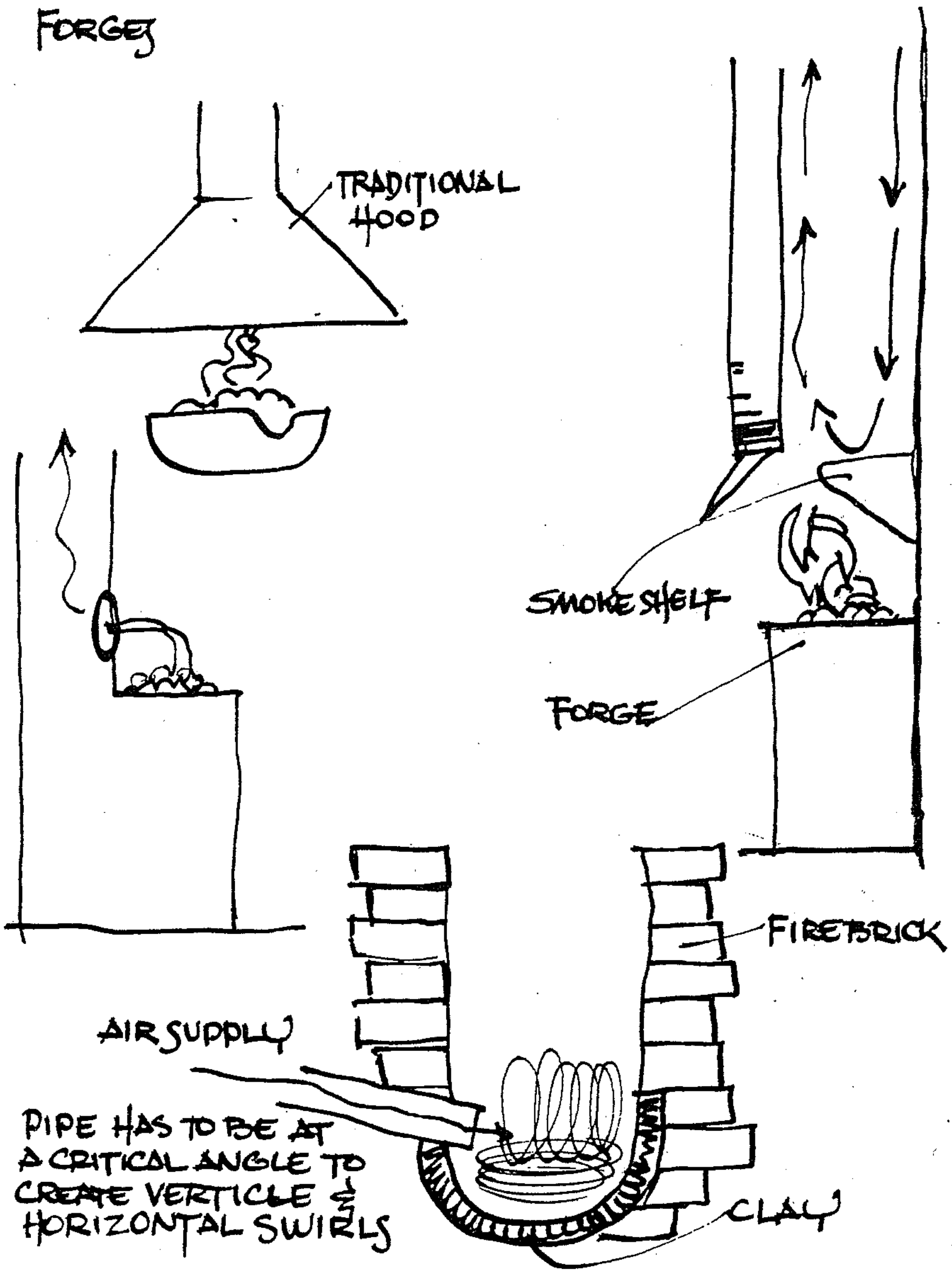


WALLY YADER
CAST PARTS FOR FORGES

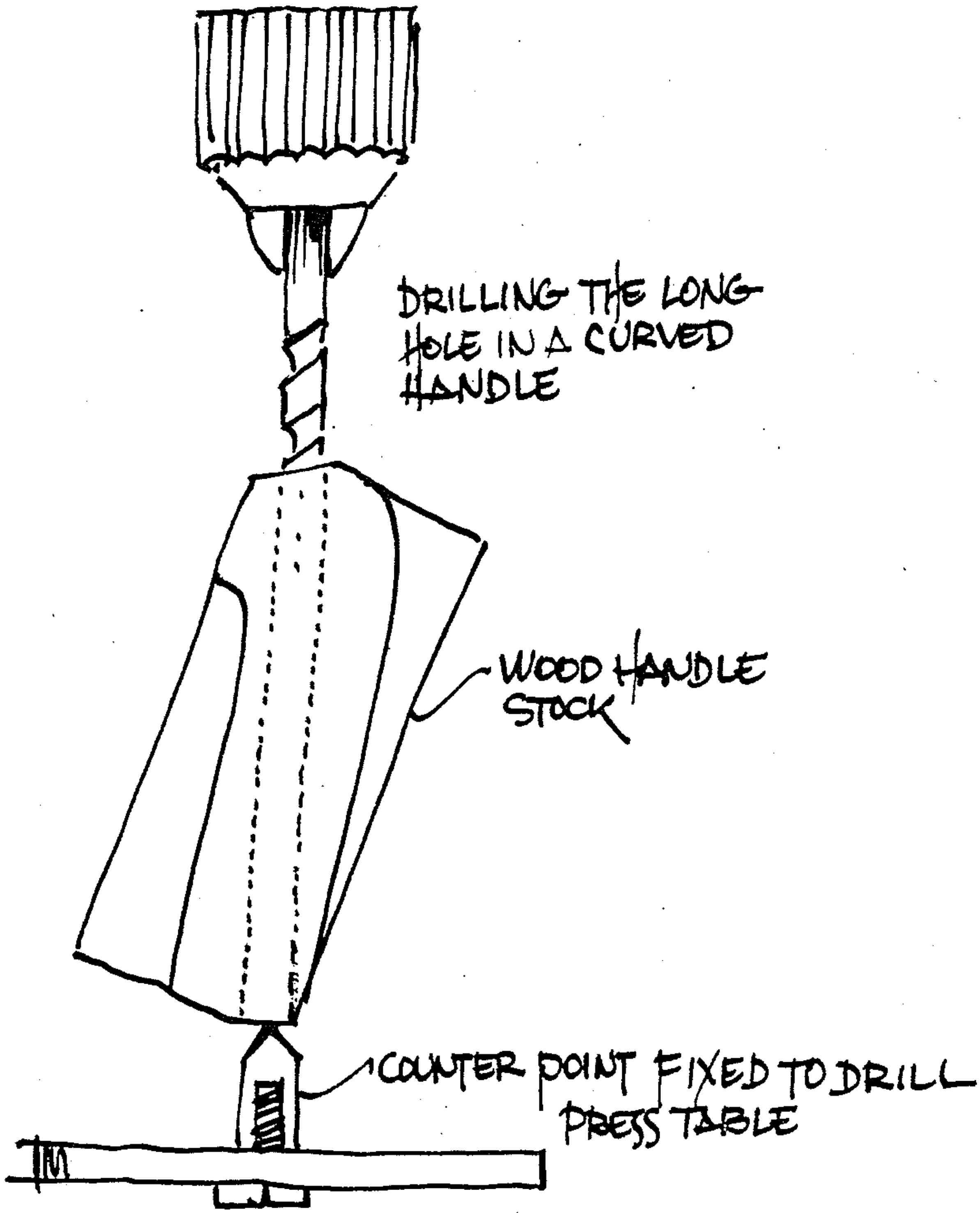


GATES AREN'T NECESSARY FOR HAND BLOWER

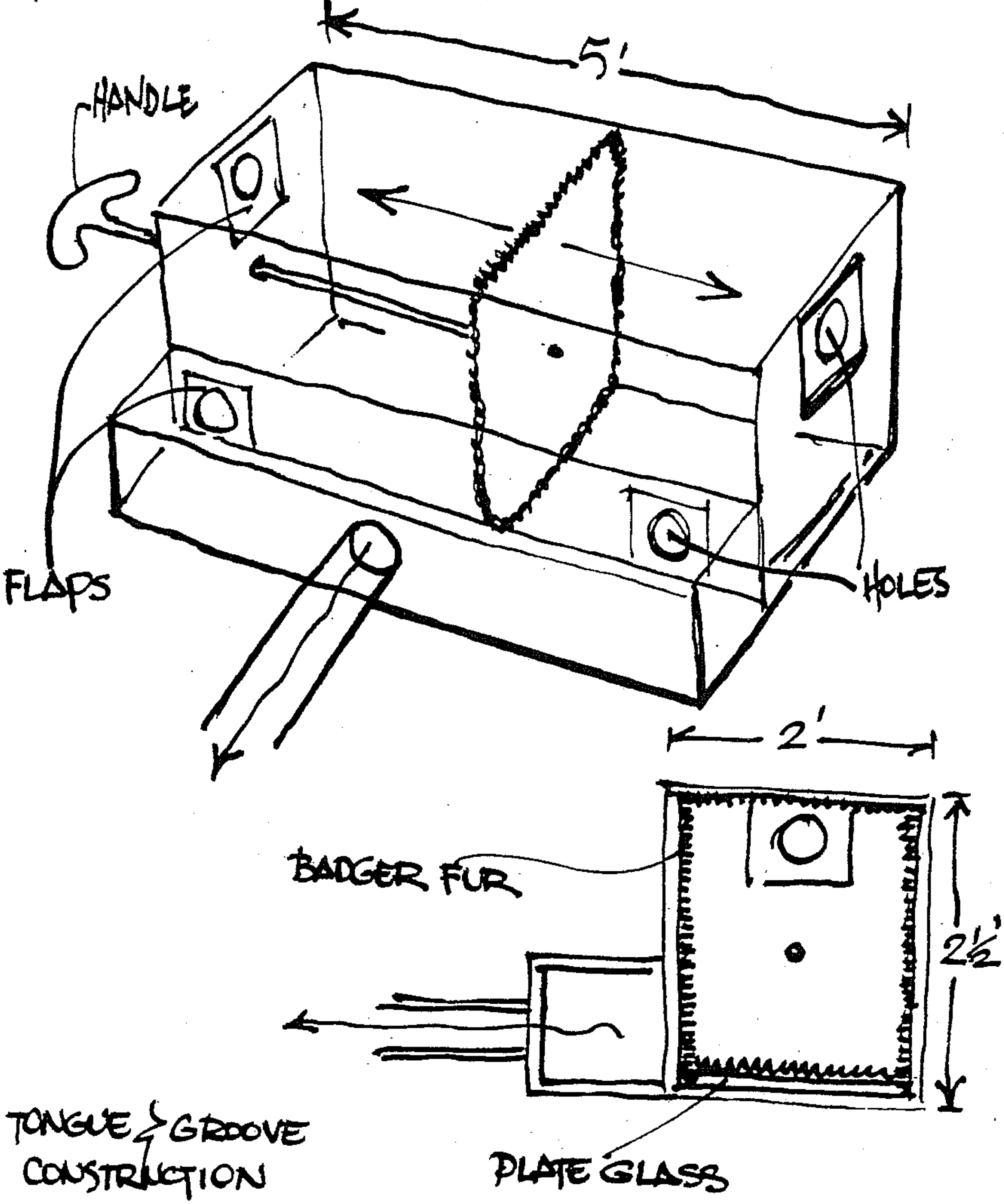


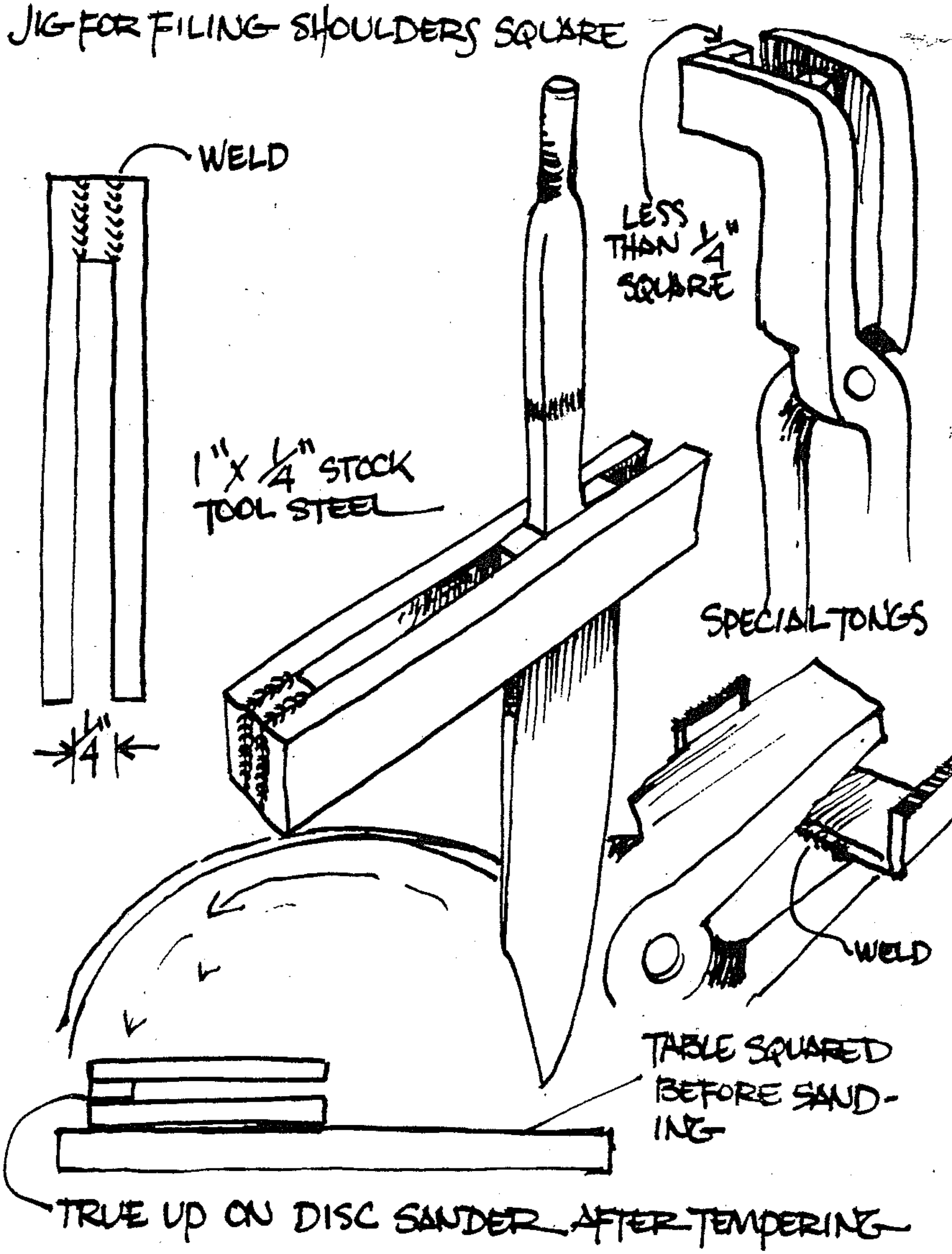

FORGES
TRADITIONAL HOOD
SMOKE SHELF
FORGE
FIREBRICK
AIR SUPPLY
PIPE HAS TO BE AT A CRITICAL ANGLE TO CREATE VERTICLE & HORIZONTAL SWIRLS
CLAY

HANDLE FOR NARROW TANG

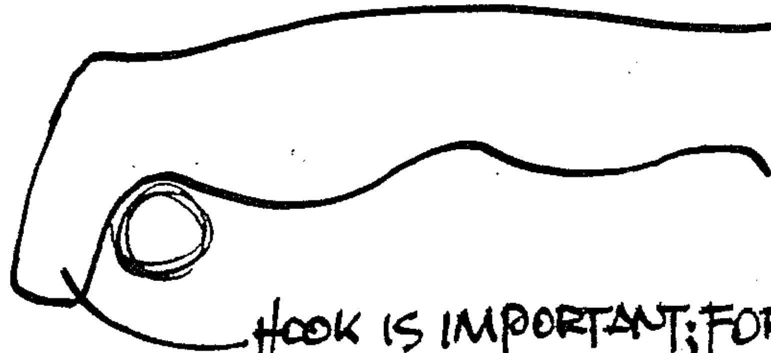


HAND OPERATED AIR SUPPLY FOR FORGE.

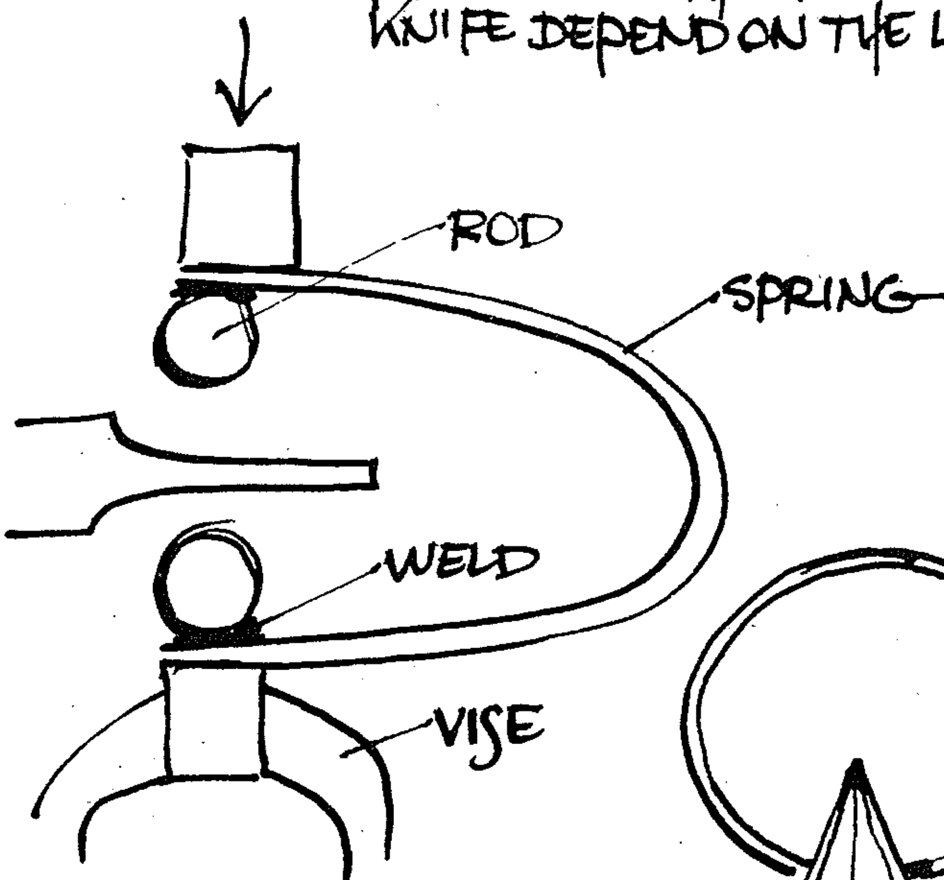


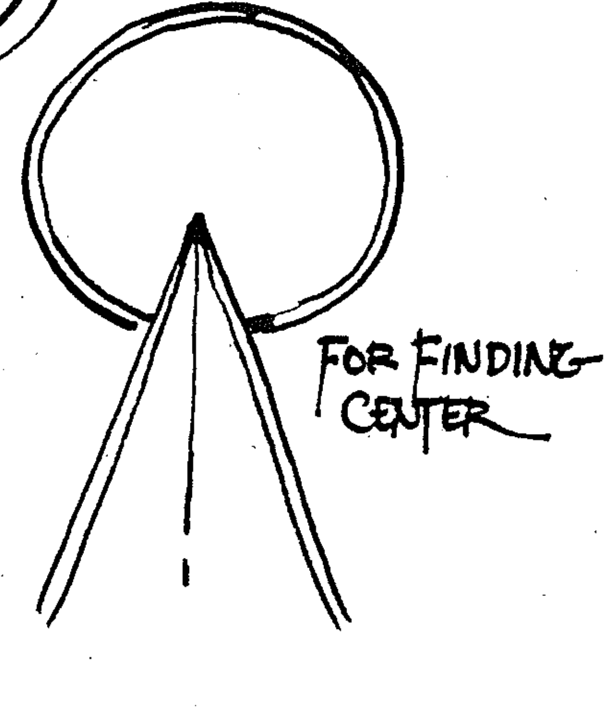

JIG FOR FILING SHOULDERS SQUARE
WELD
LESS THAN 1/4" SQUARE
1" X 1/4" STOCK TOOL STEEL
1/4"
SPECIAL TONGS
WELD
TABLE SQUARED BEFORE SAND-ING
TRUE UP ON DISC SANDER AFTER TEMPERING

GENERAL INFORMATION



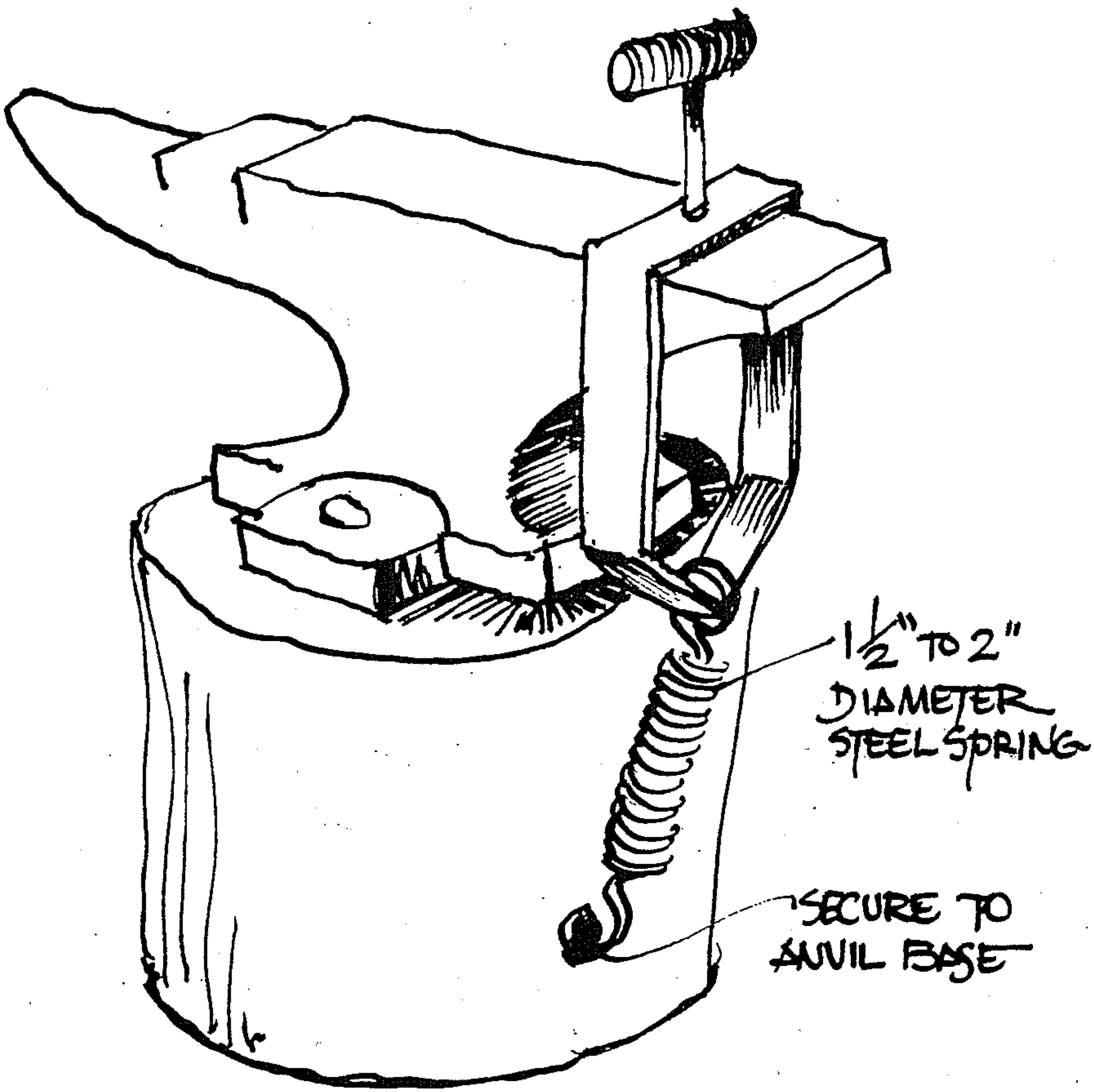
HOOK IS IMPORTANT; FOR CONTROL & TOTAL STRENGTH OF SWING OF THE KNIFE DEPEND ON THE LITTLE FINGER



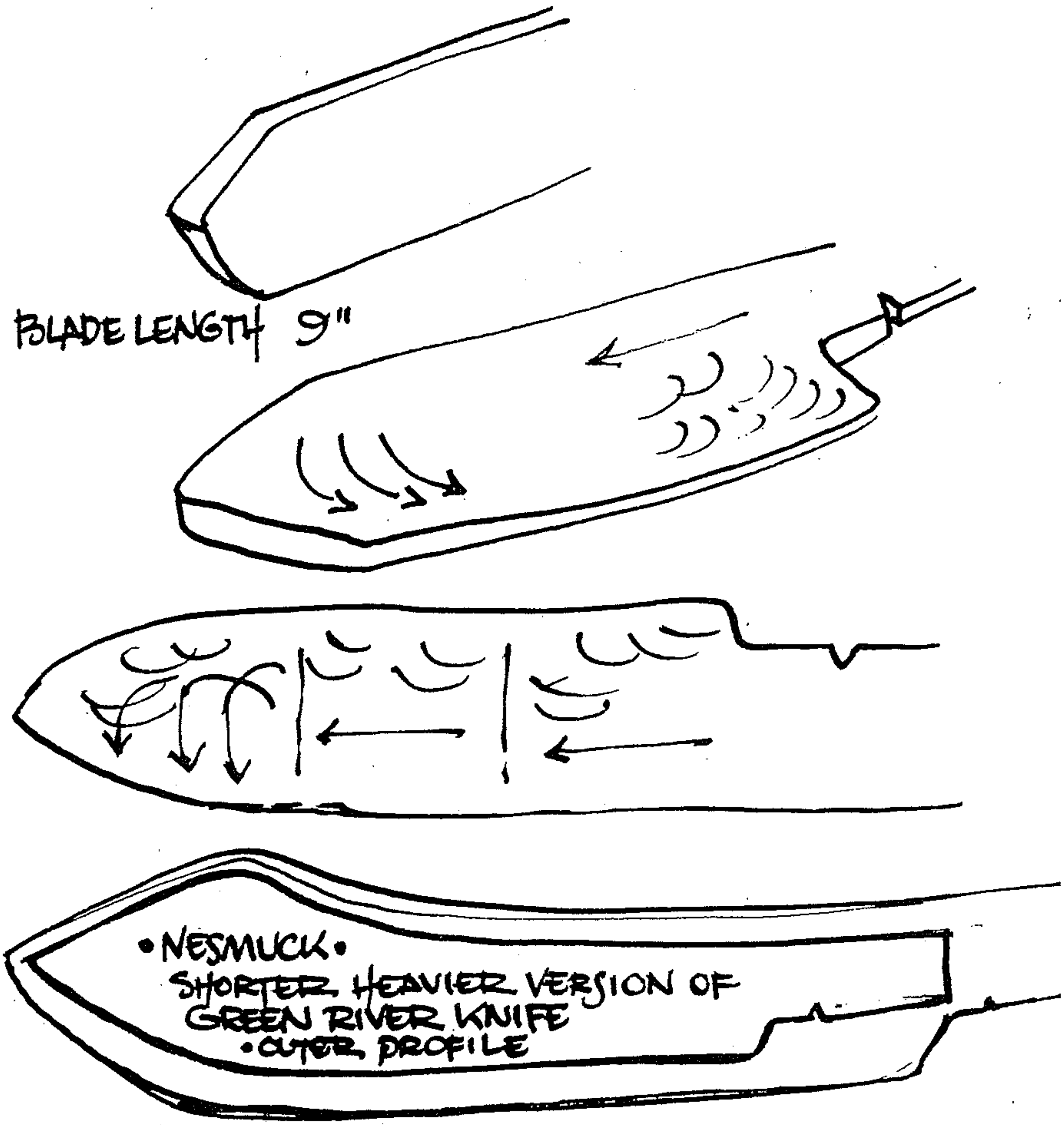


FOR FINDING CENTER

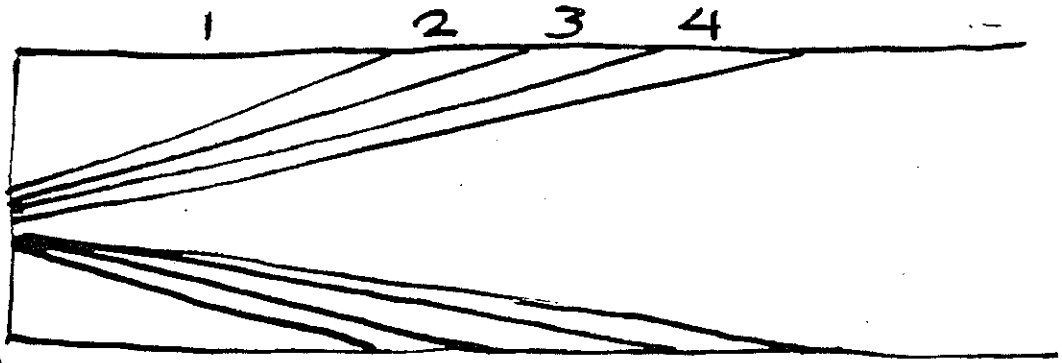
THE THIRD HAND



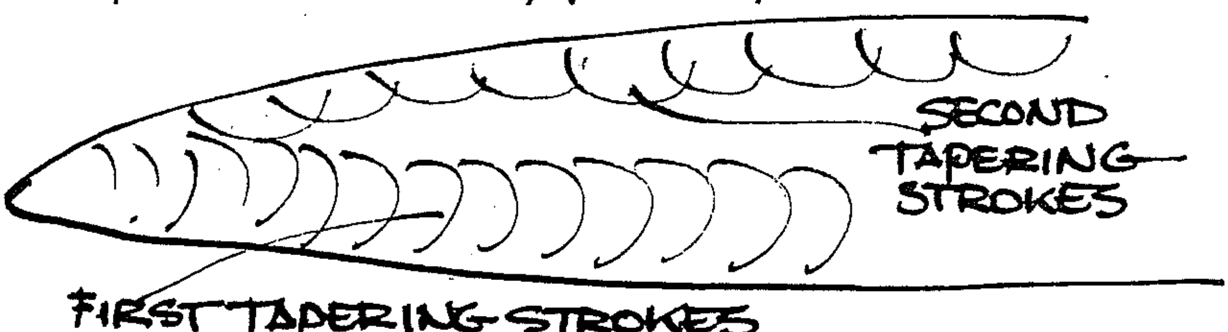
GREEN RIVER KNIFE



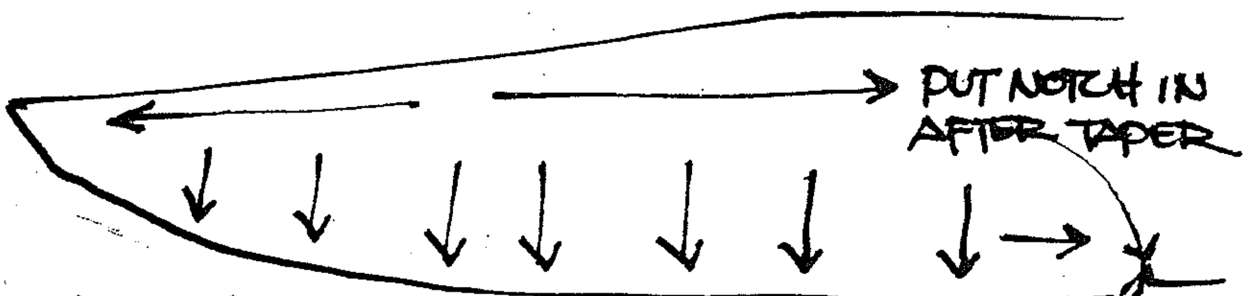
COMBAT KNIFE



POINT GOES BACK 3/4's OF THE BLADE



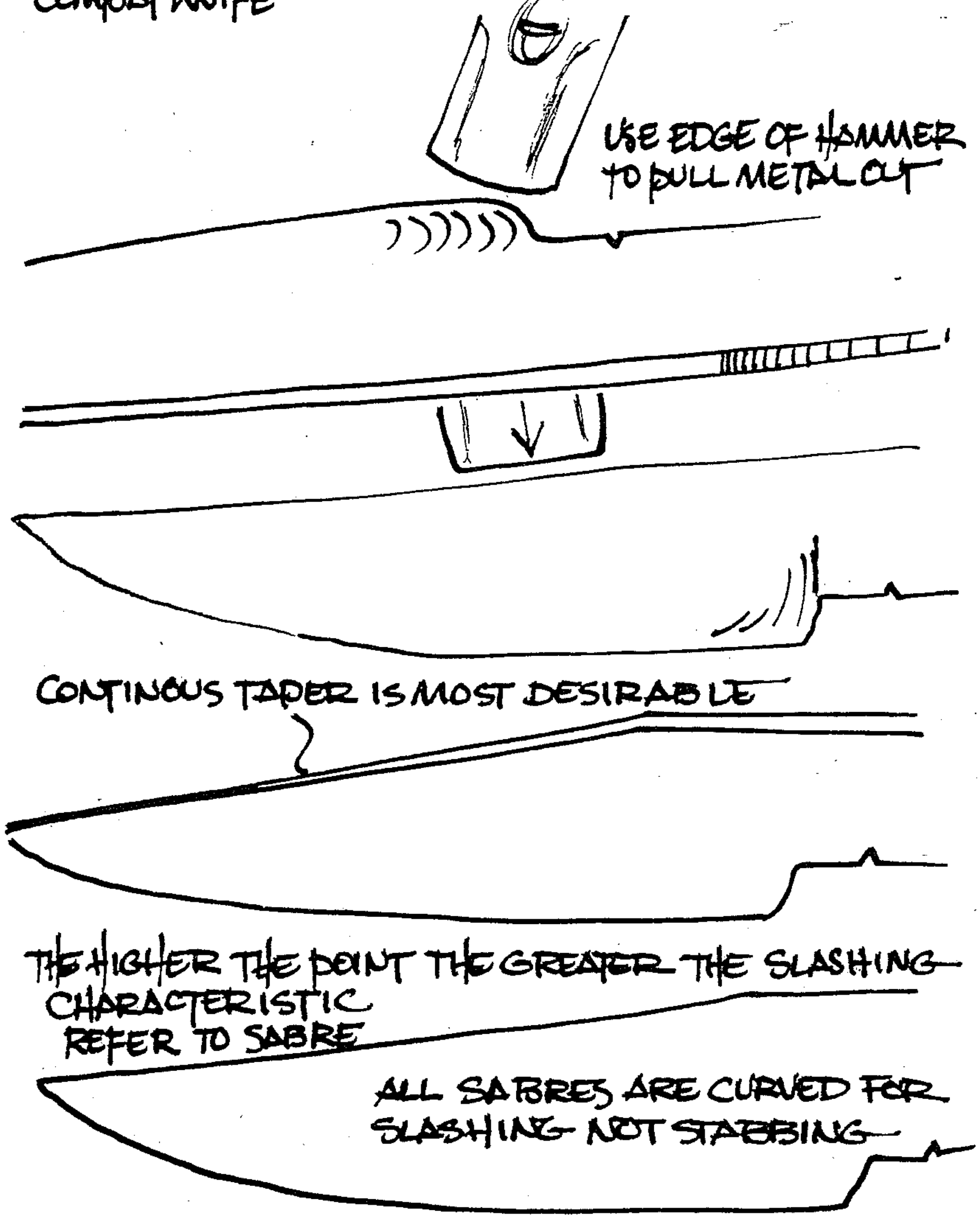
USE HORN OF ANVIL TO START TAPER

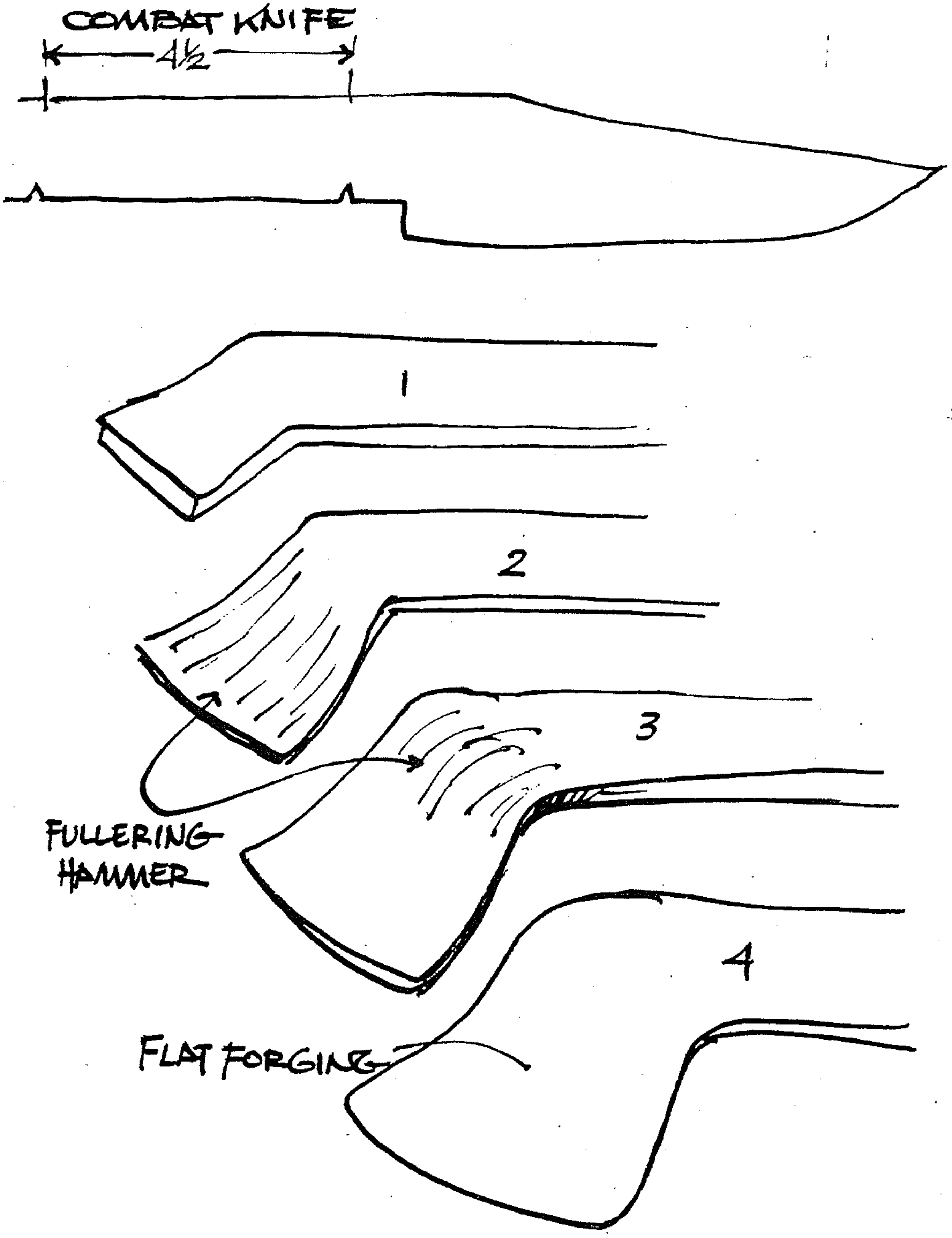


WORK TO EDGE AFTER SHAPING & TAPERING THE BLADE

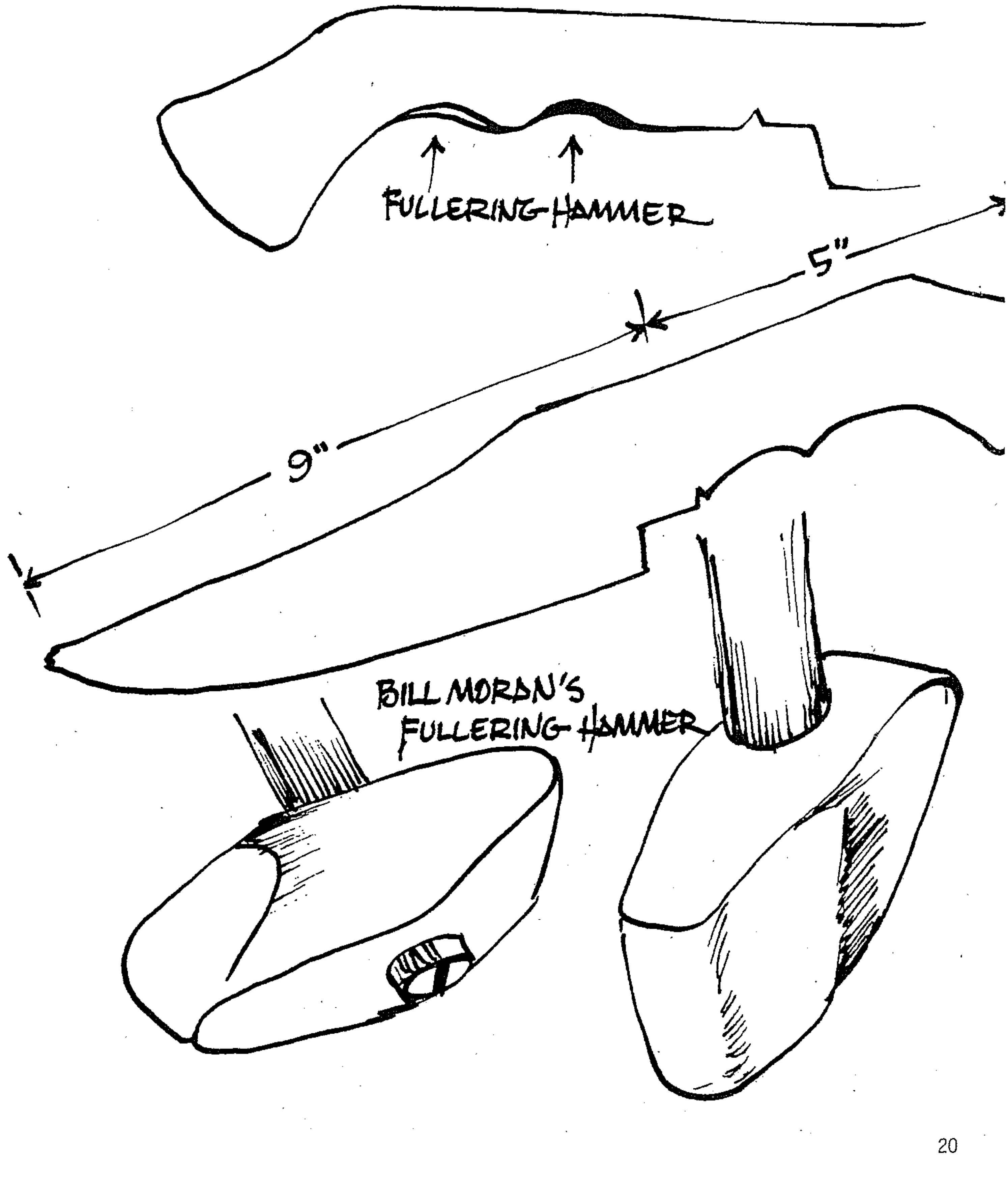
8"

COMBAT KNIFE

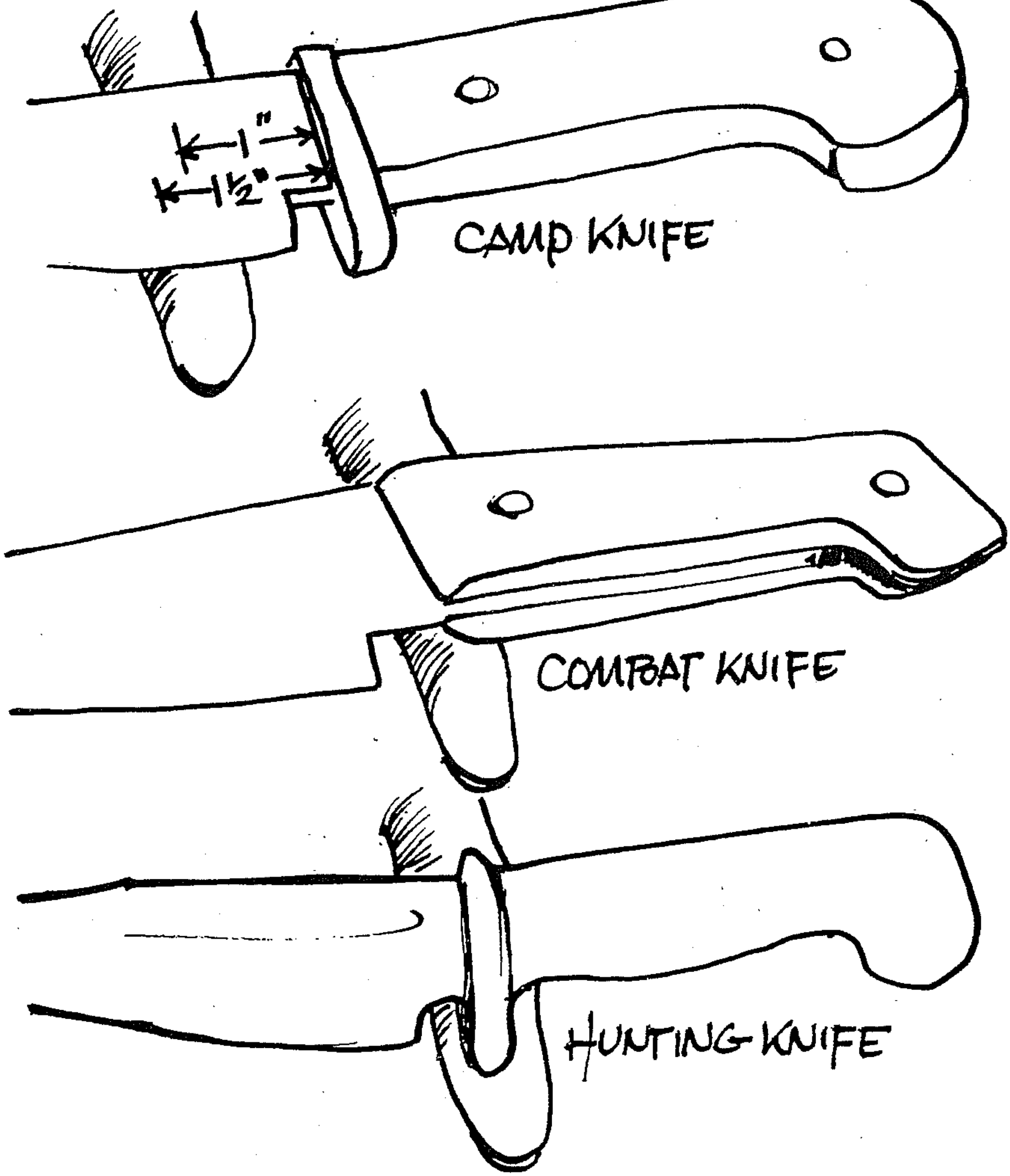



COMBAT KNIFE
4½
1
2
3
FULLERING HAMMER
4
FLAT FORGING

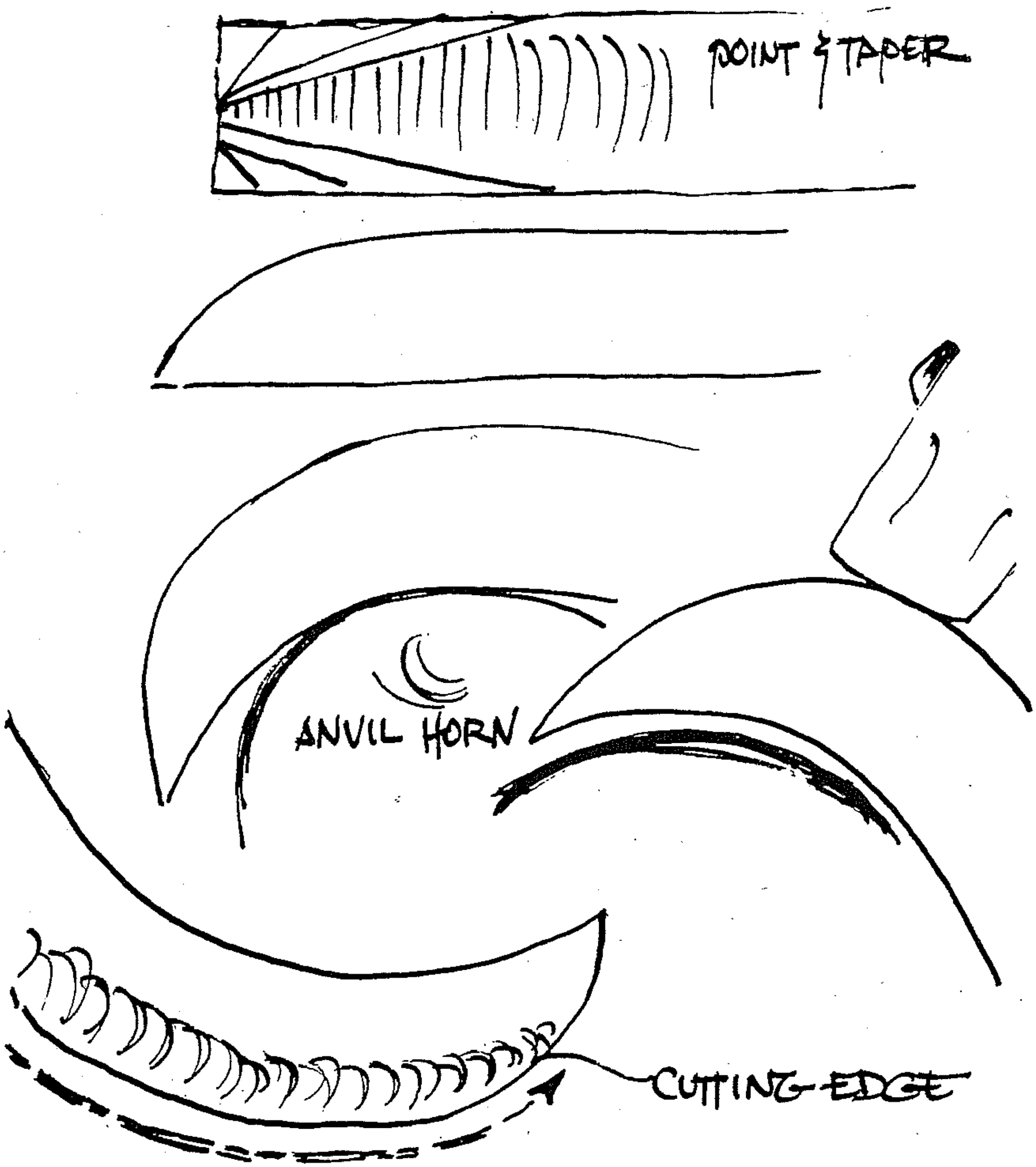
COMBAT KNIFE



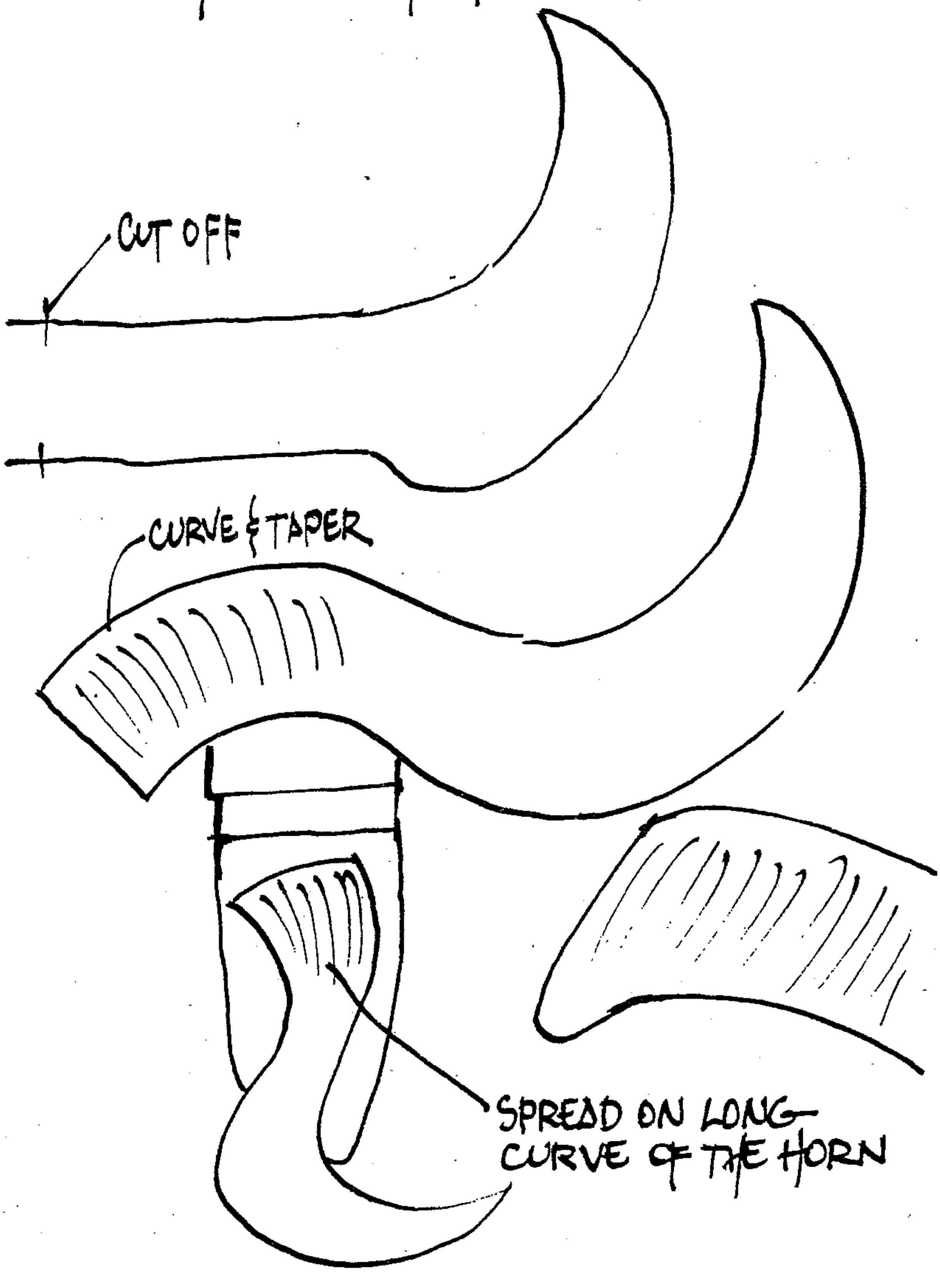
POINTS OF BALANCE



SKIVING & GENERAL PURPOSE KNIFE



SKIVING & GENERAL PURPOSE KNIFE

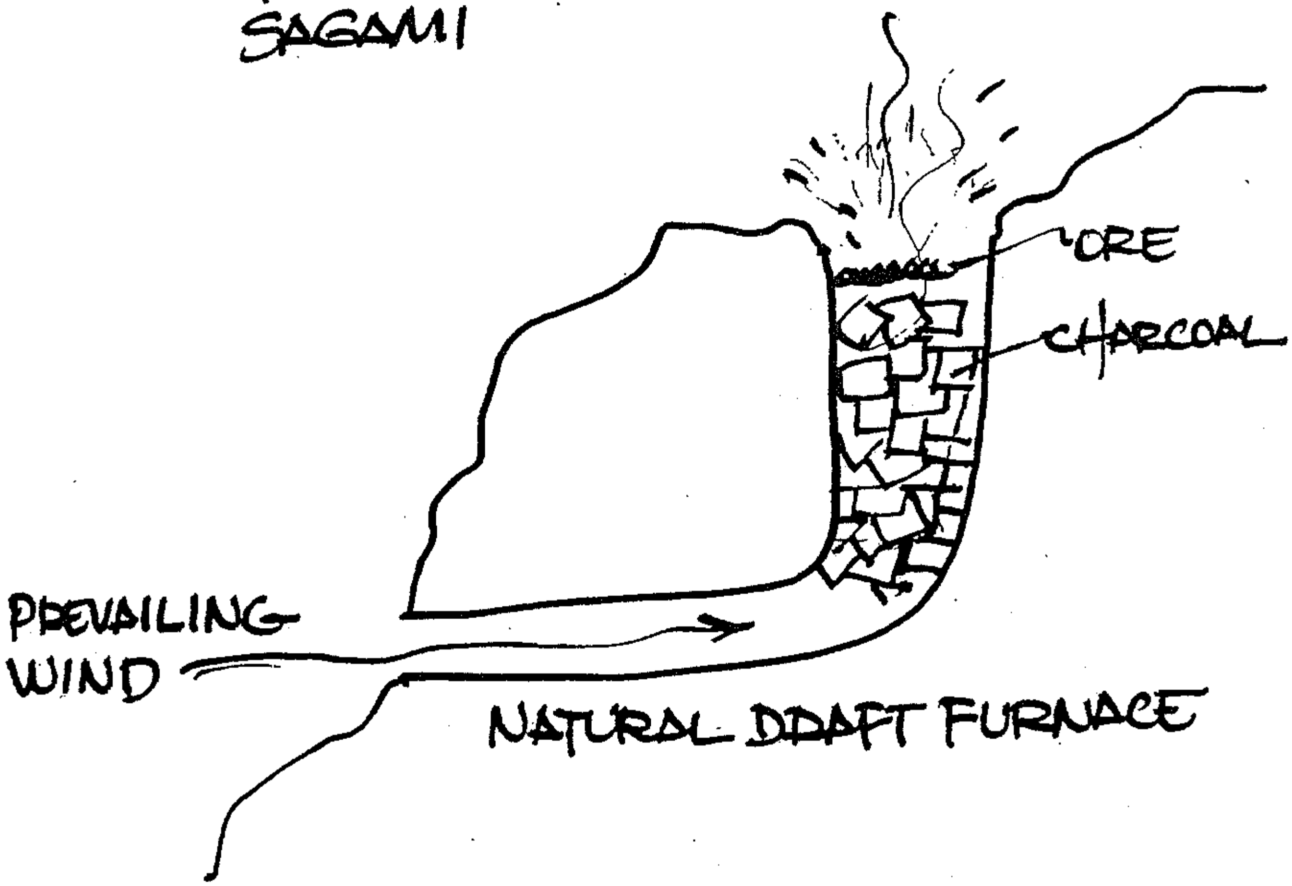


MALCOLM SHEWAN - LECTURE

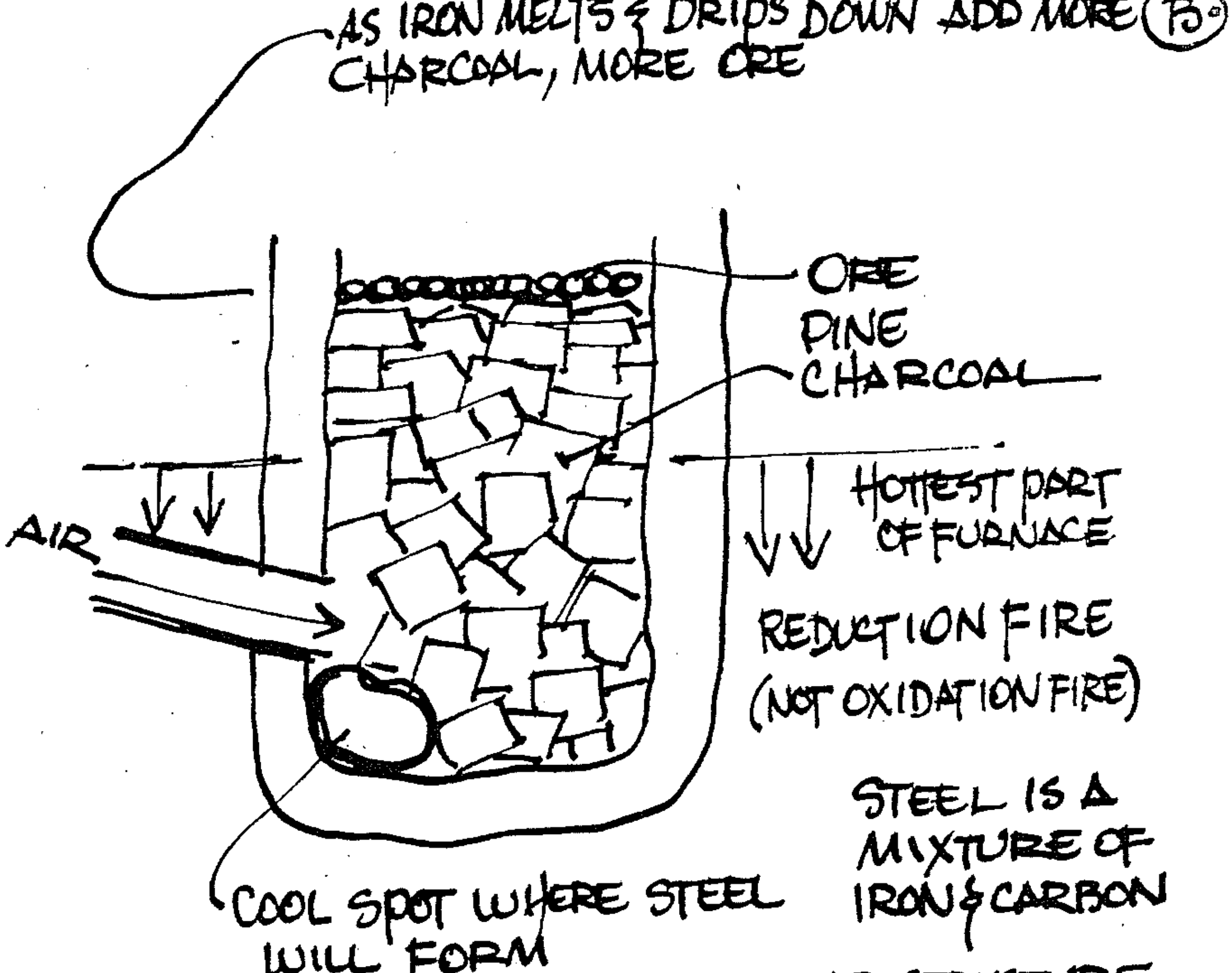
PRE-1600 JAPANESE SWORD MAKING. (A.)

STEEL (SWORD) MAKING CENTERS NEEDED;
- CHARCOAL
- IRON ORE
- POLITICAL, ECONOMICAL STABILITY

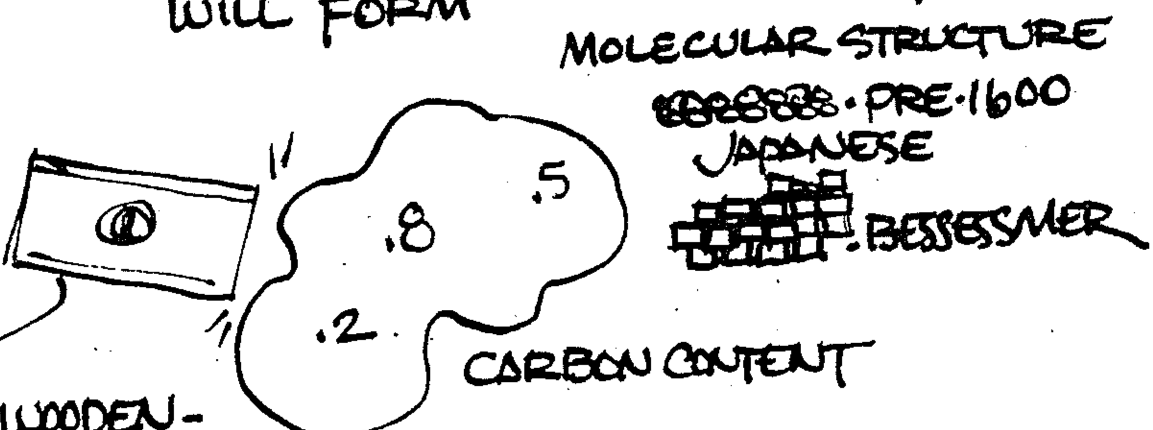
THEY WERE:
- BIZEN - FINEST ORE DEPOSITS
- MINO
- YAMASHIRO
- YAMATO
- SAGAMI



MALCOLM SHEWAN - LECTURE



STEEL IS A MIXTURE OF IRON & CARBON

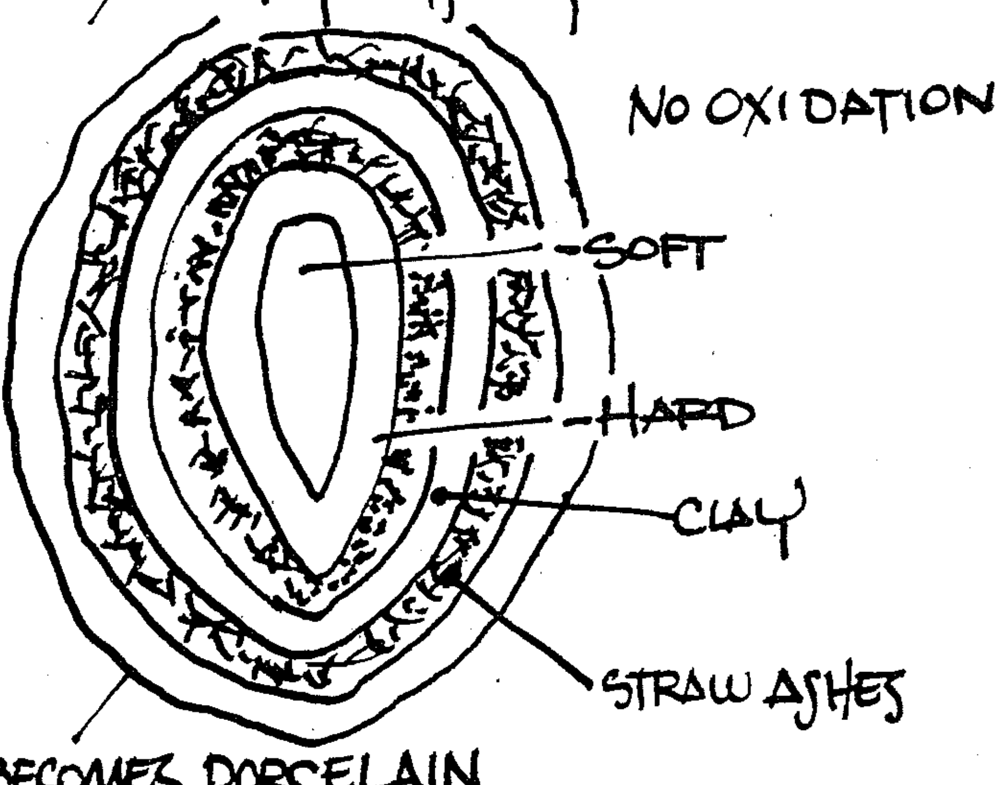


USE WOODEN-MALLET TO BEAT THE SLUG INTO A BLOCK OF STEEL (WOOD PRODUCES MORE CARBON.)

MALCOLM SHEWAN - LECTURE

THERE WERE NO PRESCRIBED FORMULAS FOR MIXTURES OF FUEL TO AIR. (C.)
CLOSEST STANDARDIZATION TO PROCESS WAS THE CEREMONY OR RITUAL.

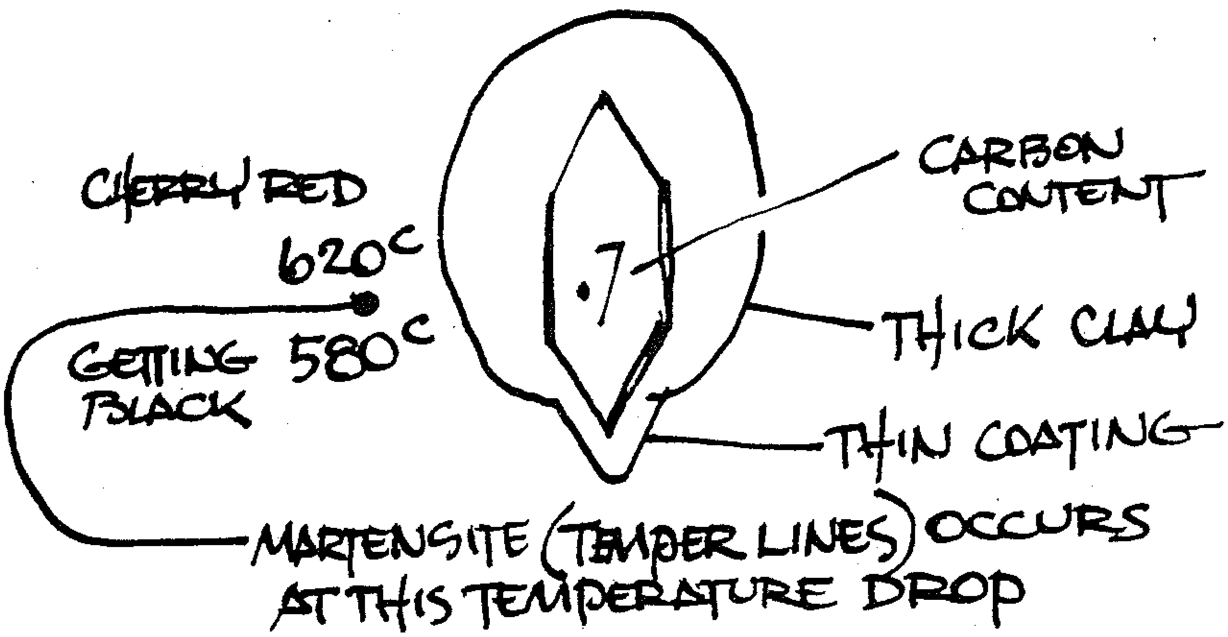
REMOVE LUMP OF STEEL FROM FURNACE
BRING UP TO WELDING HEAT & HOMOGENIZE
FOLD & WELD
COVER W/CLAY & ASHES & WELD

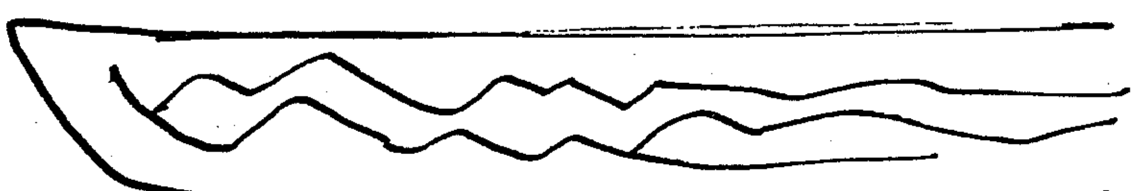


FIRE TO CONE 10 — 14

MALCOLM SHEWAN • LECTURE

HEAT TREATING IS DONE W/CHARCOAL & SAND (D)



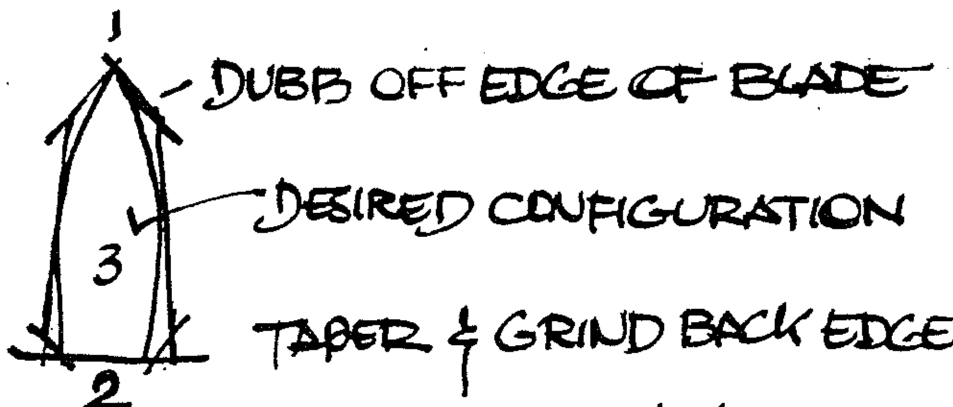


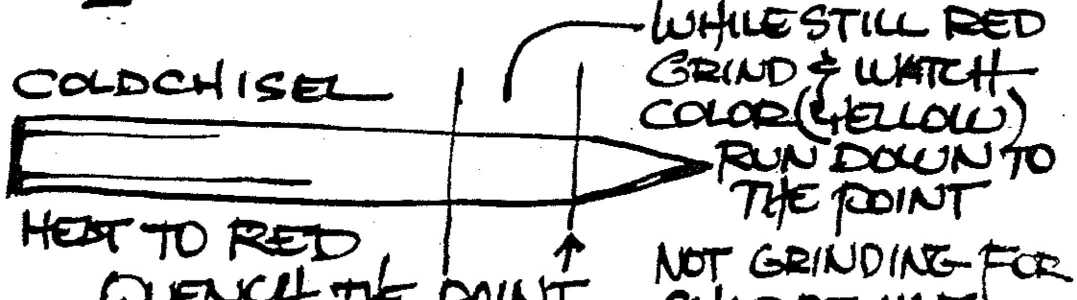
THE MEMORY OF THE METAL FROM THE FORGING CREATES THE TEMPER LINE.

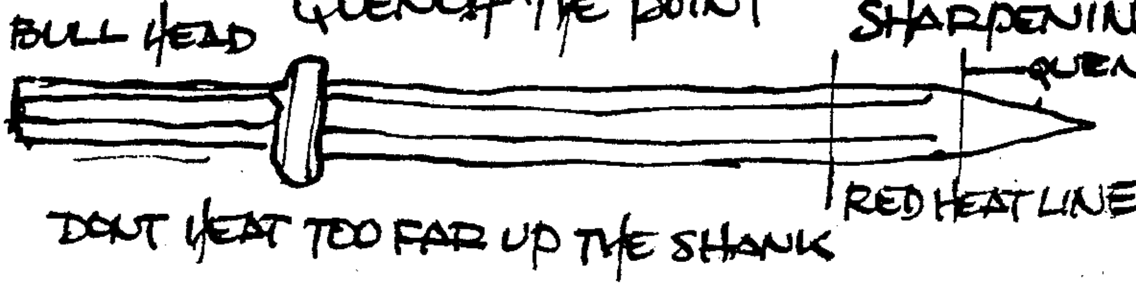
FINISHING THE BLADE

AFTER PROFILING THE BLADE, ANNEAL.
HEAT THE WHOLE BLADE INCLUDING TANG TO DULL CHERRY RED COLOR. COVER COMPLETELY W/VERMICULITE & ALLOW TO COOL SLOWLY. DON'T BOTHER W/FIRE SCALE.

WHEN BLADE HAS COOLED GRIND OFF FIRE-SCALE W/EMERY WHEEL. AFTER FIRE SCALE HAS BEEN REMOVED USE 36 GRIT ON THE BADER GRINDER FOR INITIAL GRIND







GENERAL INFORMATION

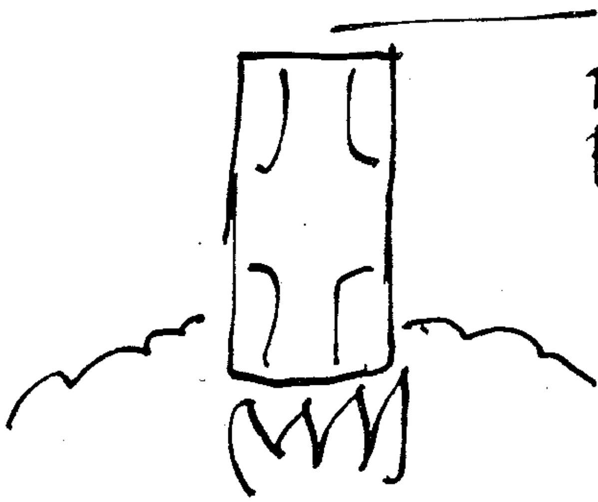
POWER HAMMER: CHECK RAM & CLUTCH

50 LB/2 HP IS A GOOD ALL ROUND HAMMER

100 LB/3 HP GOOD (NECESSARY) FOR MAKING DAMASCUS.

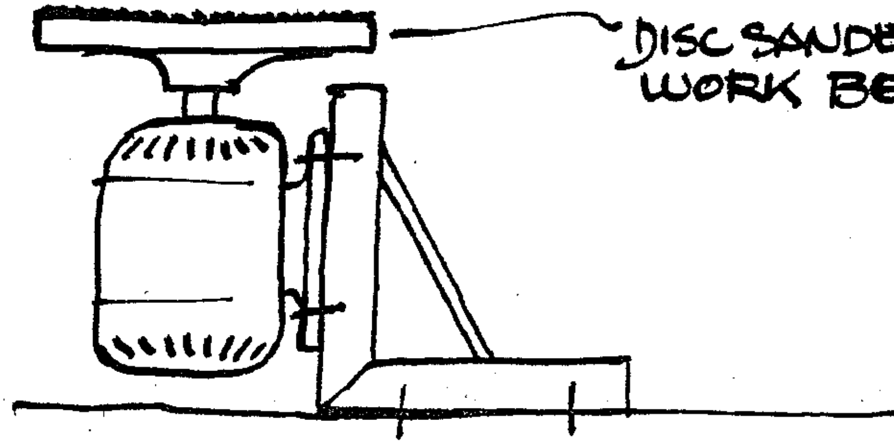
MODELS W/ WOODEN BLOCKS MOST DESIRABLE

HARDENING A HAMMER HEAD



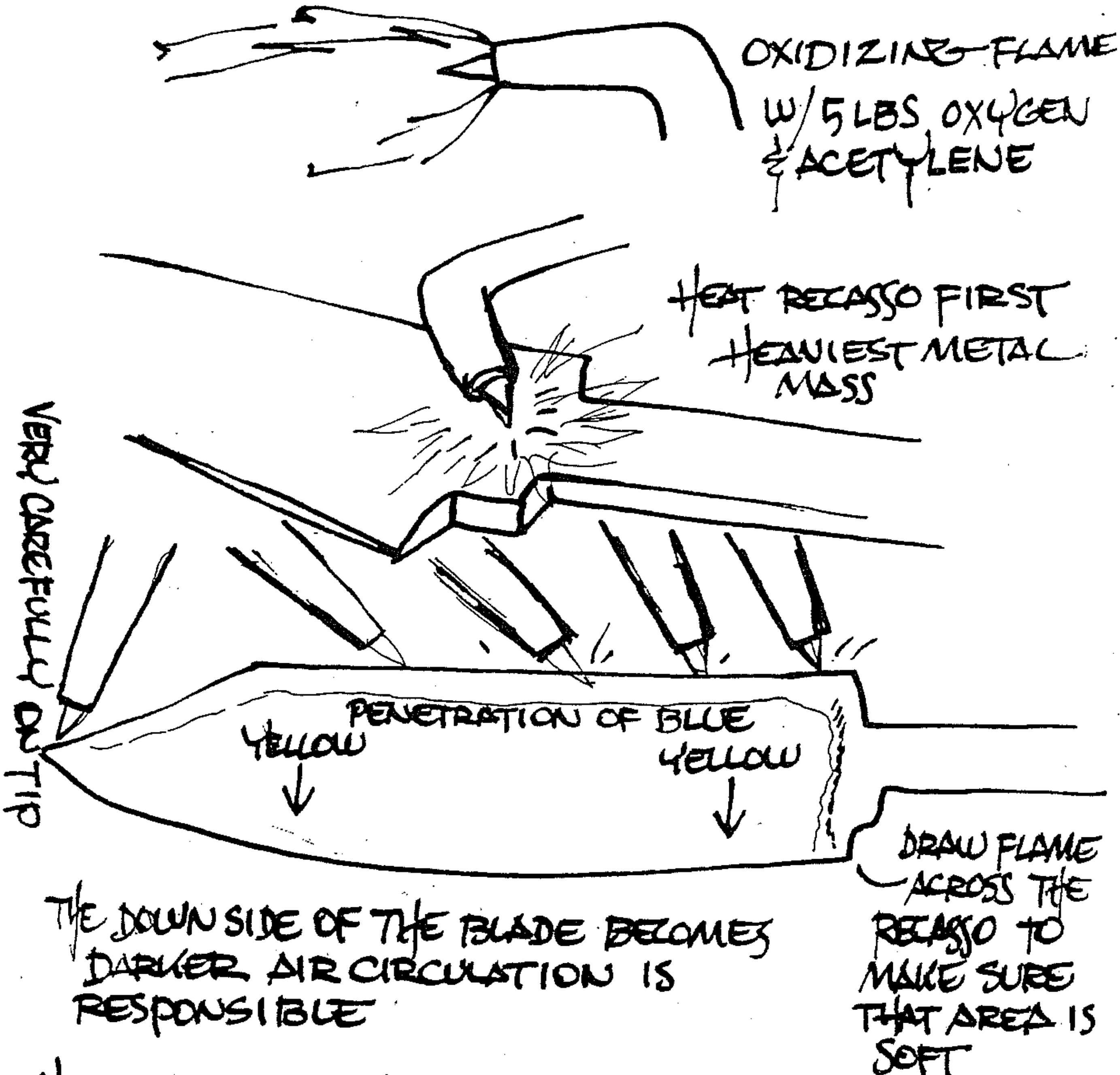
ALTERNATELY HEAT BOTH ENDS IN HOTTEST PART OF THE FORGE

QUENCH IMMEDIATELY & MOVE QUICKLY IN WATER



DISC SANDER BOLTED TO WORK BENCH.

DRAWING THE TEMPER



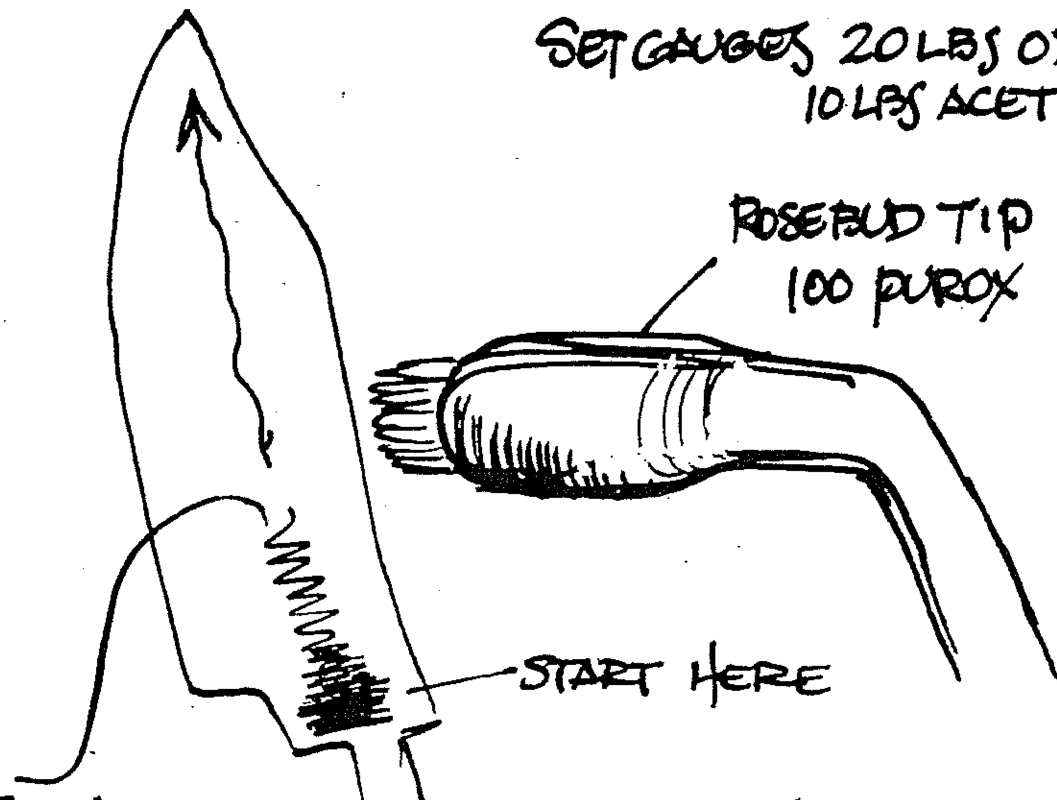
THE DOWN SIDE OF THE BLADE BECOMES DARKER AIR CIRCULATION IS RESPONSIBLE

HOLD BLADE W/VISE GRAPS ON THE TANG & DRAW THE TEMPER WHILE SEATED WITH A LOT OF LIGHT ON THE BACK OF THE BLADE

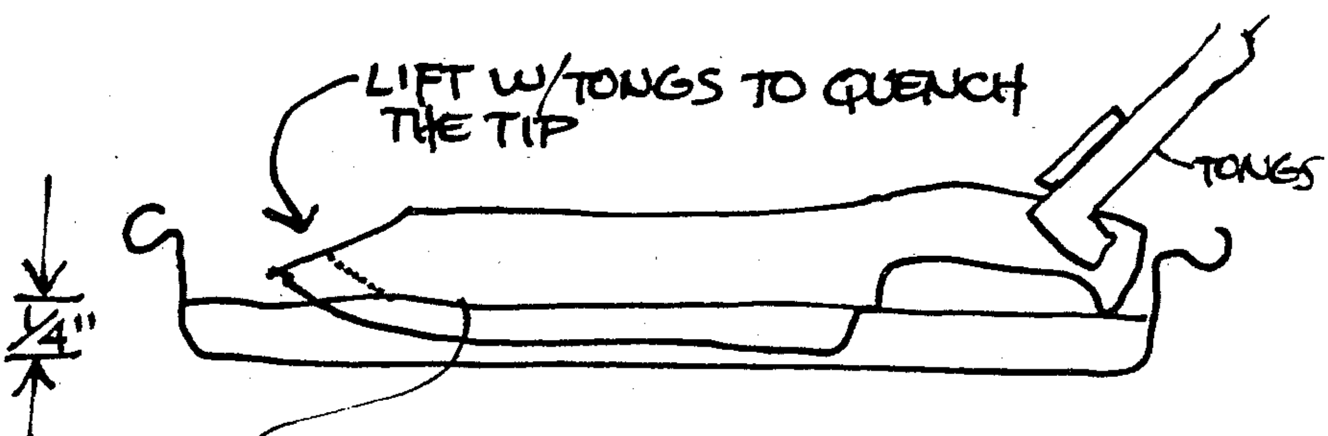
TRIPLE DRAW (EVERYTHING)

HEAT TREATING

SET GAUGES 20 LBS OXYGEN
10 LBS ACETYLENE



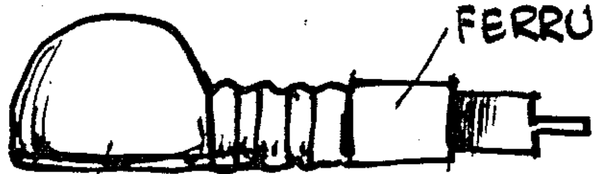
STAY IN CENTER OF BLADE W/TORCH
THE DARKER THE SURROUNDINGS THE EASIER IT IS TO SEE THE COLOR CHANGE.

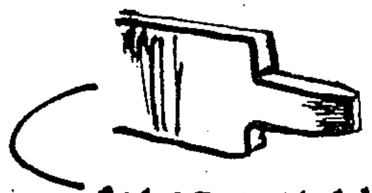


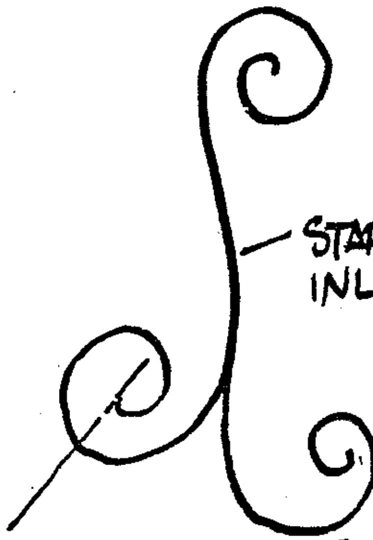
TEMPER LINE IS THE DEPTH OF THE OIL

RAECO PRODUCTS INC / QUENCHING OIL
P.O. BOX 404 • ROCHESTER NY 14602
716 • 271 8080

INLAYING SILVER WIRE



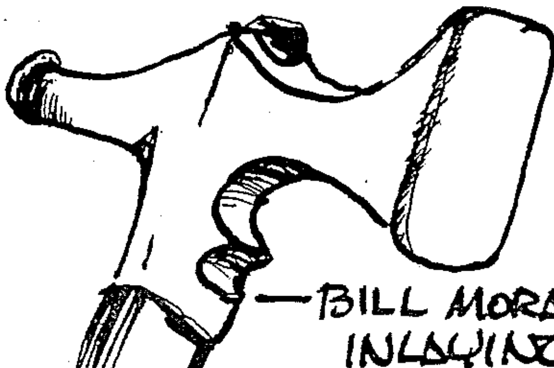




- USE 120 GRIT TO CLEAN & GROOVE FLAT FINE SILVER WIRE

  FINE SILVER WIRE

  .013 THICK .055 WIDE
- CUT W/SCISSORS FOR CUT W/O CRIMPING
- PUNCH A HOLE AT THE END OF THE SCROLL & DRILL A HOLE FOR A PIN 1/16"



GENERAL INFORMATION

WHISKERING · STEAM WOOD HANDLE UNTIL GRAIN RAISES & LET DRY. SAND W/ MEDIUM (220 PAPER). REPEAT TWO OR THREE TIMES. AFTER FINAL WHISKERING SAND W/FINE (400 PAPER). FINISH COMPLETELY BEFORE STAINING.

FOR STAINING USE FIEBBINGS DARK BROWN LEATHER DYE FOR HANDLE.
FIEBBINGS ORANGE DYE MAY BE USED FIRST.

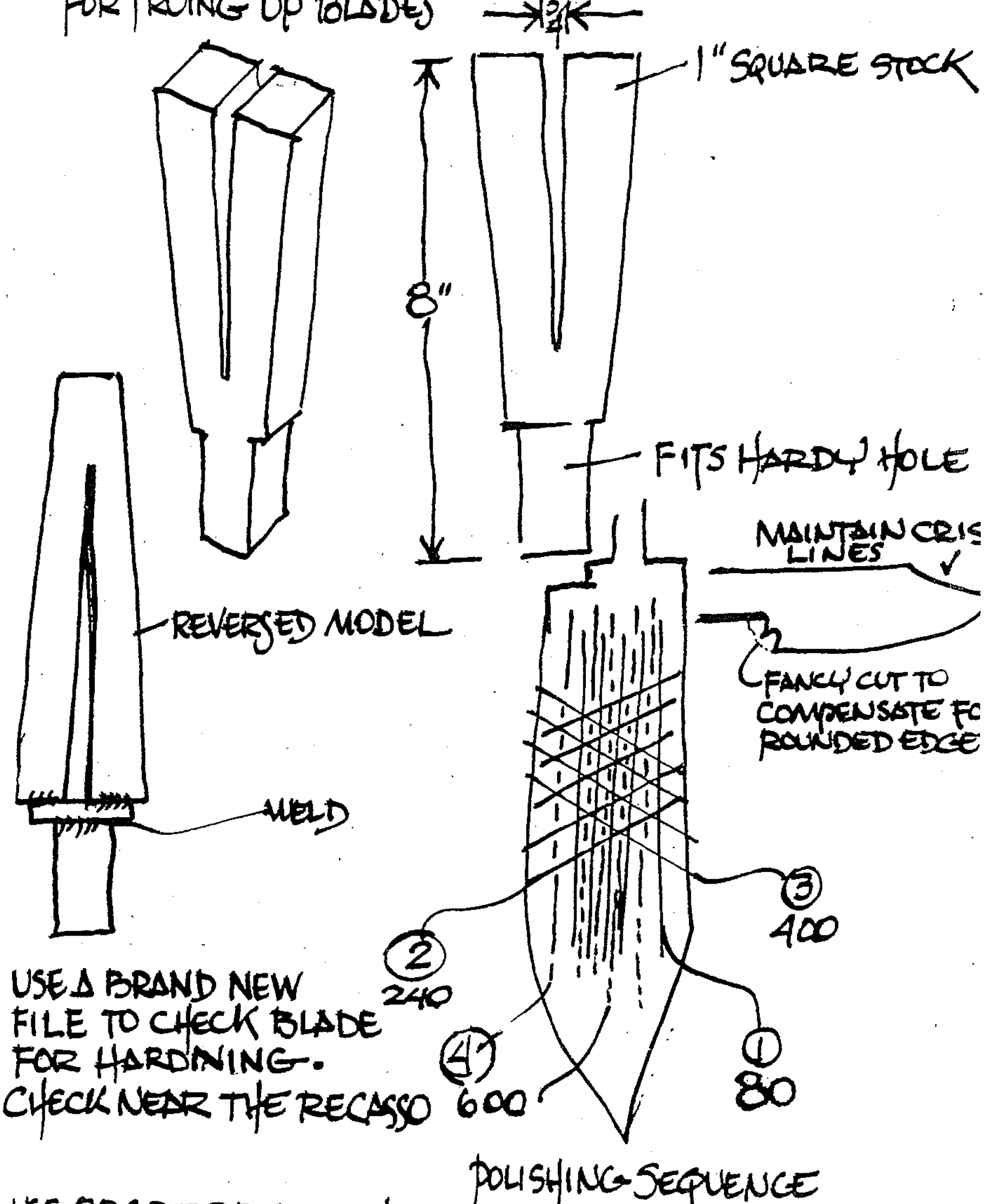
DISSOLVE STEEL WOOL IN A SOLUTION OF ½ WATER & ½ NITRIC ACID. APPLY TO HANDLE W/SWAB & LET DRY.

FINAL PRESERVATIVE. PRATT & LAMBERT'S, OKANE

BUFF W/556 GRAY ROUGE. AVAILABLE FROM MIDWEST BUFF CO / OHIO

"OUR METHODS RELY ON LEARNED SKILLS, NOT ON PUSHING A BUTTON."

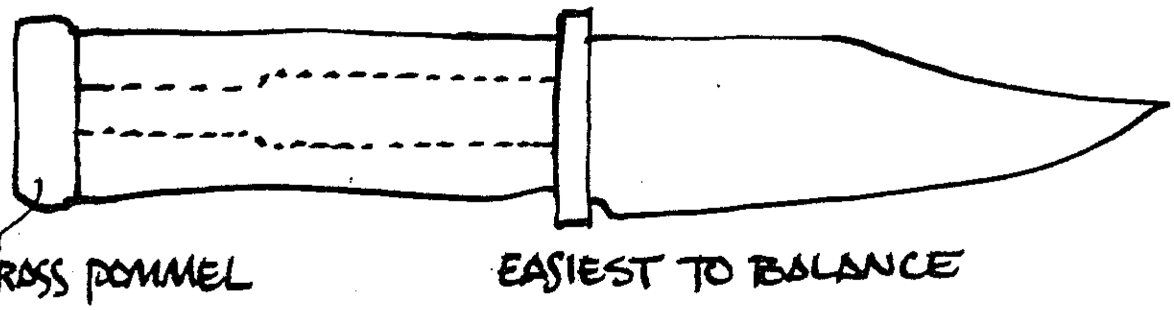
GENERAL INFORMATION
FOR TRUING UP BLADES

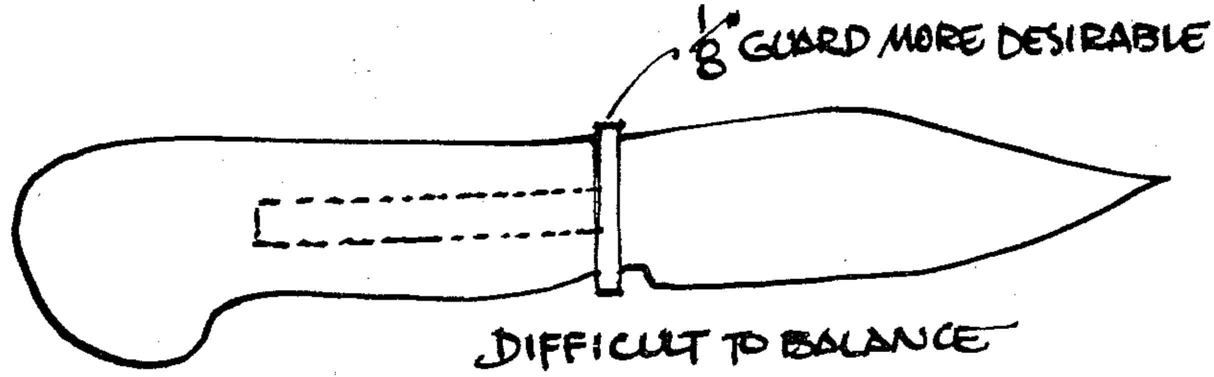


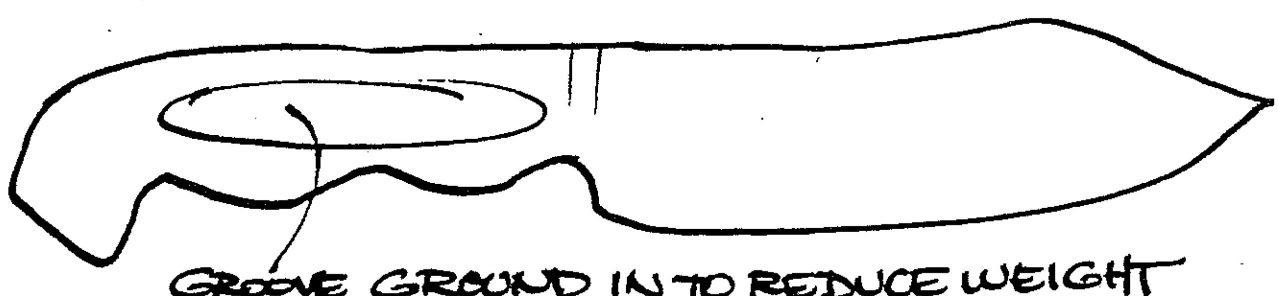
USE A BRAND NEW
FILE TO CHECK BLADE
FOR HARDINING.
CHECK NEAR THE RECASSO

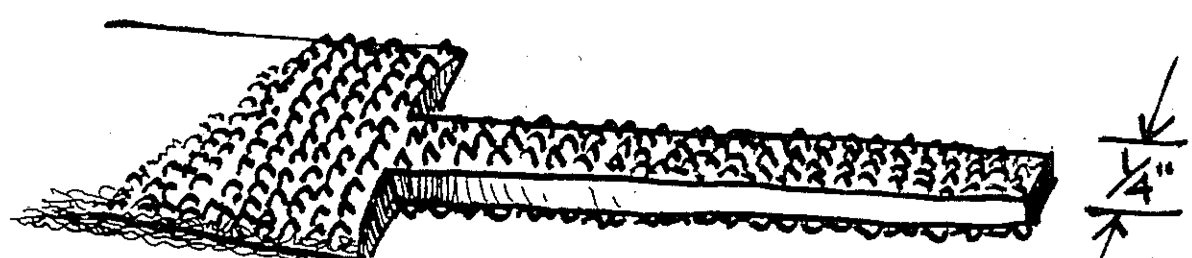
USE 80 GRIT PRIOR TO HEAT TREATING, AFTER 80 USE
POLISHING PAPERS

GENERAL INFORMATION



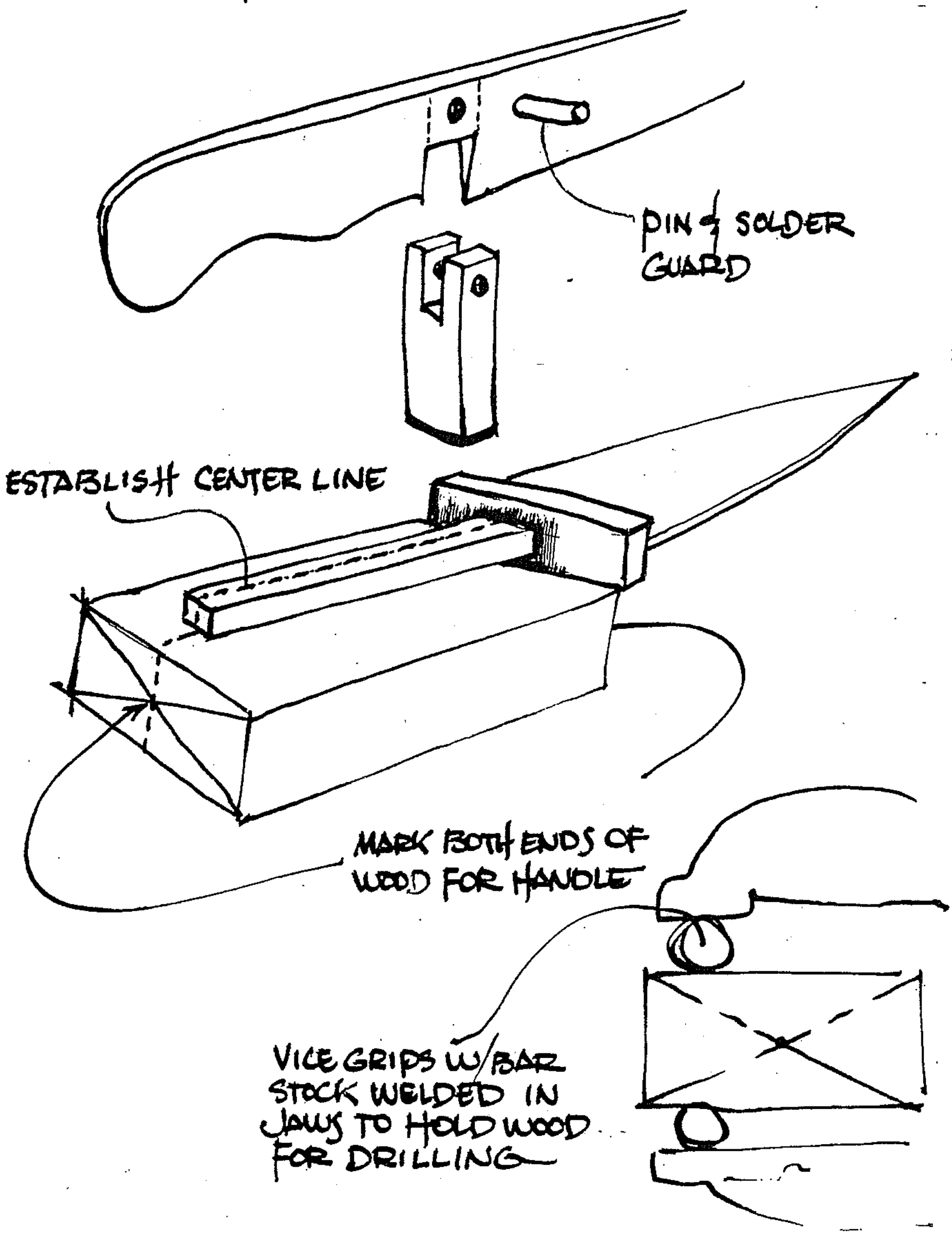




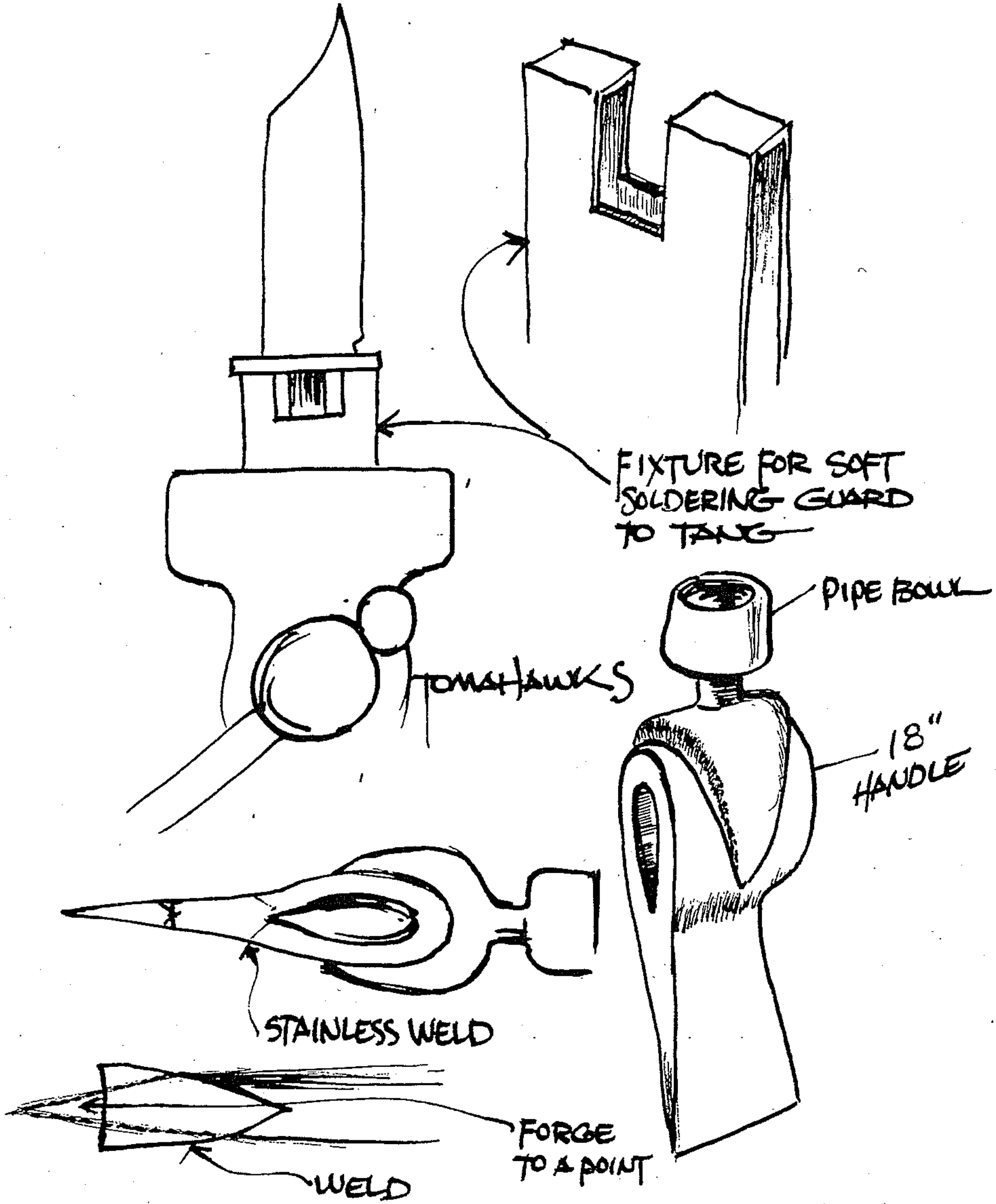


GRIND ORDINARY WOOD RASP & USE AS CLEAN OUT TOOL AFTER DRILLING STOCK FOR HANDLE.

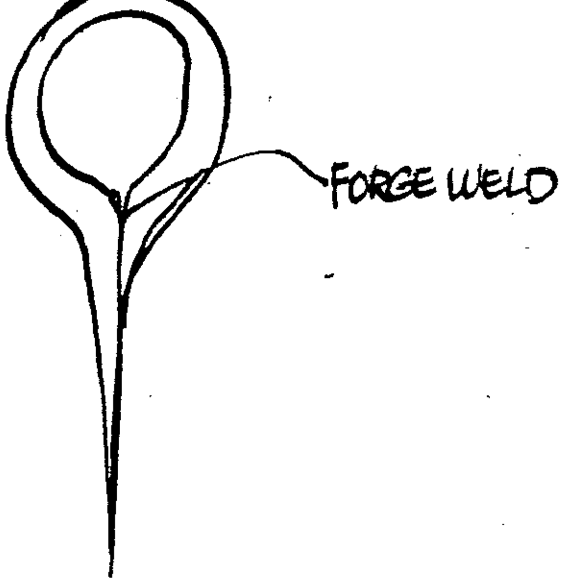
GENERAL INFORMATION

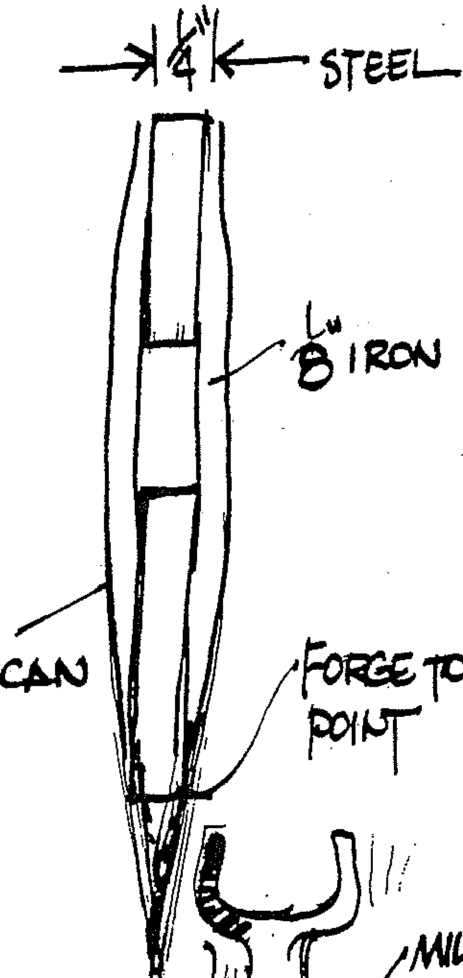


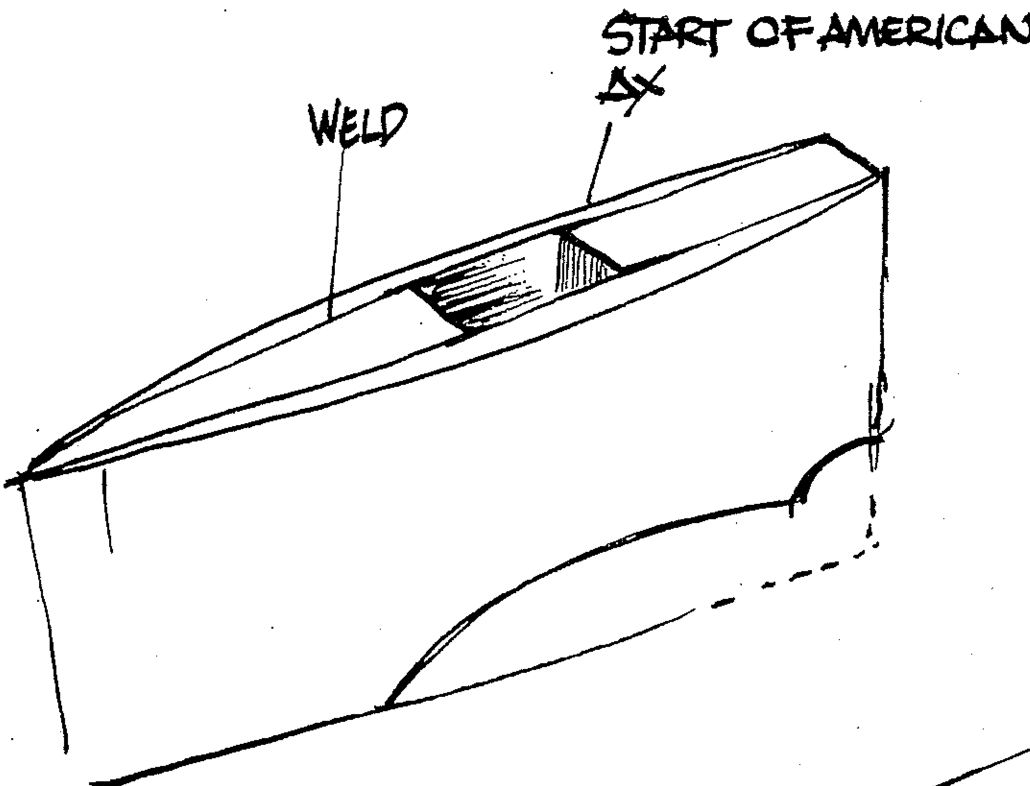
GENERAL INFORMATION

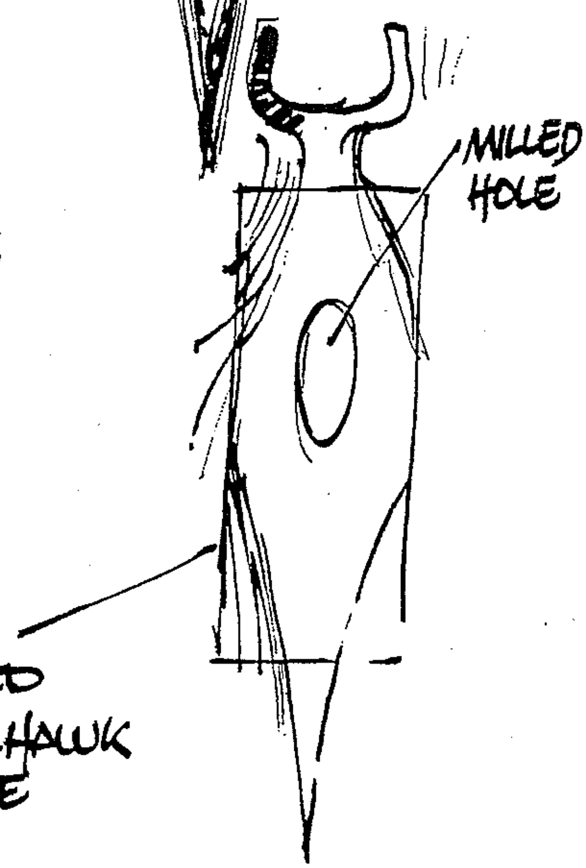


GENERAL INFORMATION



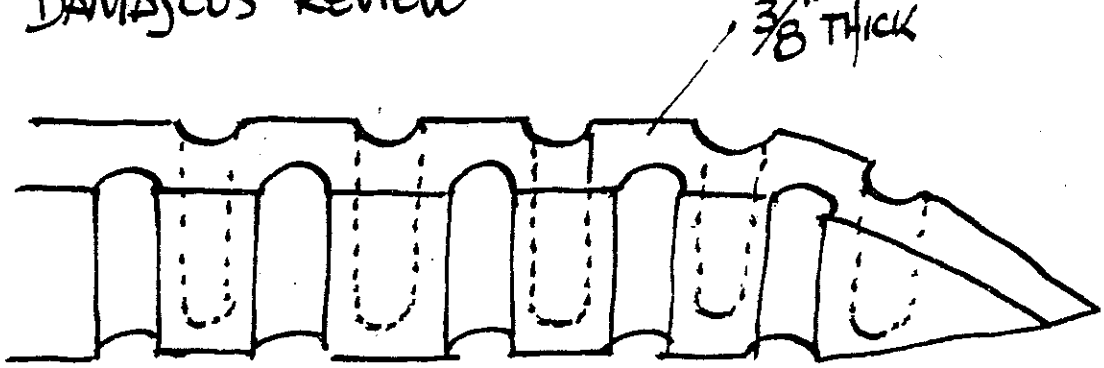


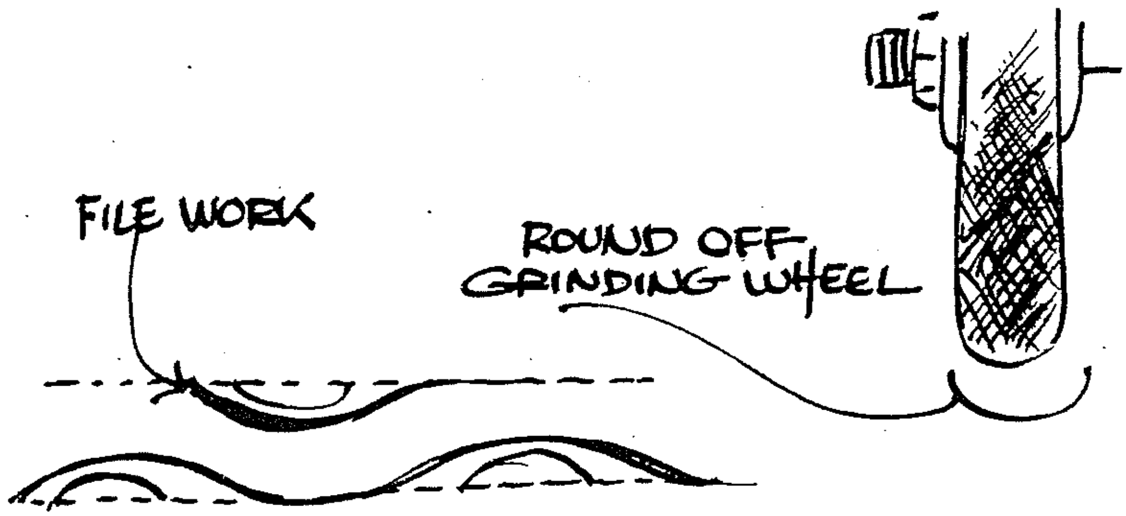




GENERAL INFORMATION

DAMASCUS REVIEW





BASS WOOD USED AS WOOD LINERS IN SHEATHS

LEATHER SOURCE - SCHULTZ TANNERY
TENNESSEE
120 SQ FT PER ROLL